BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
PROPOSED AMENDMENTS TO 35 Ill. Adm. Code 302.102 and 302.208(g) WATER QUALITY STANDARDS FOR CHLORIDES	)	**R18-32 (Rulemaking - Water)**
	)	
	)	
	)	
	)	

NOTICE OF ELECTRONIC FILING

PLEASE TAKE NOTICE that on May 30, 2019, we electronically filed with the Clerk of the Pollution Control Board of the State of Illinois, the ILLINOIS ASSOCIATION OF WASTEWATER AGENCIES' PRE-FILED QUESTIONS TO JAMES E. HUFF, P.E., copies of which is attached hereto and served upon you.

Dated: May 30, 2019

Respectfully submitted,

__/s/ Fredric Andes__________________
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WATER QUALITY STANDARDS	)	
FOR CHLORIDES	)	
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ILLINOIS ASSOCIATION OF WASTEWATER AGENCIES' PRE-FILED QUESTIONS TO JAMES E. HUFF, P.E.

1. Have you discussed this proposal with USEPA Region V to obtain their suggestions and their assessment of the likelihood of USEPA approval?

2. Are you aware that USEPA expects to release additional data regarding chloride and sulfate toxicity toward the end of 2019?

3. The petition states:

   The proposed language incorporates this request, assuming the same relationship for hardness and sulfate that was derived at temperature at 25°C applies at 10°C. This also seems like a reasonable approach until such time as further research is completed, so in a sense, the proposed standard herein can be viewed as interim water quality standard. Given that the hardness and sulfate relationship for aquatic species was based on one species, utilizing the temperature data from Jackson and Funk, combined with our data to establish a temperature relationship, is appropriate. (page 4).

   The petition thus assumes that the relationship for hardness and sulfate holds at all temperatures. Since your studies did not include hardness and sulfate data "due to limited funding", and the Jackson and Funk study relied on a single stream (White Clay Creek), how can you be sure that this relationship is appropriate across a wide range of conditions likely to be exhibited in Illinois streams?

4. Considering the work currently being performed by several researchers on the chloride toxicity issue, do you think that it may be premature to move forward with this self-admitted "interim water quality standard" based on limited data?

5. Page 5 section 2.b.: states that the temperature used would be the temperature at time of sample collection. How is an instantaneous measurement of temperature relevant to an aquatic community that will experience diurnal and seasonal fluctuations of temperature? If temperature is incorporated into the equation, wouldn't it be more appropriate to use an average or maximum/minimum value rather than an instantaneous measurement?

6. Jackson and Funk performed acute toxicity tests only. Is it fair to assume that chronic toxicity tests to evaluate sublethal effects would behave similarly?

7. Can you clarify how data concerning aquatic communities at the upper end of the moderately impaired category support the position that winter concentrations are less harmful than warm weather concentrations?

8. Was the duration of days extrapolated for all data sets or just the Chicago Sanitary Ship Canal (CSSC) at Romeoville?

9. The analysis is based on the numbers of consecutive days the chloride concentrations had a running average above a certain amount. Were those numbers real or estimated?

10. Is it likely that there is a "first-flush" phenomenon that occurs during some wet weather events? If so, how does this affect your analysis?

11. Chloride toxicity evaluation was conducted on four species at winter temperatures. Do these tests need to be repeated on the same species at summer temperatures to confirm reduced coldwater toxicity?

12. The tested species are identified as some of the most sensitive aquatic species. Have they been evaluated for their specific sensitivity to chlorides? Sulfate?

13. Are you aware that some drinking water systems in Illinois need to apply ion exchange technologies, to remove radium that is naturally present in the groundwater that they pump up from aquifers?

14. Are you aware that to regenerate the ion exchange resin columns, those systems need to periodically backwash the columns with a concentrated brine, which is very high in chloride levels?

15. When that backwash is sent to local publicly owned treatment works (POTWs), would that cause the effluent chloride levels at the POTW to potentially exceed the levels set forth in your proposed water quality standards?

16. Do you know how many POTWs in Illinois have that type of backwash being sent to them?

17. Would you expect those POTWs to have difficulty complying with the proposed chloride standards, particularly in summer? If not, please provide the basis for your conclusion.

18. What are other potential sources of chlorides to POTWs?

19. Is it accurate to say that for some communities, private water softeners would be a significant source of chloride influent levels to POTWs?

20. Would you expect that communities with significant numbers of private residential water softeners would have difficulty complying with the proposed chloride standards, especially in summer? If not, please provide the basis for your conclusion.

21. A study done with regard to Alexandria Lakes, Minnesota (referenced on page 5 of the report attached as Exhibit A) indicates that 73% of the chloride levels in POTW influent come from private residential water softeners, and 17% come from industrial softeners. Do you believe that the sources for communities in Illinois would be similar?

22. A study done for Santa Clarita, California (referenced on page 5 of the report attached as Exhibit A) indicates that private residential water softeners contribute 367 – 435 mg/L to chloride levels in POTW discharges. Do you believe that the contributions for communities in Illinois would be similar?

23. Are you aware of a study done for Minnesota Pollution Control Agency in December 2018, addressing alternatives for addressing chloride in wastewater effluent? (That report is attached as Exhibit A.)

24. That report identifies several sets of options for reducing chloride in wastewater effluent, including drinking water source reduction, point-of-entry softener optimization, and treatment at the POTW. Are you aware of any other available options?

25. That Minnesota report identifies options for drinking water source reduction, including centralized lime softening and centralized reverse osmosis (RO) softening, and describes the feasibility and cost issues for each of these options. Do you have any reason to disagree with the conclusions of that report as to those feasibility and cost issues?

26. Are you aware that using either of those centralized options would require all private homeowners to disconnect their existing water softeners?

27. The Minnesota report identifies options for point-of-entry softener optimization, which would require residents and industries to upgrade to high salt-efficiency softeners. Do you believe that such an option would be feasible or affordable for residents and businesses in communities throughout Illinois?

28. That report also identifies options for chlorides treatment at POTWs, and describes feasibility, cost, energy, and environmental concerns that would arise if those additional control systems were imposed. Do you have any reason to disagree with the conclusions of that report as to those concerns?

29. A report was prepared in 2015 for Madison Metropolitan Sewerage District regarding chloride compliance for the Nine Springs wastewater treatment plant. (That report is attached as Exhibit B.) Are you aware of that report?

30. That report also identifies options to reduce chloride levels in POTW effluents, including source water softening at the wellhead, centralized softening, and RO or electrodialysis reversal at the POTW. The report presents costs for each option, specifically analyzes concerns regarding brine management for RO treatment, and then conducts a Triple

Bottom Line analysis as to each compliance alternative. Do you have any reason to believe that the costs, feasibility issues and other identified concerns would be different for communities in Illinois?

31. Do you believe that for communities in Illinois, compliance with the proposed summer chloride standards would be feasible? If so, what options do you believe would be feasible to implement that would allow those communities to be in continuous compliance with permit limits imposed at the level of the standards, or possibly below that level?

32. Do you believe that for communities in Illinois, compliance with the proposed summer chloride standards would be affordable? If so, what is your estimate of the compliance costs (capital and annual operation and maintenance), and what would be the expected increases in sewer rates for those communities' ratepayers?

33. Do you believe that the energy and other environmental impacts that could be created by implementing some of those chloride reduction options (such as widespread use of RO) would be acceptable? If so, what is the basis for that assessment, including as to carbon footprint and as to potential landfill and other disposal options for brine?

Dated: May 30, 2019

Respectfully submitted,

ILLINOIS ASSOCIATION OF
WASTEWATER AGENCIES

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EXHIBIT A

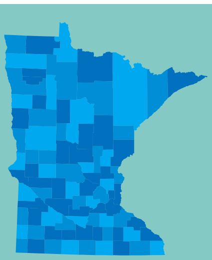
Wastewater

December 2018

Alternatives for addressing chloride in wastewater effluent

MPCA analyzes treatment options for salty parameters

MINNESOTA POLLUTION
CONTROL AGENCY



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Minnesota Pollution Control Agency

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This report is available in alternative formats upon request, and online at www.pca.state.mn.us.

Document number: wq-wwprm2-18

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Executive summary

Minnesota has a growing salty water problem that threatens its fresh-water fish and other aquatic life, despite being more than 1,000 miles from the nearest ocean. Salt – from chloride – can also impact groundwater used for drinking. It takes only one teaspoon of salt to permanently pollute five gallons of water. Once in the water, there is no way to remove the chloride.

While this report focuses on chloride, other salty parameters of concern include:

- Total dissolved solids
- Bicarbonate
- Hardness
- Specific conductance

What is the water quality standard for chloride?

Our freshwater streams and lakes naturally have low levels of chloride. High concentrations of chloride are harmful to aquatic plants and animals.

Based on guidance from the U.S. Environmental Protection Agency and the levels of chloride shown to be toxic to fish, Minnesota has a water quality standard to protect aquatic life from chloride:

- Longer chronic exposure is a 4-day average of 230 mg/L
- Shorter term acute exposure is a 1-day average of 860 mg/L

Why do municipal wastewater plants have chloride in their discharge?

The answer starts with water hardness. People soften their water to make soaps lather more and prevent calcium buildup on appliances and fixtures. Point-of-entry ion exchange water softeners are widely used to treat water hardness in Minnesota. In order to ensure continued operation of a point-of-entry ion exchange softener, it must be periodically regenerated with high salt brine that contains chloride. This brine eventually drains to a municipal wastewater system. The cumulative loading from all the point-of-entry softeners in the sewershed contributes significantly to the high chloride concentrations in the wastewater plant discharge.

Where in Minnesota is chloride in wastewater a problem?

Chloride in wastewater discharge appears to be a problem in about 100 Minnesota communities, most of them in southern and western areas of the state. Chloride flows into wastewater treatment facilities from homes and businesses that use water softeners. Treatment facilities are designed to remove particles, like grit and sand, and to biologically degrade organic waste, such as food and human waste. Once chloride is dissolved in water, it cannot be removed by settling, or biologically degraded by standard treatment processes. The technology to remove chloride is available, but is costly. It would involve microfiltration and reverse osmosis (RO), which are the same treatment processes used to produce pure water used in laboratories.

How does the Minnesota Pollution Control Agency know it is a problem?

Water monitoring data also show that salt concentrations are continuing to increase in lakes, streams and groundwater across Minnesota.

Wastewater treatment facilities started monitoring for chloride and other salty parameters in 2009. The MPCA examined the data and found that about 100 facilities have the potential to contribute to levels of chloride higher than allowed by the standard. One common tool to reduce pollutants like chloride is to issue permits with effluent limits to control the amount of a pollutant in a facility.

What are the alternatives to comply with a chloride effluent limit?

There is no feasible alternative for treating chloride once it is dissolved into water. The current alternatives for treating chloride at Wastewater Treatment Plants (WWTPs) are infeasible for reasons ranging from engineering feasibility to cost to legal constraints.

Below are the three most feasible strategies for reducing chloride in source water coming to WWTPs, which are examined further in this document:

1. Upgrade residences and businesses to high efficiency point-of-entry softeners
2. Centralized lime softening and removing point-of-entry softeners
3. Centralized reverse-osmosis softening and removing point-of-entry softeners

Minnesota salty parameter water quality standards

Minnesota's water quality standards for salty parameters and their specific designated uses are summarized in Table 1.

Under the current regulatory structure, every surface water in Minnesota is presumed to be used for Industrial Cooling and Materials Transport (3C Classification), Irrigation (4A Classification) and Livestock and Wildlife (4B). Thus, 3C, 4A, 4B standards apply to every surface water.

The chloride standard in Table 1 needs to be considered for a discharge to any water in Minnesota, even if not designated as protected for aquatic life and recreation, because all streams – even those classified as limited resource value waters – eventually flow into a water protected for aquatic life and recreation (Classification 2).

Table 1. Minnesota water quality standards associated with the common major ions or salty parameters

Parameter	Units	Water Quality Standard Value	Use classification	Designated protective use
Chloride	mg/L	230 (Chronic)	2	Aquatic life and recreation
Hardness	mg/L as CaCO3	500	3C	Industrial Cooling and Materials Transport
Total dissolved solids	mg/L	700	4A	Irrigation
Bicarbonates	mg/L as CaCO3	250	4A	Irrigation
Specific conductance	µmho/cm	1000	4A	Irrigation
Total salinity	mg/L	1000	4B	Wildlife and livestock

The MPCA is legally required to determine if a discharge from facility with a National Pollutant Discharge Elimination System (NPDES) permit has reasonable potential to violate a water quality standard. If a facility has reasonable potential to exceed a water quality standard, then that facility must receive final permit limits for that parameter.

Total dissolved solids (TDS) and salinity are parameters that measure almost the same identical underlying parameter. For the purposes of effluent limit setting, the MPCA considers salinity and TDS as measuring the equivalent underlying parameter, which is ionic strength. The MPCA does not evaluate reasonable potential for the 4B Classification - 1,000 mg/L - salinity standard. The total salt content of a wastewater is always assessed against the 4A Classification - 700 mg/L - TDS standard because it is more protective than the 4B Classification.

Monitoring for salty parameters

In 2009, the MPCA began requiring mechanical WWTPs to monitor for salty parameters if they:

1. Discharged to a low dilution stream.
2. Received a waste stream from a concentrating treatment technology (RO, ion exchange, membrane filtration, etc.).
3. Received a waste stream from a food processing facility that uses saline-based density sorting. Stabilization ponds with a controlled discharge were exempted from the salty parameter monitoring.

The salty parameter-monitoring suite includes all major cations and anions. When these WWTP NPDES permits come up for re-issuance, the MPCA is required to analyze for reasonable potential to exceed state water quality standards in their downstream receiving waters.

The majority of the WWTPs that have or will receive a chloride or salty parameter limit fit into the categories below:

1. Municipal WWTPs that are not designed to treat chloride.
2. Have a substantial fraction of their customers using point-of-entry water softeners to reduce their drinking water hardness.
3. Do not receive substantial chloride loading from concentrating technologies or food-processing facilities using density based sorting.
4. Are not designed to treat or remove any salty parameter.

Salty parameter sources of loading to WWTPs

In general, salty parameter loading fall into three categories:

1. Naturally occurring salts in the source water
2. Anthropogenic salts in the source water
3. Anthropogenic salts after the source water has been treated

Loading from salts naturally occurring in source water

Source water to a Minnesota WWTP typically comes from one of two sources: groundwater or surface water. In general, these two source waters will have distinct water chemistries. The natural geology of

Minnesota and the wonders of chemistry cause these two sources of water to diverge in chemical composition.

Groundwater salt sources

Groundwater exists in the pore spaces of rock in underground aquifers. Except for the northeast part of the state, in Minnesota the underground rock that contains the aquifer's water is composed of forms of calcium-containing minerals such as limestone or gypsum. When water moves through these types of minerals, the water acts as a solvent and dissolves the mineral. This mineral dissolution elevates the concentrations of dissolved salt in the water, causing the water to be "hard" and contain minerals. These groundwater resources tend to naturally have a high hardness and salt content because of this combination of water chemistry and geology (Figure 1).

The quantity of a dissolved salt in a groundwater is in proportion to the chemical composition of the mineral in the aquifer. In general, if the aquifer is composed of minerals with high sulfate, radium, magnesium or alkalinity, then the water in that aquifer will have high sulfate, radium, magnesium or alkalinity. While there are geographic patterns to groundwater salt content in Minnesota, it is best to measure a specific well if needing to know the salt content. Sulfate concentrations in Minnesota groundwater supply are shown in Figure 2.

All Minnesota aquifers contain minerals with very low chloride concentrations. Consequently, chloride naturally occurs in the single digit mg/L concentrations in Minnesota groundwater even if the water has an elevated hardness or mineral content. As a rule, if a groundwater has elevated chloride concentrations the excess chloride can be attributed to chloride from road salt or another anthropogenic source.

Surface water salt sources

In general, surface water has a lower salt content than groundwater in Minnesota. Surface water here can still have high hardness (>180 mg/L as $CaCO_3$) depending on the region. Like groundwater, there are geographic patterns to surface water salt content in Minnesota, but it is best to measure a specific water body if needing to know the salt content.

Again, like groundwater, Minnesota surface waters naturally have very low chloride concentrations (about < 20 mg/L chloride). As a rule, if a surface water has elevated chloride concentrations, the excess chloride can

Figure 1. Hardness concentrations in Minnesota water supply wells.

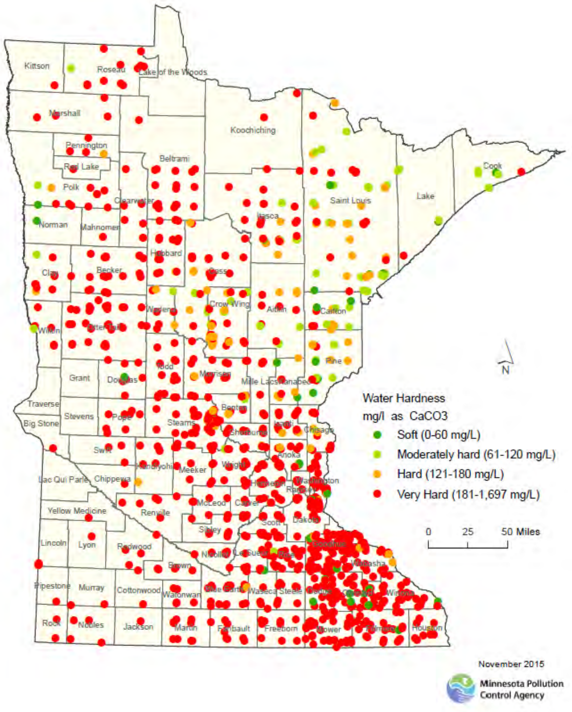
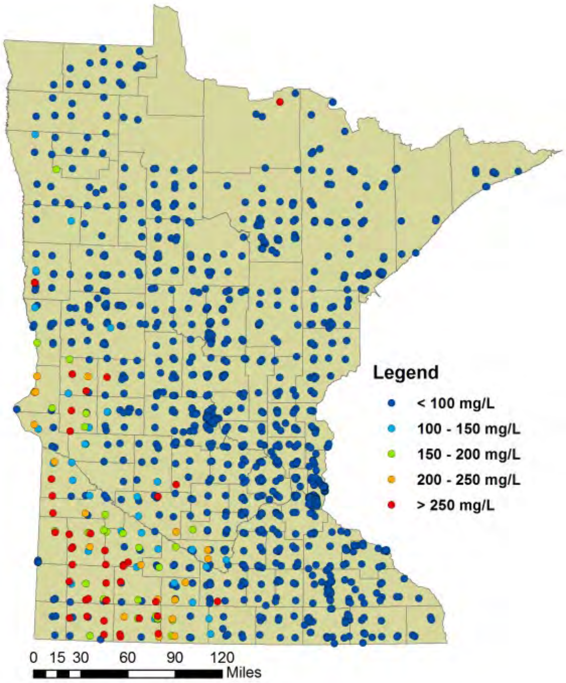


Figure 2. Sulfate concentrations in Minnesota water supply wells.



be attributed to chloride from road salt or another anthropogenic source. It is common in Minnesota to see higher surface water chloride concentrations in the wintertime because of road salt runoff.

Anthropogenic salt loading to WWTPs

According to this MPCA analysis, point-of-entry softeners are the dominant source of salt loading to the typical Minnesota municipal WWTP effluent. The dominant ion from this salt loading is chloride; chloride is a component of TDS. As chloride loadings increase, TDS and specific conductance increase proportionally.

There is no statewide system to track chloride loading from point-of-entry softeners and few cities have done any rigorous investigation of point-of-entry softener chloride loading. However, in every Minnesota city where chloride loading has been tracked – Pipestone, Morris and Alexandria – point -of-entry softeners are the dominant source. Unless there is industrial chloride loading, the dominant chloride source is almost certainly from point-of-entry softeners, especially where the source water has high hardness levels.

The city of Alexandria is one of the few cities in Minnesota to perform a citywide chloride source mass balance to its WWTP. The city found that about 10% of the chloride loading to the WWTP is from source water and is thus not amenable to source reduction. Industrial users produce about 17% of the chloride loading to the WWTP. The balance of 73% is from residential loading with the substantial majority of that chloride loading coming from point-of-entry softeners. Based on MPCA 'back of the envelope' analysis, it is reasonable that point-of-entry water softeners are contributing greater than 500 mg/L of chloride to the effluent of the Alexandria WWTP (Data: ALASD Chloride Management Plan, 2014).

The high chloride loading from point-of-entry water softeners is best thought of using the "tragedy of the commons" analogy. No single point-of-entry ion exchange water softener is individually causing high chloride concentrations in the effluent of a WWTP. However, the aggregate chloride loading from all of the point-of-entry softeners collectively contribute to the high chloride loading at the WWTP.

A mass balance study of chloride sources to WWTPs in Santa Clarita, California, estimated that on average 31 mg/L of chloride are added above baseline chloride concentrations from households not using point-of-entry water softeners. The sources of this chloride are personal care products, washings and other domestic sources. The Santa Clarita study estimated that a point-of-entry water softener added 1.34 lbs/day of salt loading to the WWTP corresponding to an increased chloride concentration above baseline of between 367 to 435 mg/L (2002 and 2014, Santa Clarita study). For lack of better data in Minnesota, it is reasonable to assume that a residence in this state is contributing chloride loading to WWTPs at similar rates to Santa Clarita.

Even with the data available, extrapolating point-of-entry water softener chloride loading from one Minnesota city to the next is a complicated task. In order to understand point-of-entry water softener chloride loading to a Minnesota WWTP, a brief primer of residential water softeners is necessary and is provided below.

Fundamentals of point-of-entry ion exchange water softener chloride loading

- Point-of-entry softeners use ion exchange resins to remove calcium and magnesium hardness from incoming water.
- As hard incoming water passes through the point-of-entry softener ion exchange column, the column eventually becomes saturated and is no longer able to remove calcium and magnesium from the influent water.

- In order to regenerate the resin, a concentrated brine of sodium or potassium chloride is backwashed through the ion exchange resin column to displace all of the calcium and magnesium ions that have accumulated on the resin.
- This highly concentrated chloride containing brine is disposed down the sanitary sewer.
- After the chloride containing brine is disposed down the sanitary sewer, incoming water is routed again through the ion exchange resin to remove hardness.
- The backwash process and disposal of salt brine is repeated as necessary to ensure that the ion exchange resin is never overloaded and always has the capacity to remove hardness from incoming water.

The amount of chloride a point-of-entry softener will load to the WWTP can be characterized generally using the concepts below. As can be seen, the chloride loading from any individual point-of-entry water softener is dependent on many variables and is specific to the individual homeowner's water chemistry, water use, hardness preferences, and softener efficiency.

$$\uparrow Water\ Hardness = \uparrow\ Greater\ Backwash\ Frequency = \uparrow Chloride\ Loading\ to\ WWTP$$

$$\uparrow Home\ Water\ Use = \uparrow\ Greater\ Backwash\ Frequency = \uparrow Chloride\ Loading\ to\ WWTP$$

$$\uparrow Degree\ of\ Desired\ Softening = \uparrow\ Greater\ Backwash\ Frequency = \uparrow Chloride\ Loading\ to\ WWTP$$

$$Poorly\ Optimized\ Backwash\ Frequency = \uparrow\ Greater\ Backwash\ Frequency = \uparrow Chloride\ Loading\ to\ WWTP$$

In general, point-of-entry water softener types can be classified into two broad categories:

- Timed softeners – These are set to regenerate the ion exchange resin on a fixed schedule. These softeners are usually older. They are less salt efficient because they are set to err on the side caution and frequently backwash more often than needed to ensure that soft water is always available to the user.
- Demand softeners – These are set to regenerate the ion exchange resin whenever the capacity of the ion exchange capacity is reached. "Smart" models can be optimized to minimize resin regeneration frequency using a variety of optimization techniques.

A full characterization of Minnesota point-of-entry water softener types and use has not been completed to the knowledge of the MCPA. However, based on conversations with state residents and water resource professionals, a large fraction of Minnesota water softeners are of the timed variety. Demand softeners are increasingly common, but are frequently not fully optimized to minimize backwash frequency and thus chloride loading.

Water softener fouling and resin efficiency

Ion exchange is not a "chloride efficient" way to remove hardness from water. The California Health and Safety Code's salt-efficiency standard is 4,000 grains of hardness as calcium carbonate ($CaCO_3$) removed per 1 pound of sodium chloride (NaCl) loaded to WWTP. This represents a loading of about 1 mg of chloride for every 1 mg of hardness of $CaCO_3$ removed.

It is unlikely that most Minnesota point-of-entry residential water softeners are operated at the ideal target salt efficiency. The California salt-efficiency standard assumes that a new high efficiency water softener is being used that is fully optimized to minimize backwashing and that the resin is operating at its installation level of efficiency. Even "optimized and smart" residential water softeners can put many hundreds of pounds of chloride down the drain over the course of a year.

The ion exchange resin beads are a plastic polymer that will reduce in ion exchange capacity over time. There are many reasons a resin might reduce in efficiency over time and common reasons are highlighted below.

Iron fouling

Any iron present in water coming into an ion exchange resin will reduce chloride efficiency. Iron present in water can reduce the exchange capacity of an ion exchange resin in two ways:

1. Ferrous iron is in a divalent oxidation state and is found dissolved in water. It is frequently called clear iron. Ferrous iron will exchange with sodium on the ion change resin and can be backwashed off the resin by regular resin brine regeneration. Any dissolved ferrous iron will add hardness to the water and increase the frequency of resin regeneration.
2. Ferric hydroxide fouling is a more problematic type of iron fouling. Ferric iron is in a trivalent oxidation state and under normal oxidized conditions will exist as an iron-hydroxide solid commonly called rust. Ferrous iron will oxidize to rust in the presence of oxygen. This rust binds to the ion exchange resin and blocks the ion exchange sites, reducing resin efficiency. This kind of fouling can only be reversed by periodic cleaning using an oxidizing salt approved by the manufacturer. A brine backwash cycle will not fully remove iron hydroxide fouling.

Chlorine and drinking water disinfecting residuals

Chlorine and other associated compounds are strongly oxidizing molecules used to maintain a disinfecting residual in drinking water to protect human health. These oxidizing compounds, when in water, will attack the polymer linkages in the ion exchange resin and over time will degrade the quality of the resin. Manufacturers have done admirable work developing resins that are more resistant to chlorine degradation in recent years but resins that are not exposed to disinfectants will last longer than resins not exposed to disinfectants. Disinfectants will reduce the efficiency of your resin in proportion to the activity of the disinfectant residuals.

The Hellenbrand water treatment company uses the formula below to estimate ion exchange resin replacement interval as a function of free chlorine in the incoming water. The Hellenbrand Company believes that ion exchange resins should be replaced when they have reduced in exchange efficiency by 20%. In Minnesota, most distribution networks run a free chlorine concentration ranging from 0.2 – 1 mg/L representing an average estimated resin replacement interval of 10 to 20 years in the absence of any other resin foulants.

$$Number\ of\ Years\ before\ Resin\ Replacement = \frac{10}{Free\ Chlorine\ (mg/L)}$$

Suspended solids

Ion exchange resins can have an identical function as a sand filter in that they remove particulate solids. However, this is not an efficient use of an ion exchange resin capacity and nearly every manufacturer acknowledges this in their recommended best practices. If present, suspended solids should be removed before the ion exchange resin. Any suspended solids in the incoming water could easily irreversibly foul a membrane resin surface.

A common source of fouling resins is using a low quality rock salt with dirt in it. This dirt will over time foul the resin during backwashing. A pure, high quality salt will increase lifetime resin efficiency.

Bed volume loss

Ion exchange resin beads are made of petroleum byproducts. When these beads are installed, they are round and not cracked. The resin beads can be damaged by the agitation caused by the backwashing process, free chlorine, and water induced osmotic swelling during regeneration. As the beads become damaged, they break into smaller pieces that have a lower mass and higher relative surface area. These small pieces are washed away during the backwashing process and this process overtime results in loss of resin bed volume. As the resin bed volume decreases, the total exchange capacity of the system decreases reducing the chloride efficiency of the water softener.

The Hellenbrand water company estimates that under normal operation a resin bed will lose 1% of its resin volume every year because of resin bead breakdown if the free chlorine concentrations are less than 0.5 mg/L. The bed volume loss can be as high as 3% annually if the resin regenerates frequently and high free chlorine concentrations are present.

Over time, this can cause substantial resin loss and reduce the ion exchange capacity and chloride efficiency of the system. The total bed loss as a percent of original bed volume can be visualized in the table below.

Table 2. Compounded resin bed volume relative to initial bed volume overtime assuming a 1% and 3% volume loss per year.

Year	Bed volume loss (1% Annual loss)	Bed volume loss (3% Annual loss)
1	1.0%	3.0%
2	2.0%	5.9%
3	3.0%	8.7%
4	3.9%	11.5%
5	4.9%	14.1%
6	5.9%	16.7%
7	6.8%	19.2%
8	7.7%	21.6%
9	8.6%	24.0%
10	9.6%	26.3%

Alternative analysis

The MPCA conducted an alternatives analysis to evaluate options that might reduce chloride loading to the WWTP. Broadly, these options fall under three categories:

1. Drinking water source reduction
2. Point-of-entry softener optimization
3. Chloride treatment at the WWTP

These categories were screened by these three questions:

1. Can the alternative produce a chloride loading reduction?
2. Could the alternative individually comply with Minnesota’s 230 mg/L chloride standard?
3. What is the feasibility and relative cost of the alternative?

Table 3 outlines the feasibility of the three reduction categories with detailed discussion.

Table 3. Feasibility of the three reduction categories to reduce chloride in wastewater discharges

	Alternative	WWTP chloride reductions possible?	Ability to bring WWTP into chloride compliance	Ability to bring WWTP into other salty parameter compliance?	Technical feasibility	Implementation feasibility	Estimated relative cost
Drinking water source reduction	Centralized lime softening	Yes	Likely*	Likely*	Yes	Feasible	High
	Centralized RO softening	Yes	Likely*	Likely**	Yes	Feasible	High
	Ferric chloride --> Ferric sulfate	Yes	Unlikely	Unlikely	Yes	Feasible	Low
Softeners	Upgrade to high salt efficiency Point-of-entry softeners	Yes	Unlikely	Unlikely	Yes	Feasible	Medium
	Upgrade industry to high efficiency softeners	Yes	Unlikely	Unlikely	Yes	Feasible	Medium
	Outlaw ion exchange point-of-entry water softeners	Yes	Likely	Likely**	Yes	Not Feasible	Medium
	Create softener column exchange and Collection Program	Yes	Likely	Likely**	Yes	Feasible	High
	Switch to non-ion exchange softeners	Yes	Likely	Likely**	No	Feasible	Medium
	Increase residential softening target	Yes	Unlikely	Unlikely	Yes	Not Feasible	Medium
WWTP chloride treatment	RO effluent - Concentrate discharged to surface water	Yes	Likely	Likely	No	Not Feasible	High
	RO effluent - Concentrate crystalized/evaporated	Yes	Likely	Likely	Yes	Not Feasible	Very High
	RO effluent - Concentrate deep well injection	Yes	Likely	Likely	No	Not Feasible	Very High
	Chlorination to UV disinfection	Yes	Unlikely	Unlikely	Yes	Feasible	Medium
	Ferric chloride to ferric sulfate	Yes	Unlikely	Unlikely	Yes	Feasible	Low
	Chloride precipitation with silver nitrate	Yes	Possible	Unlikely	Yes	Not Feasible	Very High
	Chloride anion exchange	Yes	Possible	Unlikely	No	Not Feasible	Very High
	Electrodialysis	Yes	Possible	Unlikely	Yes	Feasible	High
	Any biological treatment process	No	Impossible	Impossible	No	Not Feasible	NA

*If all point-of-entry ion exchange softeners are taken offline. ** If all point-of-entry ion exchange softeners are taken offline and source water quality has concentrations below Classification 3 and 4 water quality salty parameter standards.

Drinking water source reduction

Centralized lime softening and disconnecting point-of-entry softeners

Rationale

Switching a city's drinking water to centralized lime softening and disconnecting point-of-entry softeners is a way to reduce and come into compliance with chloride and Classification 3 and 4 water quality standards at the WWTP through chloride source reduction. The assumptions behind this alternative are outlined below:

- The city switches to a drinking water treatment plant that softens the water using lime softening. Lime softening chemically precipitates hardness, alkalinity and adds no chloride to the treated water. The water is softened to a hardness of < 100 mg/L as $CaCO3$.
- All of users are connected to both city drinking water and discharge to city sewers.
- Point-of-entry residential softeners are taken off-line because removing hardness at the point-of-entry is no longer necessary. This applies only to locations connected to city water.
- Chloride loading to the WWTP from point-of-entry softening decreases to a level that could comply with the effluent limit based on Minnesota's 230 mg/L chloride standard.
- Salty parameters decrease to a level that could comply with the effluent limit based on the Classification 3 and 4 water quality standards.

Lime softening is a chemical method of removing hardness from a drinking water. It is always employed at a centralized drinking water treatment plant and is infeasible at a residential scale or with a distributed well network.

Lime softening works by adding lime to the water, which raises potential of hydrogen (pH) to greater than 10.3 and initiates precipitation of hardness and alkalinity ions as calcium carbonate. If the water has high levels of magnesium hardness, excess lime softening would be required to increase the pH to approximately 11 and soda ash ($Na2CO3$) would also be added.

In Minnesota, drinking water is almost always excess lime softened because of high magnesium hardness.

A typical Minnesota groundwater source that has been excess lime softened will have a significantly lower mineral content than water not lime softened due to removal of calcium and magnesium. Lime softening also lowers TDS by precipitation of hardness and alkalinity. As the TDS decrease, specific conductance decreases proportionally, because there is less dissolved mineral content to conduct electricity (Table 4). If sulfate concentrations are low, then the amount of sodium added during excess lime softening through soda ash only contributes marginally to TDS and is insignificant relative to the amount of TDS removed by hardness precipitation (Figure 3).

Figure 3. Major ion content of water that has been excess lime softened and ion exchange softened compared to the untreated source water.

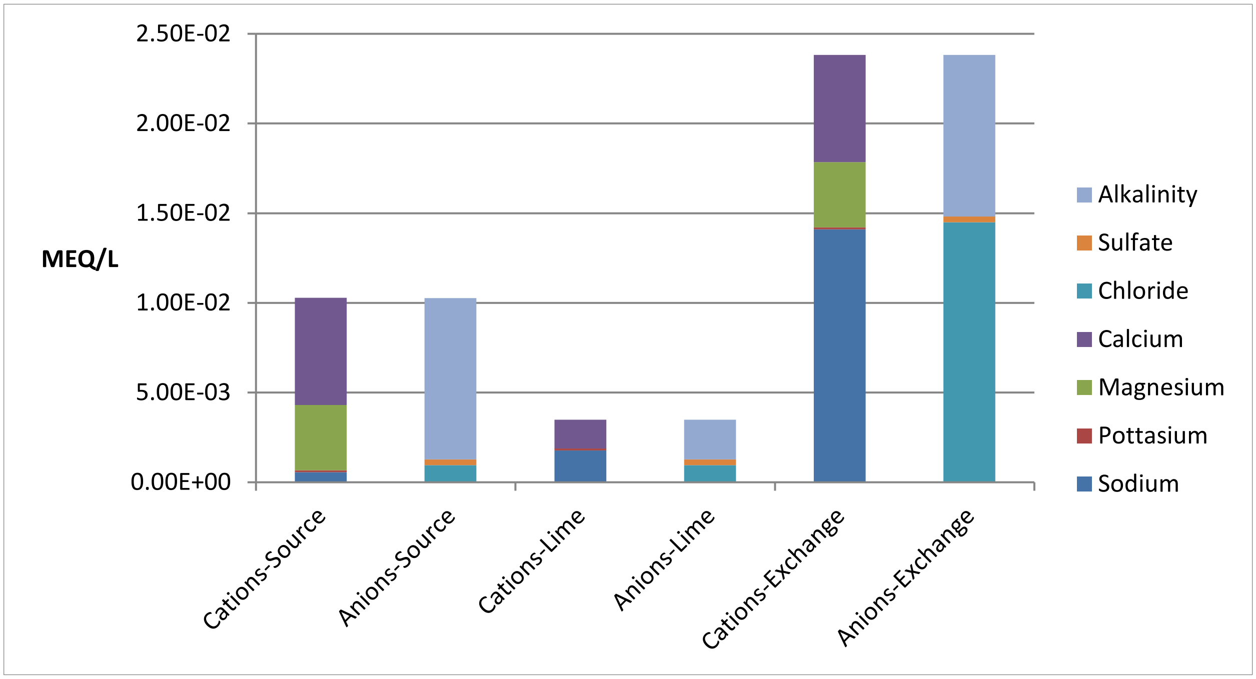


Table 4. Major ion content of water that has been excess lime softened and ion exchange softened compared to the untreated source water from Figure 3. TDS and Specific Conductance are calculated values using equations 1 and 2.

Parameter	Na	K	Mg	Ca	Hardness	Cl	SO_4	Alkalinity	Ionic Strength	TDS	Spec. Cond.
Unit	mg/L	mg/L	mg/L	mg/L	mg/L as CaCO3	mg/L	mg/L	mg/L as CaCO3	mMoles	mg/L	µmho /cm
Source	13.1	4.1	44.1	120	480	33.6	15.7	450.3	14.4	577	901
Excess Lime Softening	40.6	4.1	0.3	32.1	80.8	33.6	15.7	158	4.3	172	269
Ion Exchange Softening	324	4.1	44.1	120	480	514	15.7	450.2	28.0	1121	1751

Equations 1 and 2 are taken from Snoeyink and Jenkins, 1980. They were rearranged to calculate TDS and specific conductance for the modeled water in Table 4.

$$Equation\ 1.\ Ionic\ Strength\ (Moles) = 2.5\ X\ 10^{-5}\ x\ TDS\ (\frac{mg}{L})$$

$$Equation\ 2.\ Ionic\ Strength\ (Moles) = 1.6\ X\ 10^{-5}\ x\ Specific\ Conductance\ (\mu mho/cm)$$

Table 5 shows the general impacts of centrally limed softening and ion exchange softening to source water. These general trends will be true regardless of the specific water chemistry of the source water. Additionally, lime softening can remove gross alpha emitters, heavy metals (Pb, Cr(III), Hg, As), iron and manganese, turbidity, some organic compounds, and control algae, bacteria and viruses. Enhanced lime softening can remove dissolved organic carbon and thus decrease the formation of disinfection byproducts in the chlorination process (MWH, 2005).

Table 5. Effects of the softening strategy on the concentration of the given parameter relative to the source water at the wastewater effluent.

Parameter	Centralized excess lime softening	Point-of-entry ion exchange
Hardness	Decreased	Unchanged
Alkalinity (Bicarbonates)	Decreased	Unchanged
Total dissolved solids	Decreased	Increased
Specific conductance	Decreased	Increased
Chloride	Unchanged	Increased
Sodium	Slight Increase	Substantial increase

This assumes no significant source of the parameter between the drinking water plant and the wastewater plant. At a neutral pH between 7 to 9, greater than 95% of alkalinity is present as bicarbonate, so for the purposes of this memo alkalinity and bicarbonates can be used interchangeably.

If lime softening at the drinking water treatment plant and the full removal of point-of-entry ion exchange softeners is implemented then the wastewater plant would comply with its chloride limits and the Classification 3 and 4 parameters in Table 1. The predicted ranges associated with this treatment alternative can also be found in Table 6. The predicted values in Table 6 assume that there is no significant source of these parameters between the drinking water plant and the wastewater plant. For typical Minnesota drinking water, TDS would be less than 700 mg/L after excess lime softening. However, if the source water has a high absolute concentration of ions that are not removed during softening (Na, Cl, K, SO4) then the predicted concentrations in Table 6 are not valid.

Table 6. Expected levels in a wastewater effluent of the selected parameter if the chloride treatment alternative involving excess lime softening at the drinking water plant is fully implemented.

Parameter	Units	Average range	Water quality standard
Chloride	mg/L	< 230	230 (2B)
Hardness	mg/L as CaCO3	< 500	500 (3B)
Total dissolved solids	mg/L	< 700	700 (4A)
Bicarbonates	mg/L as CaCO3	< 250	250 (4A)
Specific conductance	µmho/cm	< 1,000	1,000 (4A)

When is it necessary to disconnect all point-of-entry water softeners?

Installing centralized lime softening and removing all point-of-entry softeners, has the highest degree of certainty of ensuring compliance with chloride and salty parameter limits.

Making specific assumptions, listed below, it may be possible to reliably meet chloride effluent limits through centralized lime softening while still allowing the use of high efficiency point-of-entry softeners in the distribution network.

- All point-of-entry softeners are rated as having high salt efficiency of at least 4000 grains of hardness per pound of salt.
- All point-of-entry softeners are optimized to minimize salt use.
- The water supplied to households is softened to less than 8 gpg or 137 mg/L as CaCO3.

- There are no significant sources of chloride (chlorine, SIUs, road salt intrusion, source water, etc…) that could cumulatively contribute to a violation of chloride limits when high efficiency point-of-entry softeners chloride loading is also included.

The MPCA recommends that a numeric evaluation of all potential chloride sources be completed before a municipality commits to recommending the use of high efficiency point-of-entry water softeners in the wastewater collection network. Evaluating the information provided in the “upgrading to high-efficiency softeners” section of this report could also be useful.

Feasibility

This option has the potential to reduce chloride loading to the WWTP. This option also has the potential to meet the chloride limits because it eliminates chloride loading from point-of-entry water softeners. A reduction in chloride concentrations in the WWTP effluent that complies with permit limits is theoretically possible. Every city that fully implemented this alternative could comply with the chloride water quality standard.

This option is technically feasible.

However, this option has some significant feasibility concerns:

- The city would need to develop the political will to finance, design, and construct a lime softening drinking water plant.
- All or a large majority of city residents and businesses would need to connect to a drinking water distribution network. For cities with no water distribution network, this represents significant challenges for customers adjusting to new systems and cities building the infrastructure.
- The city would need to establish the authority to create rules, incentives, and inspections to eliminate and verify the elimination of point-of-entry water softener use.
- Typically, drinking water treatment plants do not soften down to less than one grain of hardness like many point-of-entry softeners. Typically, lime softened water has a target hardness of four to five grains of hardness. Residents who point-of-entry soften to one grain of hardness or less would need to adjust to water with increased hardness levels. While the water may feel different, four to five grains of hardness is acceptable for most boilers and lathering concerns.
- Industrial users receiving city drinking water would need to evaluate whether softened waters work with their industrial processes.
- Source waters with high sulfate concentrations limit the TDS endpoint that is possible using lime softening. Lime softening might not be feasible for high sulfate waters as a means to reduce TDS.
- Lime sludge storage and disposal plans would need to be managed.

Cost

Bolton and Menk provided estimates for the costs of building treatment plants to soften water with lime, and for total operation and maintenance (Figures 4 and 5). The costs assume a 10-hour working day for the operators and sludge thickening of the lime solids. The costs in Figure 5 incorporate the costs of a 20-year pay back schedule for the capital costs with a 4% interest rate and an O&M cost of $7/1,000 gallons of water produced.

Figure 4. New lime softening drinking water plant capital costs by population size.

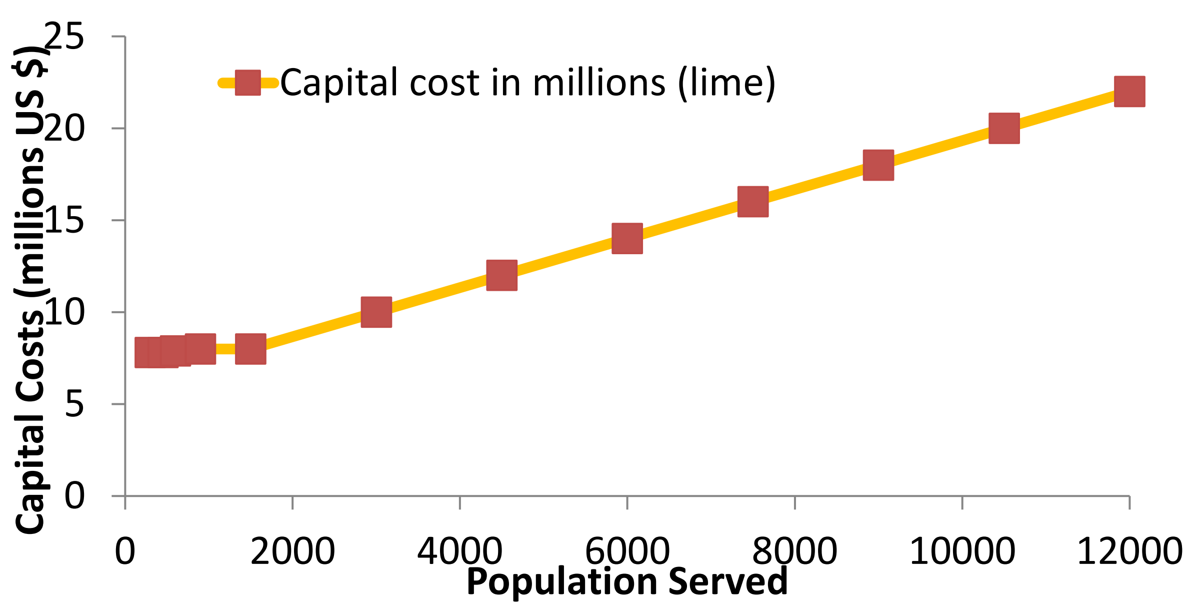
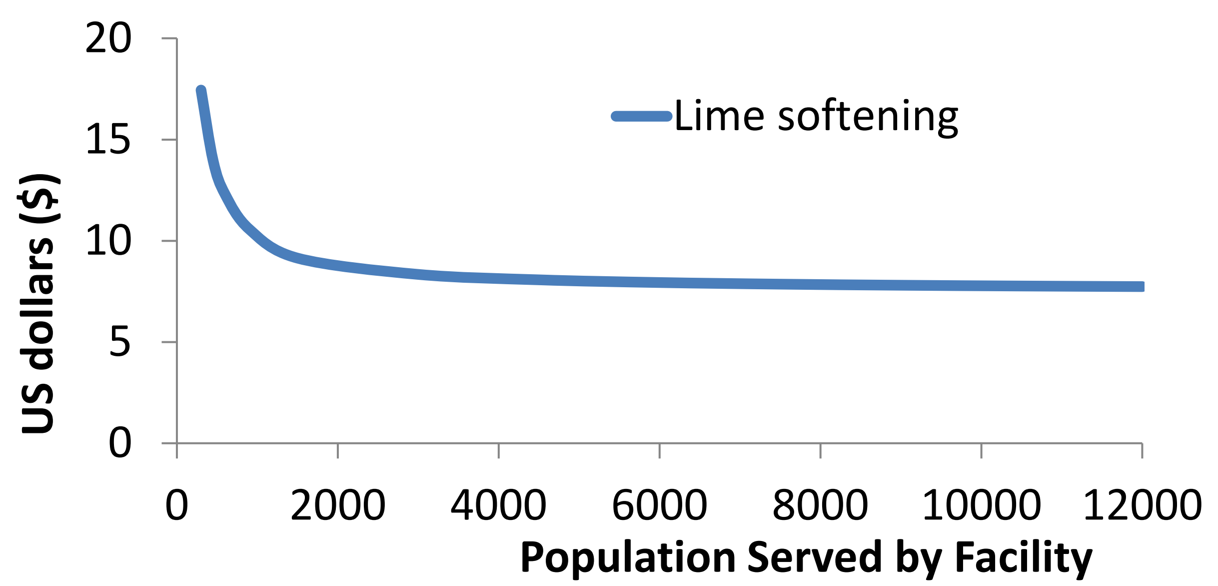


Figure 5. Annualized lime softening drinking water plant costs (capital and O&M) by population size.



These costs represent an initial estimate for new lime softening plants. Costs for lime softening plants depend greatly on the source water quality among a myriad of other factors. It is unlikely that other communities could build lime-softening plants for significantly less than these numbers. If the water has a high sulfate content (ienon-carbonate hardness) then the O&M costs could be even higher than in Figure 5, because higher amounts of soda ash could be required and soda ash is at least two times more expensive than lime.

Centralized lime softening can be a cost effective way for residents to softener their water compared to point-of-entry softening. The city of Bloomington, Minnesota, has centralized softening and has performed an analysis for users that shows that a point-of-entry user can save up to $30 a month on their drinking water costs through centralized softening compared to point-of-entry water softening. When factoring in the costs of a typical point-of-entry water softener including purchase, installation, operation and maintenance, centralized softening saved Bloomington users about $1.21/1,000 gallons of water (Personal Communication, Steve Roepke, City of Bloomington).

The costs of installing a drinking water distribution network, connecting residents to city drinking water or disconnecting point-of-entry water softeners are not considered in this analysis because they are specific to each individual city. Nevertheless, these costs are non-trivial and would be expensive.

Centralized reverse osmosis softening and disconnecting point-of-entry softeners

Rationale

Switching a city's drinking water to centralized RO softening and disconnecting point-of-entry water softeners is a way to reduce chloride and comply with chloride standards at the WWTP. The assumptions behind this alternative include:

- The city switches to a drinking water treatment plant that softens the water using RO. Reverse osmosis physically removes hardness and adds no chloride to the water.
- All or a substantial fraction of users are connected to both city drinking water and discharge to city sewers.
- Point-of-entry residential softeners are taken off-line because hardness removal at the point-of-entry is no longer necessary. This applies only to locations connected to city water.
- Chloride loading to the WWTP from residential users is reduced to a level that could comply with the effluent limit based on the 230 mg/L chloride standard.
- If the source water has concentrations of Classification 4 parameters below the applicable water quality standards, then the facility will potentially comply with potential Classification 3 and 4 limits.

Feasibility

This option has the potential to reduce chloride and TDS loading to the WWTP. This option has the ability to meet Classification 3 and 4 limits if the source water has TDS, hardness and alkalinity concentrations below the Classification 3 and 4 water quality standards.

RO softening does not reduce the salt loading a WWTP would receive relative to the source water. RO softening works by reducing the salt loading the end-users receive and routing the concentrated salt mass to the WWTP. Figure 6 demonstrates how flow and salt mass is routed using centralized RO softening. If the water supply has salt concentrations that are above Classification 3 and 4 water quality standards, then this option would not be able to guarantee compliance with a Classification 3 and 4 limit at the WWTP (Table 7).

Q = Flow; Ch = Concentration of Hardness; Mh = Mass rate of Hardness; Ccl = Concentration of Chloride;

Mcl = Mass rate of Chloride

Figure 6. How RO softening could guarantee compliance with chloride limits but not hardness limits if the source water has high hardness values.

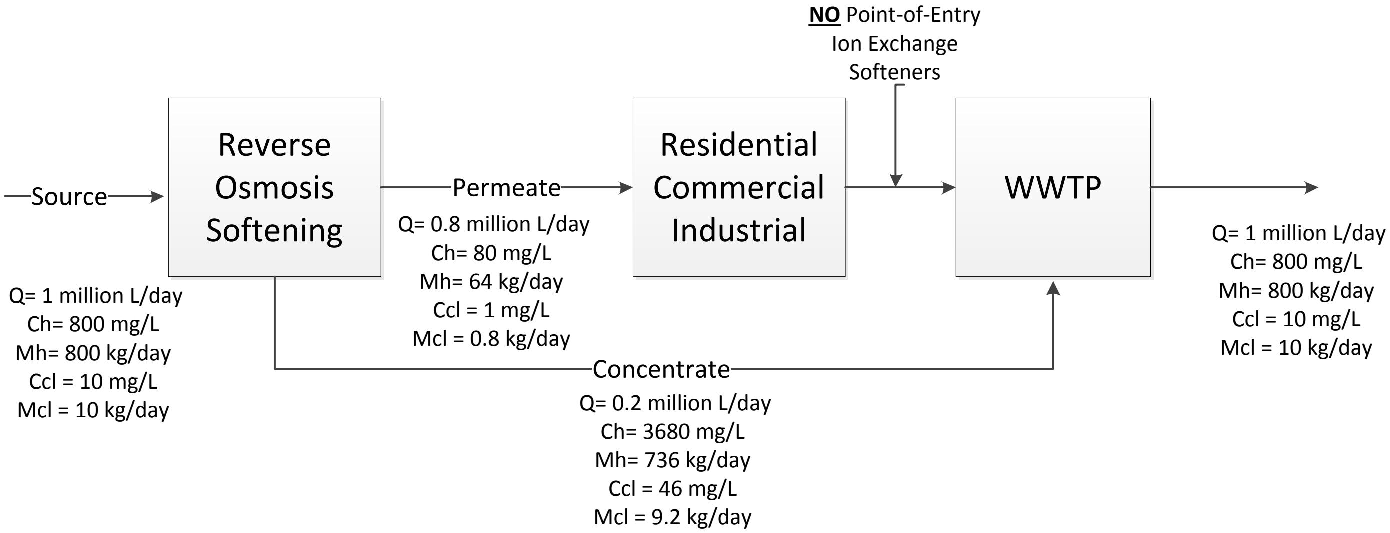


Table 7. Reasonable potential for a given parameter using RO softening and eliminating IX softeners if the source water also has RP.

Parameter	Source water RP	RP at WWTP using centralized RO softening and eliminating IX softeners
Chloride	No	No
TDS	Yes	Yes
Specific Conductance	Yes	Yes
Hardness	Yes	Yes
Alkalinity	Yes	Yes

This option also has the potential to be able to meet the chloride limits because it eliminates chloride loading from point-of-entry water softeners. A reduction in chloride concentrations in the effluent of the WWTP greater than 350 mg/L is theoretically possible in some locations.

This option is technically feasible.

However, this option has some significant implementation concerns highlighted below:

- The city would need to develop the political will to finance, design, and construct an RO drinking water plant.
- All or a large majority of city residents and businesses would need to connect to a drinking water distribution network. For cities with no water distribution network, this represents significant challenges for customers adjusting to new systems and cities building the infrastructure.
- The city would need to establish the authority to create rules, incentives, and inspections to eliminate point-of-entry water softener use.

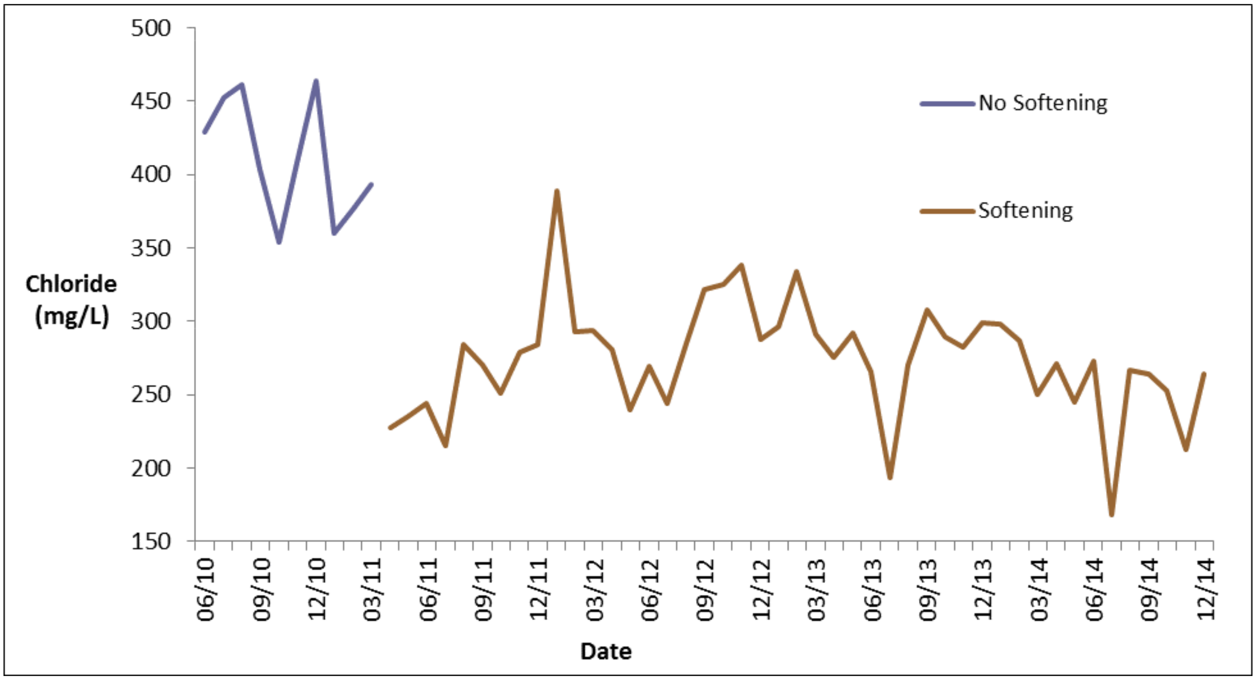
- Typically, drinking water treatment plants do not soften down to less than one grain of hardness like many point-of-entry softeners. Typically, lime softened water has a target hardness of four to five grains of hardness. Residents who point-of-entry soften to one grain of hardness or less would need to adjust to water with increased hardness levels. While the water may feel different, four to five grains of hardness is acceptable for most boilers and lathering concerns.
- Industrial users receiving city drinking water would need to evaluate whether softened waters work with their industrial processes.
- The city would need to find a way to manage the RO concentrate stream. An RO concentrate stream has highly concentrated salt concentrations that are notorious for failing toxicity tests and “salty” discharge limits when discharged directly to Minnesota surface water. Some cities will be able to send RO reject to the WWTP if the WWTP has a high assimilative capacity with respect to the receiving water.
- A RO plant is less water efficient compared to a lime softening plant. Typically, about 20 to 25% of the water being RO treated is wasted as concentrate not fit for consumption.

This option has been implemented at the St. Peter, Minnesota, WWTP and has successfully reduced effluent chloride to concentrations that are close to complying with an effluent limit based on 230 mg/L chloride standard in the absence of available stream dilution. The St. Peter WWTP does not have chloride limits in its current permit because it discharges directly to the Minnesota River, which has a high assimilative capacity for dilution.

In March of 2011, the city of St. Peter initiated operations of a drinking water RO softening plant. City residents were notified that they no longer needed to soften their water to the same degree as before. City residents are still allowed to operate point-of-entry water softeners; the city has no metrics that track water softener use before and after the RO plant initiated operation.

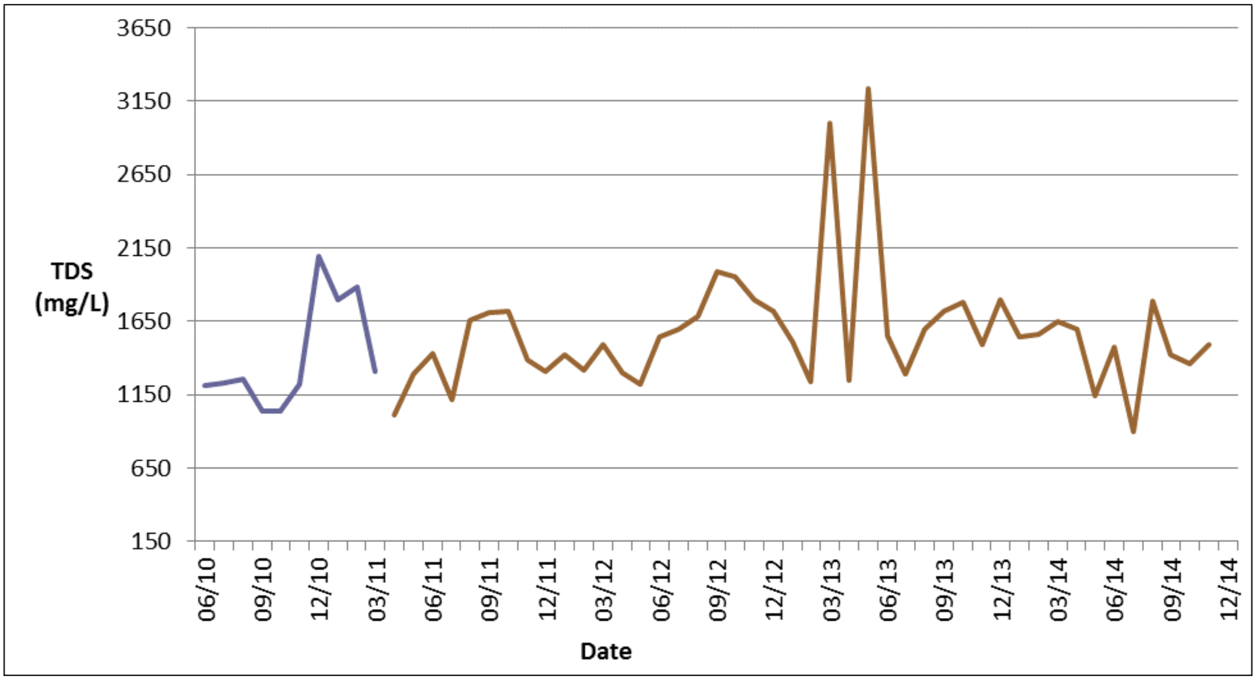
There is a significant difference in effluent chloride concentrations from the WWTP from before and after the RO plant initiated operation (Figure 7). An average chloride reduction of 136 mg/L was achieved after the RO plant was initiated. There is a non-significant trend of effluent chloride concentrations decreasing from 2013 to 2014; it is possible that further reductions in effluent chloride concentrations could be expected as more residents take their point-of-entry water softeners off line. The WWTP currently has no limits for any salty parameters and will not receive any in their new permit issuance they discharge to the Minnesota River where there is ample stream dilution available.

Figure 7. Effluent chloride concentrations at the St. Peter WWTP before and after RO softening at the drinking water treatment plant.



It should be noted that the St. Peter WWTP receives the RO concentrate from the drinking water treatment plant. There has been no significant difference in the effluent TDS concentration at the WWTP before and after initiation of the RO plant (Figure 8). This suggests that the reductions in chloride loading from point-of-entry water softeners has been balanced by the increase in total salt loading from

Figure 8. Effluent TDS concentrations at the St. Peter WWTP before and after RO softening at the drinking water treatment plant.



the RO concentrate stream. A RO concentrate stream has elevated levels of total dissolved salts because the total salt load in the influent water is concentrated into approximately 25% of the influent flow.

When is it necessary to disconnect all point-of-entry water softeners?

Installing centralized RO softening and removing all point-of-entry softeners, has the highest degree of certainty of ensuring compliance with chloride and salty parameter limits.

Making specific assumptions, listed below, it may be possible to reliably meet chloride effluent limits through centralized RO softening while still allowing the use of high efficiency point-of-entry softeners in the distribution network.

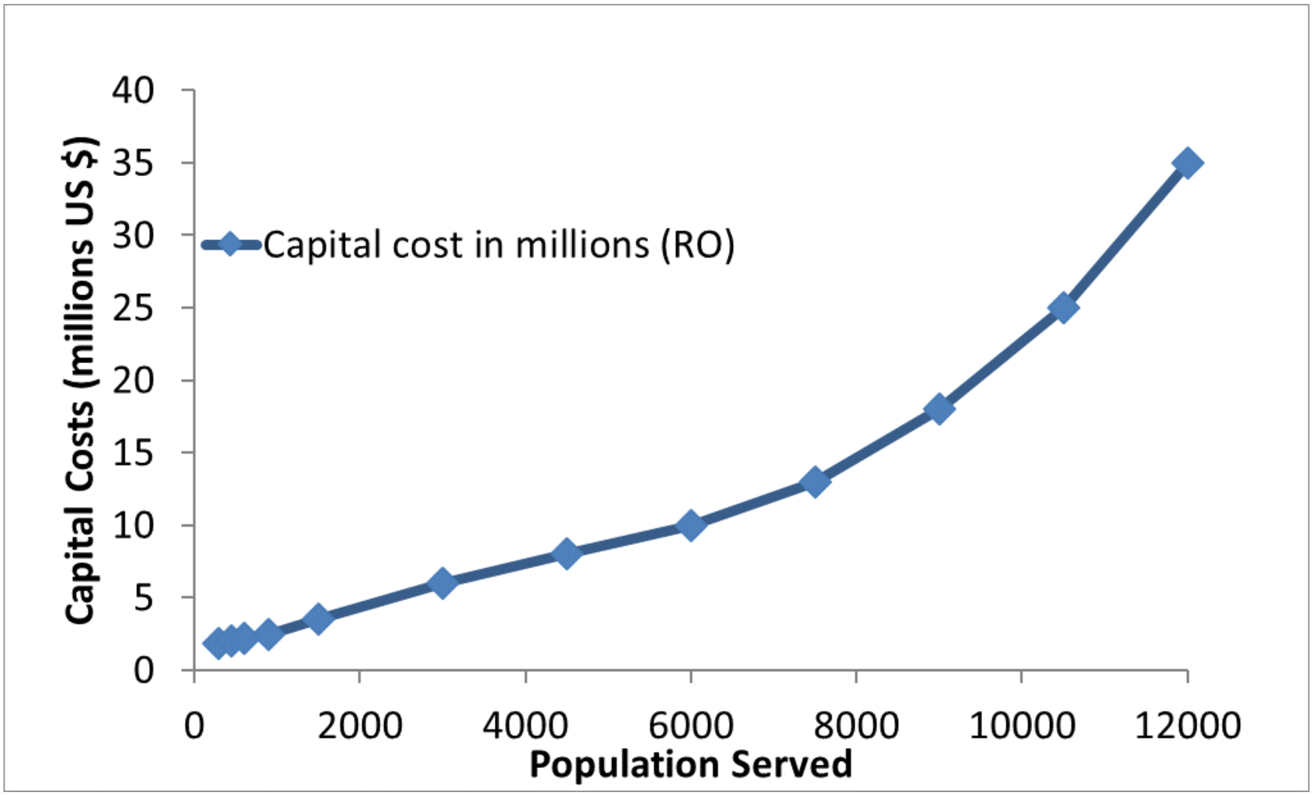
- All point-of-entry softeners are rated as having high salt efficiency of at least 4000 grains of hardness per pound of salt.
- All point-of-entry softeners are optimized to minimize salt use.
- The water supplied to households is softened to less than 8 gpg or 137 mg/L as $CaCO_3$.
- There are no significant sources of chloride (chlorine, SIUs, road salt intrusion, source water, etc…) that could cumulatively contribute to a violation of chloride limits when high efficiency point-of-entry softeners chloride loading is also included.

The MPCA recommends that an evaluation of all potential chloride sources be completed before a municipality commits to recommending the use of high efficiency point-of-entry water softeners in the wastewater collection network. Evaluating the information provided in the “upgrading to high-efficiency softeners” section of this report could also be useful.

Cost

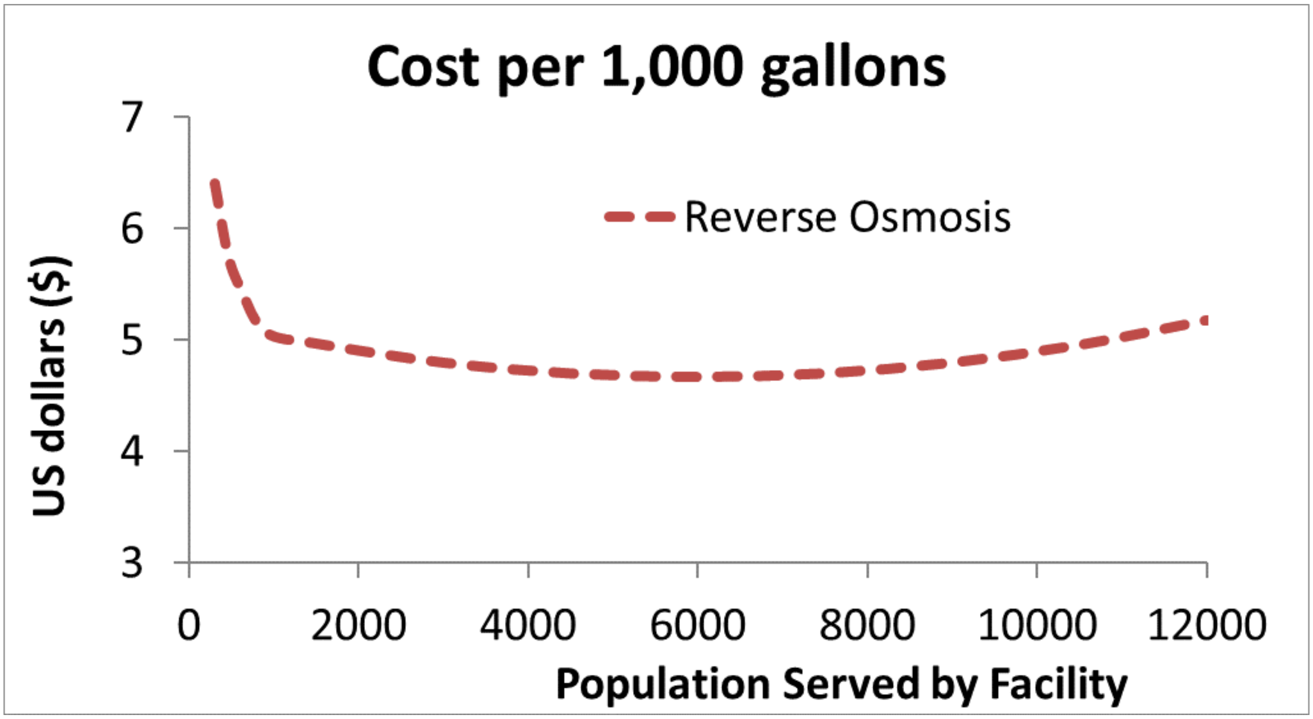
Bolton and Menk provided the MPCA cost estimates for new RO softening water treatment plants capital and O&M costs in the Figures 9 and 10 that follow. The costs in the Figure 10 incorporate the

Figure 9. New RO softening drinking water plant capital costs by population size.



costs of a 20-year pay back schedule for the capital costs with a 4% interest rate and an O&M cost of $4/1,000 gallons of water produced.

Figure 10. Annualized RO softening drinking water plant costs (capital and O&M) by population size.



These costs represent an initial best guess for new RO softening plants. Costs for RO softening plants are very dependent on the source water quality among a myriad of other factors. It is unlikely that other communities would be able to build RO softening plants for significantly less than these numbers.

RO can be a cost-effective way for small communities to centrally soften their water. RO treatment can be automated in a way that lime softening cannot be and because of this less operator work and skill requirements is required for RO treatment.

Switching from chloride-containing additives to additives without chloride

Rationale

Drinking water treatment plants frequently use additives such as ferric chloride or aluminum chloride hydroxide as coagulants in their treatment systems. If a drinking water plant were to switch to an additive such as ferric sulfate or alum that do not contain chloride, then chloride loading to the WWTP would ultimately be reduced.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

This option does not have the potential for a WWTP to meet its chloride limit. A reduction in chloride concentrations in the WWTP effluent of less than 25 mg/L is theoretically possible, assuming the drinking water plant uses additives that contain chloride and switches to a chloride free additive.

This option is technically feasible. Switching to coagulants that do not contain chlorides is feasible for many coagulants. The non-chloride containing versions of these additives are often similar in function and cost.

Chlorination must remain as an option for disinfection for drinking water treatment plants. Chlorinating drinking water is a public health necessity. Alternatives for chlorine disinfection at a drinking water treatment plant are not considered in this analysis.

Cost

Switching to chloride free versions of certain chemicals is a cost-effective option because many of the non-chloride versions are cost competitive compared to the chloride containing version and could be dosed using the same equipment.

Upgrade to high salt-efficiency residential softeners

Rationale

As mentioned in the background section of this document, residential ion exchange softeners can be broadly classified into two categories:

- Timed softeners – These are set to regenerate the ion exchange resin on a fixed schedule. These softeners are usually older. They are less salt efficient because they are set to err on the side caution and frequently backwash more often than needed to ensure that soft water is always available to the user.
- Demand softeners – These are set to regenerate the ion exchange resin whenever the capacity of the ion exchange capacity is reached. “Smart” models can be optimized to minimize resin regeneration frequency using a variety of optimization techniques.

New ‘smart’ water softeners are sold by many manufacturers. The smartest of these models use automated process controls that continuously monitor the water and automate backwashing in order to minimize salt loading to the WWTP. There are many brands in Minnesota that sell water softeners with high salt-efficiency ratings greater than 4,000 grains of hardness as $CaCO_3$ / 1 lb NaCl. An optimized demand softener could be about 40-50% more salt efficient than a poorly optimized timed softener (ALASD, 2014; Lake et al., 2015).

If a resident were to uninstall an old timed softener and replace it with a new optimized demand softener, there would be a reduction in the chloride loading to the WWTP. A new demand softener could be optimized to minimize backwashing and the newer model would have a more efficient ion exchange resin.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

This option has the potential for a WWTP to meet its chloride limit as an individual alternative. However, the WWTP effluent chloride must be with an “attainable margin” to the limit on chloride effluent.

The MPCA operationally uses the following definition of “attainable margin”.

- Measured maximum effluent chloride concentrations are within 100mg/L of the predicted monthly average chloride effluent limit.
- Measured average effluent chloride concentrations are within 50 mg/L of the predicted monthly average chloride effluent limit.

“Attainable margin” means that the required effluent chloride reductions are small enough improving the efficiency of point-of-entry softeners in the distribution network could ensure compliance with final chloride effluent limits. The “attainable margin” definition above is a best professional judgement based on evaluation of cities who have attempted to meet their chloride limits using high-efficiency softeners and point-of-entry chloride loading modeling. A facility may also be within the attainable margin if it has specific documented plans that demonstrate effluent limits could be met through chloride source reduction.

Most WWTPs with chloride limits are discharging chloride concentrations well above effluent limits based on the 230 mg/L standard. For these facilities, it is unlikely that upgrading residences to high-efficiency water softeners will reduce chloride loading by the required amount to guarantee consistent compliance with the chloride water quality standard.

It is possible to make high-efficiency ion exchange softeners look feasible on paper in terms of reducing chloride loading to the WWTP. However, these calculations become less feasible if factoring in a more conservative chloride efficiency rating along with the necessary requirements for ion exchange softeners to be replaced, optimized and maintained.

For facilities averaging chloride concentrations within the “attainable margin” of their chloride limit, it would be worth evaluating the viability of upgrading residences to high-efficiency softeners. It is unlikely that any individual community could attain consistent compliance with just high efficiency softeners. If evaluating this option, a community would need to examine every pro and con, and have a professional engineer review and sign off on the evaluation.

This option is technically feasible.

This option has some implementation concerns:

- As mentioned in the background section, ion exchange is not a chloride efficient way to remove hardness from water. A water softener salt efficiency target of 4,000 grains of hardness as $CaCO_3$ removed/1 pound of NaCl loaded to WWTP represents a loading of about 1 mg of chloride for every 1 mg of hardness as $CaCO_3$ removed.
- Many cities across the United States have grappled with whether high efficiency demand type softeners could help a WWTP come into compliance with chloride limits. A summary of their experiences is provided below.

Alexandria Area Lake Sanitary District (ALASD), Minnesota

One of the most relevant chloride studies to Minnesota is one for ALASD by Wenck Associates as part of its chloride management plan. The study looked at the scenario where all point-of-entry water softeners use a high-efficiency demand based system that minimizes chloride loading to the WWTP. According to the Alexandria chloride management plan, “It became abundantly clear that moving to demand softeners alone would not meet the current permit limit of 252 mg/L (chloride).” The 252 mg/L chloride limit is the WWTP permit limit that would comply with the 230 mg/L water quality standard on a monthly basis.

Personal communications with ALASD indicates that it has examined how upgrading residences to high-efficiency softeners could reduce chloride loading at its WWTP outfall. ALASD reports that high-efficiency softeners could theoretically reduce chloride loading by about 46%, but that the actual reductions would likely be closer to 20% because perpetual maximum softener efficiency is not likely over time. Another contributing factor is that high iron levels in the residences’ source water adds about six grains per gallon of hardness to their water and consequently requires higher backwashing frequency.

The city and its consultants said the city could not come into compliance with its chloride limit by only upgrading to high-efficiency softeners. The main reason for this is because only 70% of the residential wastewater users are connected to city drinking water. The rest have their own private drinking water wells and use softeners to treat their water at the point-of-entry. The typical private well in the Alexandria area has high hardness (36 grams per gallon), and even with a high efficiency softener, treating water that hard using ion exchange sends prohibitively high chloride loads to the WWTP. It would be prohibitively expensive to connect the 30% of users to the drinking water distribution network because they are diffusely located near the edge of city limits.

Santa Clarita, California

The Santa Clarita, California, WWTP has a restrictive 100 mg/L chloride limit. In order to comply with this limit, since 2002 the plant has performed a yearly chloride source evaluation to identify where chloride loading could be reduced. As a result of these studies, the city provided incentives to its residents to install high-efficiency softeners as a way to reduce chloride loading. Residents also received incentives to remove their point-of-entry water softeners. Hundreds of high efficiency water softeners were installed or removed throughout the city as part of this program.

Ultimately, the incentives to replace inefficient point-of-entry water softeners did not reduce chloride loading to the extent required to meet the 100 mg/L chloride limit at the WWTP. The city enacted and began enforcing a ban on point-of-entry residential softeners in 2008 coupled with a softener buy-back program.

Under the current chloride water quality standard (230 mg/L), Minnesota cities would not have to reduce chloride loading to the extent of Santa Clarita (100 mg/L). Nevertheless, there are important findings from the Santa Clarita water softener reduction effort:

- California sanitary district engineers have expressed strongly that they wish they had never initiated a program to install high-efficiency water softeners. Installing high-efficiency water softeners created the public perception that the chloride problem was solved, and when the city took the additional step to outlaw point-of-entry water softeners, there was much public ill will.
- A system of softener laws, supported by the California Legislature, was required to be enacted, enforced, and funded. The city actively seeks out and inspects homes they suspect of having point-of-entry water softeners installed and levels fines up to $1,000 for those in violation.
- Enacting this ban required the city to interact with vendors that sold water softeners to prevent their sale and compensating all water softener rental companies for water softeners installed in residents' homes.

Lake Geneva, Wisconsin

The Lake Geneva, Wisconsin, WWTP has a 250 mg/L chloride limit and discharges to an infiltration basin. The compliance point for the 250 mg/L chloride limit is groundwater monitoring wells downgradient of their infiltration basin. The city is sporadically not in compliance with its chloride limit. The infiltration basin receives stormwater from a nearby highway and consequently the infiltration basin receives chloride loading from both the WWTP and road salt.

The city has a majority of homeowners using point-of-entry water softeners. The city has performed numerous studies and for various reasons has been unable to determine the exact chloride loading from the WWTP to its compliance points because of the difficulties in estimating chloride loading from road salt and inflow and infiltration.

The city has partnered with Culligan to incentivize residents to upgrade to high-efficiency water softeners. According to the city engineer, this has reduced chloride loading to the WWTP, but this is difficult to measure because of high inflow and infiltration (Dan Winkler P.E., Lake Geneva City Engineer, personal communication). The city has also implemented chloride limits on hauled septage to their WWTP that have been effective in reducing chloride loading.

As mentioned above, it is difficult to say exactly how much chloride reduction occurred by switching residents to high-efficiency softeners. It is apparent that switching residents to high-efficiency softeners did not immediately and drastically improve the Lake Geneva WWTP chloride problem.

Madison, Wisconsin

The WWTP for the city of Madison, Wisconsin, has a chloride limit of 395 mg/L and is not in compliance with that limit, typically discharging in the low 400 mg/L chloride. The WWTP currently has a variance from its chloride standard and is striving for compliance with its final permit limit. The city has committed to a strategy of upgrading high-efficiency softeners as a way to comply with its chloride limit.

Madison receives about 57% of its chloride load from residential water softeners, estimating about 101,000 residential water softeners discharge to the WWTP. The city has a distributed drinking water well network, so lime softening at each of its 22 wellheads is much less feasible than in a city with a more centralized drinking water treatment plant.

The city receives a portion of its chloride load from road salt infiltrating into the wellhead protection area. The city is attempting to minimize this load by optimizing road salt application next to wellhead protection areas.

The city has released a report detailing its efforts to determine if upgrading to high-efficiency point-of-entry water softeners could help meet its chloride limit. The study was able to secure funds to either professionally optimize the currently installed softener or upgrade to a new high-efficiency softener. The study then measured chloride loadings from the softeners and found that on average:

- Optimizing the current soften reduced chloride loading by 28%
- Installing new softeners reduced chloride loadings by 46%

The 46% average reduction in chloride loading from new high-efficiency water softeners is a large number that should be used with caution when applied to other cities. The 95% confidence uncertainty intervals associated with that 46% range from 13% to 80%. The large uncertainty intervals result from the wide variation in efficiency and potential chloride reductions from any single softener. An old, poorly optimized timer-based softener might have a loading reduction closer to 80% while there might only be marginal reductions from upgrading a newer well-maintained softener. Also, if the city was able to achieve a 46% reduction in loading from residential water softeners, that would only represent an approximate 26%-reduction in their total chloride load. At that rate, Madison would still not be in compliance with permit limits.

The 46% average reduction in chloride was measured within several weeks of installation after a professional optimization. It is unlikely that the softeners would still operate at their initial efficiency after 5 to 10 years.

The softener optimization study highlights some important suggestions that could possibly further reduce chloride loading from commercial and industrial users. These are not detailed here but could generally be categorized as installation and plumbing improvements for major users.

Costs

The city of Bloomington, Minnesota, estimates that it costs $4.70 to soften 1,000 gallons of water at home, including the costs of operating, installing, and maintaining a point-of-entry water softener. Bloomington estimates it costs an additional $1.21/1,000 gallons to soften at point-of-entry compared to at the drinking water treatment plant. This represents a total monthly cost per household of $35.28, assuming a per household monthly water use of 7,500 gallons. According to the analysis, a resident would expect to save about $30 a month in water treatment costs by using centralized lime softening instead of point-of-entry softening.

A new high-efficiency water softener costs about \$500-\$1,000 without the costs of delivery and installation. An analysis conducted by the WaterReuse Research Foundation estimates that the 10-year life cycle cost of an ion exchange water softener is \$3,500 for water with 150 mg/L hardness.

Upgrade industries to high efficiency softeners

Rationale

There are industrial practices, including upgrading water softeners, which can reduce chloride loading to the WWTP.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

However, this option does not have the potential for a WWTP to meet its chloride limit, unless:

- The facility is already close to the 230 mg/L chloride standard
- Industries discharge significant chloride loading
- Industrial users use technologies that are amenable to chloride reduction strategies

This option is technically feasible for industrial users. These technologies are not feasible for home point-of-entry users because high capital costs are cost-prohibitive.

Some of the feasible implementation strategies include:

- Switching to ion exchange softeners that use a brine reclaim process
- Implementing electrostatic precipitation descaling technologies that can eliminate the need for water softening
- Switching to a dual tank ion exchange column

Cost

These options have been shown to be feasible for industrial users in Madison, Wisconsin, and have shown paybacks of one year (Kathy Lake, Madison Sewer District, personal communication).

Outlaw ion exchange point-of-entry water softeners

Rationale

If a city were to ban point-of-entry water softeners, then they would not be in operation and no chloride would be backwashed to the WWTP.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

This option has the potential for a WWTP to meet its chloride limit.

This option is technically feasible.

However, this option poses some serious implementation concerns:

- Residents would abruptly have no option to reduce hardness in their water. Hardness in some Minnesota cities can be extremely high (>500 mg/L as $CaCO_3$) and this poses problems for boilers, water heaters, and aesthetic concerns.
- The city would need to establish the authority to create rules, incentives, and inspections to eliminate point-of-entry water softener use.

Cost

- The city would need to determine how to address residents' financial loss from the impact of harder water and money invested in softeners.
- The city of Santa Clarita, California, offered rebates of $500- $2,000 per household to compensate for ion exchange softeners that could no longer be used. These numbers seem reasonable for Minnesota.

Create softener column collection and exchange program

Rationale

With a softener column collection program, residents bring their water softeners to a centralized location to be recharged. There would be no need for water softeners to be backwashed in homes. The brine used to recharge these softeners could be reclaimed at the collection center and not discharged to the WWTP.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

This option has the potential for a WWTP to comply with the 230 mg/L chloride standard assuming:

- All residential ion exchange softeners are collected and re-charged at a centralized treatment location.
- This centralized treatment location does not discharge chloride to the WWTP.
- The centralized treatment location would need to find a sustainable political and economic model.
- There are businesses in Minnesota that operate ion exchange water softener collection programs. It is unclear how the business would reclaim the brine.
- This option is technically feasible assuming that the centralized treatment center is able to treat recharge brine and manage the residual sodium and chloride.

Cost

This is the least certain alternative to assign a cost because of the uncertainties as to who would pay the costs of point-of-entry softening and what kind of treatment would be required at the centralized treatment location to deal with the brine.

It is safe to say that this option would be significantly more expensive than operating a residential point-of-entry water softener as they are currently operated.

Switch residents to non-ion exchange softeners

Rationale

If residents used a softening technology that did not use ion exchange, then there would be no need to backwash the ion exchange resin and no chloride loading to the WWTP.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

This option has the potential for a WWTP to meet its chloride limit.

This option is technically feasible for some treatment alternatives. The technical feasibility of each treatment alternative is summarized below from the WaterReuse Research Foundation report, "Evaluation of Alternatives to Domestic Ion Exchange Water Softeners."

Template Assisted Crystallization (TAC)

This technology works by using specially coated plastic beads that form colloidal scale calcium carbonate crystals. After passing through the TAC beads, the calcium that was previously dissolved in the water is transformed into a solid phase microscopic colloidal calcium carbonate crystal, decreasing the free calcium concentration. When the free calcium concentration decreases, the scaling potential is decreased and surfactants perform better. This technology is not typically used at a treatment plant scale and available units are intended for residential use.

Advantages:

- Passive system that doesn't require chemical use or electricity
- Reduces scale formation by >90% and increased detergent effectiveness
- Uses no salt and adds no sodium to water
- No "slimy" water as with ion exchange systems

Disadvantages:

- No dissolved iron, dissolved manganese, phosphates or hydrogen sulfide can be present in the water before treatment
- Not a widespread technology in Minnesota
- Doesn't remove hardness, just transforms it temporarily to a benign solid form that is safe for human consumption
- Can only reduce free calcium concentrations to the solubility product of calcium carbonate

Electrically induced precipitation

This technology works by precipitating calcium carbonate using an electric field. The calcium carbonate precipitate forms on an electrode. The electromagnetic field also causes particles to precipitate that form nucleation sites for further precipitation.

Advantages:

- Reduced scaling by about 50% in test cases
- Produces a soft scale that can be easily removed

Disadvantages:

- Requires electricity year round
- Not a widespread technology

Magnetic water treatment

This technology uses an electric field to change the solid calcium carbonate physical adhesion properties.

Advantages:

- Reduced scaling by about 50% in test cases
- Produces a soft scale that can be easily removed

Disadvantages:

- Requires electricity year round
- Not a widespread technology
- If iron, dissolved oxygen or dissolved silica is present, effectiveness is reduced
- Works best under continuous pipe-full flow conditions
- Substantial body of peer-reviewed literature showing this option is ineffective

Capacitive deionization

This treatment technology uses charged electrodes to adsorb charged ions in the water.

Advantages:

- Removes almost all hardness including other anions

Disadvantages:

- The unit must be regularly backwashed and the polarity of the electrodes must be reversed in order to clean
- Requires electricity
- Not a widespread technology in Minnesota and residential technology is still being developed

Water conditioners

This technology works by adding a chemical to the water that inhibits or controls calcium carbonate precipitation. These chemicals vary in type and include combinations of acids, chelators, and phosphate-based inhibitors. Each has advantages and disadvantages as described below.

Advantages:

- Phosphate-based chemicals are routinely and successfully used at drinking water treatment plant to inhibit scaling.
- Calcium carbonate precipitation is a function of acidity. Adding acids to water will reduce calcium carbonate precipitation.

Disadvantages:

- Non-phosphate based residential chemical conditioners lack quality, peer-reviewed evaluation of their performance.
- Common chemical chelators such as Ethylenediaminetetraacetic acid (EDTA) and citric acid add biochemical oxygen demand to the water. Adding biochemical oxygen demand to residential water encourages microbial growth and biofouling.
- Adding acids to water encourages corrosion of metal piping. The dosage of acid required would need to be carefully managed to prevent corrosion.
- It is unclear if the pH required to prevent calcium carbonate precipitation would be within acceptable drinking water pH values.

Cost

The average 10-year capital and operation and maintenance (O&M) cost per unit for each alternative is listed in Table 8 below, as taken from the report. TAC is cheaper than ion exchange. The costs of water conditioners were not evaluated because the technologies have not been shown to be valid.

Table 8. Costs of non-ion exchange softeners

Treatment alternative	Total annual O&M costs	Capital costs	10-year life-cycle cost
Electrically induced precipitation	$194	$2,375	$4,151
Magnetic water treatment	$11	$760	$855
Capacitive deionization	$102	$4,000	$4,873
Template assisted crystallization	$27	$1,098	$1,326
Ion exchange	$168	$2,048	$3,478
Water conditioners	NA	NA	NA

Increase residential softening target

Rationale

Ion exchange water softeners are designed to remove all hardness and to soften water to the minimum value of less than one grain per gallon of hardness.

Water that is moderately soft (3-5 gpg) can be aesthetically pleasing and meet residential needs. If the water supplied to a residence was only partially softened to 3-5 gpg, then the ion exchange column would receive less hardness loading and would need to be backwashed less frequently. This could provide a reduction in chloride loading to the WWTP.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

However, this option does not have the potential for a WWTP to meet its chloride limit. This is because most WWTPs in Minnesota that need to reduce their chloride discharges currently have concentrations well over the level needed to meet the standard. This method would reduce chloride buy 15-40% depending on source water, which is not enough to comply with the water quality standard in most cases.

This option is technically feasible. For example, Culligan produces a water softener with a bleed valve that allows for changing the target of water softening in homes.

WWTP chloride treatment

RO effluent - concentrate discharged to surface water

Rationale

RO is used to physically remove chloride from effluent. The concentrate from the RO system would be discharged to the receiving water for the WWTP discharge.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

This option has the potential for a WWTP to meet its chloride limit.

This option is technically feasible. RO at WWTPs has been successfully operated in California.

This option has some significant implementation concerns, especially with respect to how to manage and permit the RO concentrate:

- It is standard practice for the MPCA to require Whole Effluent Toxicity (WET) testing for RO concentrate discharged to surface waters. It is the experience of the MPCA that untreated RO concentrate is certain to fail acute and chronic WET testing discharge requirements. The MPCA cannot permit new NPDES discharges for which the permittee is certain to fail WET testing requirements. It would be the responsibility of the permittee to ensure that any discharge of RO concentrate would pass all WET testing.
- RO concentrate has high salt concentrations. It is the experience of the MPCA that RO concentrate frequently fails to meet Classification 3 and 4 water quality standards for salty parameters, especially TDS, bicarbonate and hardness. The surface water discharge would also need to comply with effluent limits based on the 230 mg/L Classification 2B chloride standard.

- The MPCA cannot permit new NPDES discharges for which the permittee is certain to fail water quality standards. It would be the responsibility of the permittee to ensure that any discharge of RO concentrate complied with Classification 2, 3 and 4 water quality standards.
- Complying with anti-degradation water quality standards would also be required for a new RO concentrate discharge to surface water to be authorized.
- A WWTP could choose to install a pipeline to transport RO concentrate to a receiving water with high assimilative capacity, such as a high flow river with low chloride concentrations. This option has been done in Minnesota to meet phosphorus limits, but is expensive and not a true way to eliminate the chloride problem. Permitting and financing this option is theoretically possible but would be difficult. Piping RO concentrate to a river body with high assimilative capacity for chloride should be considered a design option of last resort. It is not a good use of water resources.

Cost

The costs for this analysis were not calculated because this option was not considered feasible because of NPDES permitting regulations.

RO effluent - concentrate crystalized/evaporated

Rationale

RO is used to physically remove chloride from the effluent. The concentrate from the RO system would discharge to an evaporator/crystallizer. The evaporator/crystallizer would evaporate the water leaving a more solid, concentrated brine that could be disposed of in a landfill.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

This option has the potential for a WWTP to meet its chloride limit.

This option is technically feasible. However, it should be noted that land drying of RO concentrate is not feasible due to low yearly evaporation rates in Minnesota.

This option has some significant implementation concerns, especially with respect to energy use associated with evaporating/crystalizing the RO concentrate:

- The evaporated/crystalized brine needs to be disposed of in a landfill or be re-used somehow. Cities would need to develop plans with state and county solid waste authorities and the solid waste industry.
- It requires a tremendous amount of energy to evaporate/crystalize RO concentrate. A personal communication with a design engineer at Bolton and Menck found that a small WWTP (~1 million gallons per day) would require the energy from four large windmills continuously to operate.
- The city would need to develop the infrastructure to deliver large amounts of energy to the evaporator/crystallizer.
- Unless the source of energy for the evaporator/crystallizer is carbon neutral, the operation would increase greenhouse gas emissions.

Cost

In 2018, the MPCA commissioned an investigation that determined the costs and implementation concerns associated with using RO with evaporation and crystallization to treat salts at end of pipe. The results of that study can be found at https://www.pca.state.mn.us/sites/default/files/wq-rule4-15pp.pdf on the MPCA webpage and was funded by the Minnesota Environment and Natural Resources Trust Fund.

The study allowed the MPCA to make the following conclusions:

- The reverse osmosis process is complex and the equipment is difficult to maintain.
- The equipment for the evaporative process is extremely expensive to build and has a high energy demand.
- The salt waste that is left over at the end of the reverse osmosis process is very expensive to manage and dispose of.
- No MN city could afford to use RO with evaporation/crystallization at their wastewater plant.

The study estimated the following generalized cost for treating wastewater using RO with evaporation and crystallization. These costs are additional costs beyond secondary treatment and assume that the full wastewater stream is being treated. Contact the MPCA for specifics on how these figures were calculated.

Figure 11. Additional Capital Costs to treat with RO end of pipe.

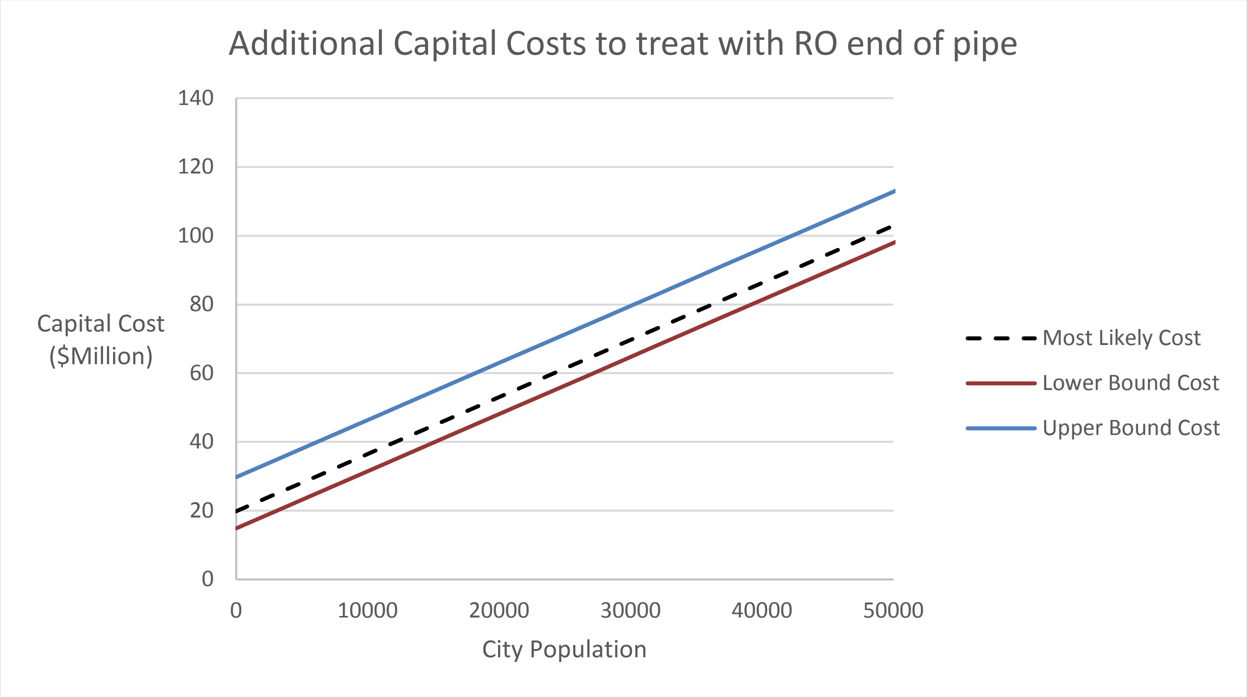
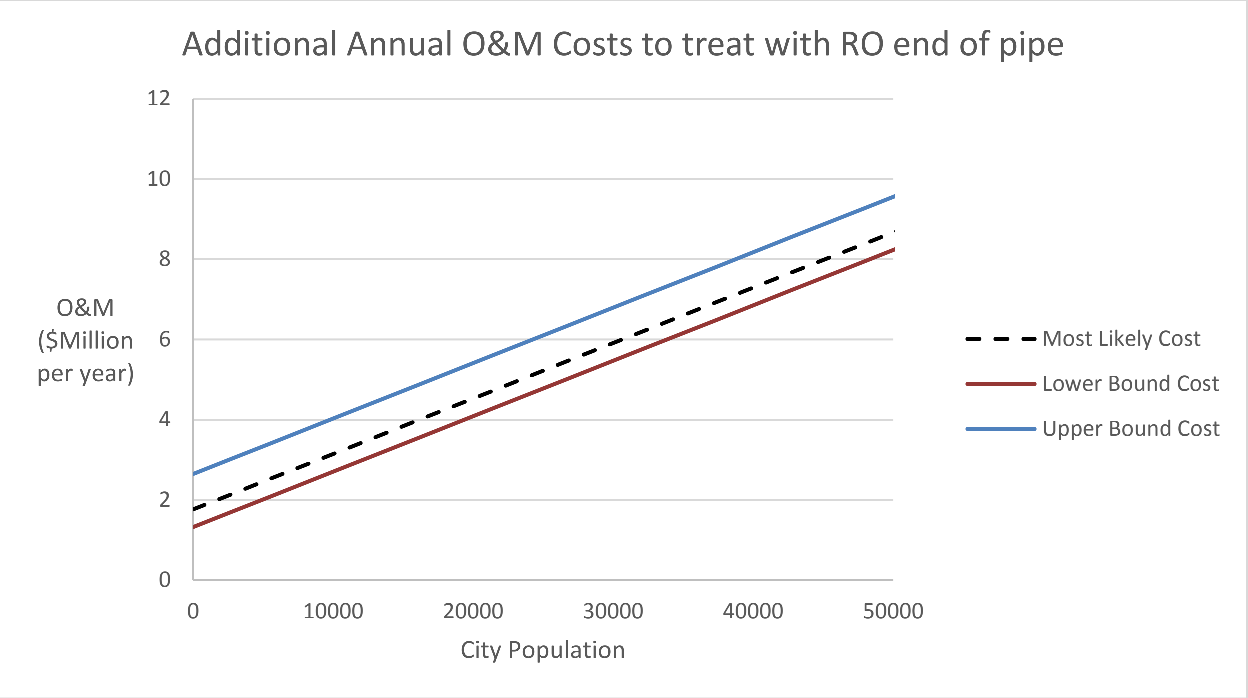


Figure 12. Additional Annual O&M Costs to treat with RO end of pipe.



RO effluent – concentrate deep well injection

Rationale

RO is used to physically remove chloride from the effluent. The concentrate from the RO system is injected into the ground for deep well disposal.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

This option has the potential for a WWTP to meet its chloride limit.

This option is technically feasible. Deep well injection of RO concentrate is practiced in California.

However, this option is not feasible in Minnesota because injection of waste into the ground is illegal.

Costs

The costs associated with this option were not calculated because it deep well injections are illegal in Minnesota.

Switching from chloride containing additives to additives without chloride

Rationale

WWTPs frequently use additives such as ferric chloride or aluminum chloride hydroxide as coagulants in their treatment systems. If a drinking water plant were to switch to an additive such as ferric sulfate or alum that does not contain chloride, then chloride loading to the WWTP would ultimately be reduced.

Feasibility

This option has the potential to reduce chloride loading to the WWTP.

However, this option does not have the potential for a WWTP to meet its chloride limit. A reduction in chloride concentrations in the WWTP effluent less than 25 mg/L is theoretically possible, assuming the WWTP plant uses additives that contain chloride.

This option is technically feasible.

Switching to coagulants that do not contain chlorides is feasible for many coagulants. The non-chloride containing versions of these additives are often similar in function.

Cost

Switching to chloride-free versions of certain chemicals is a cost-effective option because many of the non-chloride versions are cost competitive compared to the chloride-containing version and could be dosed using the same equipment.

Chlorination to UV disinfection

Rationale

Chlorine used to disinfect effluent ultimately decays to chloride, which increases chloride concentrations in the WWTP effluent.

If a WWTP switches from using chlorine to UV disinfection, then chloride loading would decrease in the WWTP.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

However, this does not have the potential for a WWTP to meet its chloride limit, unless the chloride concentration of the WWTP is very close to the limit that would comply with the 230 mg/L standard.

This option is technically feasible. There are many WWTP in Minnesota operating UV disinfection.

This option would be expected to reduce chloride concentrations somewhere between 10 and 20 mg/L, but depends on chlorine usage. The Santa Clarita, California, WWTP found that every 1 mg/L of chlorine removed reduces chloride concentrations by 1 mg/L.

Costs

Switching to UV disinfection is generally considered to be cost competitive with chlorine disinfection. UV disinfection has the advantage of eliminating the need to safely store and manage toxic chemicals on site at the WWTP.

Estimating the costs of switching to UV disinfection from chlorine is difficult because the costs are extremely dependent on the WWTP flow rate, site characteristics, and water quality among other factors. Nevertheless, there are many WWTPs in Minnesota that have switched from chlorine to UV disinfection and found it to be cost-effective.

Chloride precipitation with silver nitrate

Rationale

Chloride can be precipitated from aqueous solutions through the following reaction.

$$AgNO_{3^{aq}} + NaCl_{aq} \rightarrow AgCl_s + NaNO_{3^{aq}}$$

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

This does have the potential for a WWTP to meet its chloride limit. However, there are many technical feasibility concerns:

- The solid silver chloride precipitate would have to be disposed of at a hazardous waste landfill.
- It requires about 3 mg of silver to precipitate 1 mg of chloride.
- The infrastructure to supply, produce and deliver large quantities of silver nitrate to WWTPs would need to be developed.
- Aqueous free silver ion is a potent biocide and residual free silver toxicity poses a huge concern.

This option is not technically feasible because of the reasons listed above.

Costs

Reliable costs on industrial scale silver nitrate are not available. A preliminary cost estimate assuming the market rate of silver of $17/ troy ounce was assumed for lack of better information. At this price, it would cost about $625 of silver per 1,000 gallons to reduce chloride concentrations in effluent wastewater by 100 mg/L.

This option is extremely expensive.

Chloride anion exchange

Rationale

Chloride can be removed from water using chloride anion exchange resins.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

There is uncertainty whether this option could comply with the 230 mg/L chloride limit.

This option is not technically feasible.

Chloride anion exchange is not a widespread technology and no known large-scale chloride anion exchange plants are known to operate in the United States. This option would also require regenerating the chloride anion exchange resin. Regeneration would likely involve the use of large amounts of high strength acids and bases that would need to be managed to comply with NPDES permit limits and safety concerns.

Costs

The costs associated with this option were not calculated because the option is not technically feasible and there is no available way to estimate costs. It is reasonable to assume that costs would be extremely high.

Electrodialysis

Rationale

Electrodialysis is a treatment process that uses electrodes and semi-permeable membranes to produce low dissolved salt water.

Feasibility

This option has the potential to reduce chloride concentrations from the WWTP discharge.

There is uncertainty whether this option could comply with the 230 mg/L chloride limit. There are functional Electrodialysis plants around the world that treat brackish and salty water to drinking water standards. However, none of these plants treat water from a municipal WWTP. High-level engineering design and testing would be required to make this option work.

Electrodialysis is not a feasible option for treating chloride.

Costs

The costs associated with this option were not calculated because the option is not technically feasible without a tremendous amount of design work and there is no available way to estimate costs. It is reasonable to assume that costs would be extremely high.

Biological treatment

Rationale

Chloride is not an ion that can be removed using biological treatment.

Feasibility

Chloride is considered a conservative substance with respect to biological treatment. There are no biological based treatment systems that could be engineered to treat chloride. For example, chloride is used as conservative tracer in water balance studies at WWTPs because it is unreactive chemically or biologically.

Treating chloride using biological techniques is not a feasible option.

Costs

There are no costs for biologically treating chloride because it is not possible.

Ranking of feasible alternatives

The most feasible options for WWTPs to comply with the 230 mg/L chloride standard are ranked below. These options consider a balance of cost, engineering feasibility, and implementation concerns.

1. Upgrade residences and business to high efficiency point-of-entry softeners
2. Centralized lime softening and disconnecting point-of-entry softeners
3. Centralized RO softening and disconnecting point-of-entry softeners
4. RO at WWTP with evaporator/crystallizer

The most feasible treatment alternative is upgrading residences to high efficiency water softeners. However, there are numerous caveats to this option that would make it a poor compliance alternative for many Minnesota municipalities. **When selecting this alternative, the MPCA would likely require a professional engineer to formally sign plans that demonstrate that upgrading to high efficiency softeners is a feasible compliance alternative for the specific municipality in question.**

Considerations for upgrading to high efficiency softeners:

- WWTP effluent chloride concentrations should be within 100 mg/L of permit limits. In other words, the WWTP only needs a small reduction in chloride loading for full compliance.
- The majority of residences would be switching from inefficient softeners to high-efficiency softeners.
- Making progress toward permit limits is not enough. The engineering plan must ensure full and long-term (20-plus years) compliance with final chloride permit limits.

- A cohesive plan for upgrading residential water softeners would be necessary and must be signed by a professional engineer licensed in Minnesota.

The MPCA sees centralized lime softening and disconnecting point-of-entry softeners at the drinking water plant as the second most feasible option because:

- It allows for final compliance with permit limits if correctly implemented
- It's a common technology in Minnesota

This option should work providing that after a municipality starts centralized water softening:

- All residential water softeners are disconnected
- Inflow and infiltration are managed
- Industrial chloride loading is managed

The MPCA would probably not require a professional engineer to sign off on this plan.

Centralized RO softening and disconnecting point-of-entry softeners was ranked third because the RO concentrate stream would need to be managed and or treated, making the option less feasible than lime softening for most Minnesota municipalities.

Using RO at the effluent of the WWTP and installing evaporator/crystallizers was ranked fourth because this option is technically feasible but would incur significantly more costs on the community than the other higher ranked options.

This analysis does not consider using a combination of the listed alternatives to comply with the chloride limit. A combination of several of the listed alternatives could be effective in complying with the chloride water quality standard. However, a detailed site-specific analysis for each WWTP would be required. It is unlikely that a blanket combination of these alternatives would work for every WWTP.

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EXHIBIT B

Prepared for:
Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Madison, Wisconsin

Prepared by:
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60329238
June 2015

Chloride Compliance Study
Nine Springs Wastewater Treatment Plant
Final Report

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Executive Summary

The Madison Metropolitan Sewerage District (District) Nine Springs Wastewater Treatment Plant (NSWTP) provides treatment of wastewater collected from the Madison metropolitan area. The District is a special purpose government agency as defined by the State of Wisconsin Statute 200, and is governed by a 5-member commission.

Increasingly stringent effluent limits for chloride are expected to be enforced for the NSWTP in the future by the Wisconsin Department of Natural Resources (WDNR). The Wisconsin Pollutant Discharge Elimination System (WPDES) permit for the NSWTP contains a variance to the water quality standard for chloride, but includes several conditions relative to the variance. These conditions include meeting interim effluent limits for chloride, and implementing source reduction measures to reduce the chloride load to the NSWTP. However, it is expected that the interim chloride limits for the NSWTP will be reduced in future permits with the ultimate goal of meeting the Water Quality Based Effluent Limit (WQBEL). Since the effluent receiving streams, Badger Mill Creek and Badfish Creek, provide minimal dilution of the NSWTP effluent, the future chloride limits are expected to reflect the WQBEL of 395 mg/L on a weekly average basis. The District has therefore undertaken this study to identify and rank alternatives for compliance at the NSWTP with the future chloride WQBEL.

Several technology options were identified to minimize the discharge of chloride to the NSWTP, and to provide removal of chloride from the effluent of the NSWTP. Technology options were then selected and grouped to form alternatives for further development and evaluation. AECOM completed a Triple Bottom Line (TBL) analysis in conjunction with the District's technical team to select technology options and to rank alternatives developed from the technology options. The TBL determination of project 'value' is carried out through a system of measurement that has two main elements:

- Indicators that are designed to measure certain attributes of value
- A rating system that applies a consistent set of rules to normalize, interpret, classify, aggregate and represent the measure indicator values to make them useful for decision-making.

AECOM's TBL tool compares proposed alternatives across three different categories:

- Financial and operational – compares financial impact to project and operational considerations
- Environmental – compares impacts on local environment
- Social and community – compares impacts and risks on local residents and their acceptance of proposed strategies as well as the project's role in shaping the District's image as a leader in innovative environmental technologies

Each category is made up of multiple criteria, built upon measurable indicators. AECOM worked with the District review team to select and define the criteria used in the TBL analysis. Selected criteria and the scoring system are described in Section 4.0.

Mass balances were constructed to estimate the sources and fate of chloride at the NSWTP for the current and future design conditions. A future design year of 2030 was selected to provide consistency with the District's other capital planning work. A summary of the mass balance scenarios is provided below. Details of the mass balances are provided in Figures 2-1 through 2-6.

Summary of Chloride Mass Balance Scenarios

Figure	Influent Flow Rate	Influent Chloride Load	Effluent Chloride Load
2-1	Current annual average (40.50 MGD)	Current annual average 140,000 lbs/day (414 mg/L)	141,958 lbs/day (420 mg/L)
2-2	Current annual average (40.50 MGD)	Current maximum day 169,400 lbs/day (502 mg/L)	170,958 lbs/day (509 mg/L)
2-3	Current maximum day (56.70 MGD)	Current maximum day 169,400 lbs/day (358 mg/L)	171,303 lbs/day (363 mg/L)
2-4	2030 annual average (44.55 MGD)	2030 annual average 169,400 lbs/day (456 mg/L)	173,050 lbs/day (466 mg/L)
2-5	2030 annual average (44.55 MGD)	2030 maximum day 204,974 lbs/day (552 mg/L)	206,883 lbs/day (562 mg/L)
2-6	2030 maximum day (62.37 MGD)	2030 maximum day 204,974 lbs/day (394 mg/L)	207,546 lbs/day (402 mg/L)

The evaluation of chloride sources to the NSWTP revealed that chloride contributed as a result of the use of zeolite water softeners by the District's residential, commercial and industrial customers is the most significant source, contributing an estimated 57% of the total chloride load on an annual average basis. Zeolite water softeners contribute chloride to the NSWTP as a result of the salt that is used to regenerate the zeolite resin. Also significant is the discharge of chloride by industrial customers, contributing an estimated 18% of the total load on an annual average basis. A summary of the annual average chloride contributions to the NSWTP is provided below. It should be noted that the relative chloride contributions may vary seasonally, largely due to the impacts of road de-icing which takes place during cold weather months.

Summary of Annual Average NSWTP Wastewater Chloride Contributions

Chloride Source	Annual Average Chloride Mass (lbs/day)	Annual Average Percent of Total
Background from potable water supply wells	11,491	8 %
Typical contribution from domestic wastewater	11,829	8 %
Zeolite water softener contribution	80,500	57 %
Industrial input	25,000	18%
NSWTP chemicals, septage and hauled waste	3,138	2 %
Road de-icing	10,000	7 %
TOTAL	**141,958**	**100 %**

A number of technology options were identified to eliminate the need for use of zeolite softeners, and to provide treatment for removal of chloride at the NSWTP. Additional technology options were identified to address the waste residuals that would be generated as a result of chloride treatment. The technology options are summarized below.

- Source reduction options
    - Reducing chloride concentrations in well water supplies
    - Softening of well water supplies to eliminate need for residential zeolite softeners
    - Reducing chloride load from industrial/commercial sources and zeolite softeners
- Chloride Treatment at NSWTP
    - Minimize or eliminate chemicals that contribute chloride at NSWTP
    - Treatment of NSWTP effluent to remove chloride
        - Reverse osmosis
        - Electrodialysis reversal
        - Ion exchange
    - Brine minimization
        - Microfiltration/reverse osmosis
        - Softening followed by microfiltration/reverse osmosis
        - Evaporation
        - Brine concentration/crystallization
        - Freeze/thaw
        - Natural treatment systems
        - Evaporation ponds
        - Brine disposal
            - Deep well injection
            - Industrial waste disposal facility
        - Beneficial use
            - Storage and use for winter road de-icing
            - Other beneficial uses for concentrated salt solution

As required by the WPDES permit, several chloride pollution prevention and source reduction measures are currently being implemented by the District, including:

- Source reduction for industrial/commercial customers
- Education of residential customers regarding use of residential zeolite softeners
- Encouraging water softening efficiency improvements
- Minimized use of chloride-containing chemicals at the NSWTP

The TBL screening process was used to identify three chloride compliance alternatives for further development and evaluation. These alternatives were selected during a workshop with the District's technical team, and include:

- Source water softening at either individual water supply wells or a centralized treatment facility
- Treatment of a portion of the NSWTP effluent using reverse osmosis and various degrees of brine minimization technologies
- Treatment of a portion of the NSWTP effluent using electrodialysis reversal and various degrees of brine minimization technologies

Conceptual design information was developed for each of the three chloride compliance alternatives and variations. Based on an analysis of historical data, it was determined that a firm design capacity of 15 MGD would be required for the chloride treatment system at the NSWTP, in order to reliably achieve the target weekly average chloride limit of 395 mg/L during the future design year 2030. The system would need to operate at an average annual rate of 2.6 MGD during the current chloride and hydraulic loading conditions and at an average annual rate of 7.3 MGD during the future design year 2030. Chloride treatment rates are anticipated to vary seasonally, with higher treatment rates required during colder temperature months when chloride contributions to the NSWTP are the highest. For the source water softening alternatives, it was determined that the wells that supply approximately 60% of the NSWTP flow would need to be softened to offset an adequate amount of zeolite softener use during months with the highest chloride loads to the NSWTP, for a total softened water capacity of approximately 50 MGD.

Conceptual design information included a basis of design for source water softening and for chloride treatment at the NSWTP, identification and sizing of major treatment equipment, process flow diagrams and associated mass balances, and site plans. The primary focus of this study was to evaluate chloride compliance alternatives at the NSWTP, and therefore the alternatives related to treatment at NSWTP (Alternatives 2A, 2B, 2C, 3A, 3B, and 3C) were developed in somewhat greater detail than those that involved softening of the potable water supply (Alternatives 1A and 1B). Descriptions of the chloride compliance alternatives and conceptual designs are provided in Section 6.0. Details of the conceptual design information are provided in the appendices to this document. A summary of the chloride compliance alternatives is provided below.

Summary of Chloride Compliance Alternatives

Alternative		Description
1A	Source water softening – wellhead treatment for hardness (22 wells)	Treatment for removal of hardness at water supply source (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at individual wells. It was assumed that 22 individual treatment systems each capable of softening a 3.0 MGD raw water supply would be required.
1B	Source water softening – centralized treatment for hardness (50 MGD firm capacity	Treatment for removal of hardness from water supply at a centralized location (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at a single centralized treatment site. It was assumed that the centralized system would be capable of producing 50 MGD of softened water. Infrastructure improvements to direct water from supply wells to the treatment facility and from the treatment facility to the distribution system are assumed to include 135 miles of watermain at a cost of $1,000,000 per mile.

Alternative		Description
2A	Treatment at NSWTP using RO	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
2B	Treatment at NSWTP using RO with brine minimization using evaporation	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal, followed by evaporation of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
2C	Treatment at NSWTP using RO with brine minimization using evaporation and crystallization	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal, followed by evaporation and crystallization of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
3A	Treatment at NSWTP using EDR	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
3B	Treatment at NSWTP using EDR with brine minimization using evaporation	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal, followed by evaporation of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
3C	Treatment at NSWTP using EDR with brine minimization using evaporation and crystallization	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal, followed by evaporation and crystallization of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.

Some key considerations for each alternative include:

1A – Source water softening – wellhead treatment for hardness removal

Treatment of a portion of the water supply to remove hardness using nanofiltration or reverse osmosis technology would eliminate the need for residential, commercial and industrial use of zeolite softeners, which contribute chloride to the sewer system. An estimated 22 individual treatment systems would be required for wellhead softening. This approach would minimize the need for modifications to the water distribution system, but would require construction and operation of a significant number of water treatment systems. Only those customers located in areas served by water treatment systems would receive softened water; therefore, not all customers served by the District would receive the same level of water service. This alternative would be successful only if customers served by softened water eliminated the use of their zeolite softening systems, which may be difficult to enforce by the District and its customer communities. Wastewater generated from the water treatment systems would be discharged to the District sewer system, and would result in increased hydraulic load to the NSWTP.

1B – Source water softening – centralized treatment for hardness removal (50 MGD firm capacity)

This alternative is similar to 1A, except that a single water treatment plant would be constructed and operated to soften a firm design capacity of approximately 50 MGD of water. The annual average operating capacity of the centralized water softening facility would be 23.8 MGD. Significant water distribution system improvements would be required to convey well water to the new water softening plant, and to transfer softened water back to the various existing water distribution pressure zones. Only a portion of the District's customers would receive softened water, and those customers would need to eliminate their use of zeolite softeners in order to achieve the required reduction in chloride load to the NSWTP. The hydraulic load to the NSWTP would increase due to discharge of wastewater from the centralized water softening plant.

2A – Treatment at NSWTP using reverse osmosis

Removal of chloride from a portion of the NSWTP effluent utilizing reverse osmosis technology would result in a blended effluent chloride concentration below the weekly average limit. Pretreatment would be required to remove low concentrations of suspended solids from the NSWTP secondary effluent and protect the reverse osmosis membranes from excessive fouling. The treatment system would be housed within a building, and would occupy a significant area at the NSWTP. A large volume of wastewater containing concentrated chloride would be generated by the reverse osmosis system, and would pose a significant challenge for storage, handling and disposal. It is expect that the wastewater, or brine, would need to be disposed off-site at a deep well disposal facility (outside of Wisconsin), or an industrial wastewater facility. The expected cost for disposal of the brine is substantial.

2B – Treatment at NSWTP using reverse osmosis and brine minimization using evaporation

This alternative is the same as 2A, with the addition of an evaporator system to reduce the volume of the brine produced by the reverse osmosis system. The evaporator system would require additional space at NSWTP, and would be housed within a building. The evaporator system requires substantial energy to evaporate water from the brine to reduce the volume for disposal. The capital and operating costs of the evaporator are significant; however, substantial savings in disposal cost are expected due to reduced brine volumes.

2C – Treatment at NSWTP using reverse osmosis and brine minimization using evaporation and crystallization

This alternative is the same as 2B, with the addition of a crystallizer system to further reduce the volume of the brine from the reverse osmosis system. The resulting waste product would be in the form of a slurry. The addition of the crystallizer system increases the space requirement, capital and operating costs compared to alternatives 2A and 2B. However, the hauling and disposal costs would be the lowest of the alternatives utilizing reverse osmosis treatment at the NSWTP.

3A – Treatment at NSWTP using electrodialysis reversal

Alternative 3A is similar to 2A, except that electrodialysis reversal technology would be used for removal of chloride from a portion of the NSWTP effluent instead of reverse osmosis. Electrodialysis reversal is less susceptible to fouling by suspended solids compared to reverse osmosis, and therefore pretreatment is not expected to be required. Electrodialysis reversal technology is currently available from only a single equipment supplier. The equipment would be housed within a building, and would require a significant amount of space at the NSWTP. Similar to reverse osmosis, a major drawback of this alternative is that a large volume of wastewater containing concentrated chloride would be produced, requiring storage and off-site disposal. Handling and disposal would represent a significant annual cost.

3B – Treatment at NSWTP using electrodialysis reversal and brine minimization using evaporation

This alternative is the same as 3A, with the addition of an evaporator system to reduce the volume of the brine produced by the electrodialysis reversal system. The evaporator system would require additional space at NSWTP, and would be housed within a building. The evaporator system requires substantial energy to evaporate water from the brine to reduce the volume for disposal. The capital and operating costs of the evaporator are significant; however, substantial savings in disposal cost are expected due to reduced brine volumes.

3C – Treatment at NSWTP using electrodialysis reversal and brine minimization using evaporation and crystallization

This alternative is the same as 3B, with the addition of a crystallizer system to further reduce the volume of the brine from the electrodialysis reversal system. The addition of the crystallizer system increases the space requirement, capital and operating costs compared to alternatives 3A and 3B. However, the hauling and disposal costs would be the lowest of the alternatives utilizing electrodialysis reversal treatment at the NSWTP.

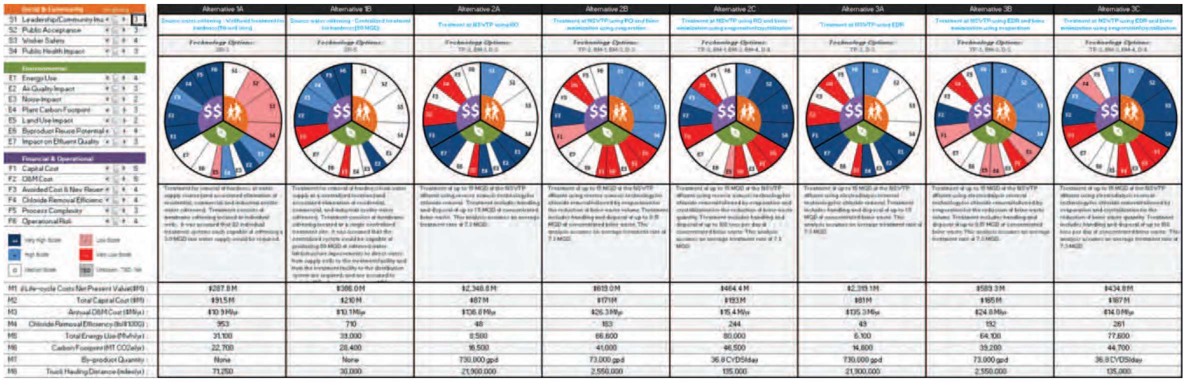
Projected capital, and annual operating and maintenance costs were developed at a conceptual level for the treatment alternatives summarized above. The estimated capital costs are consistent with a Class 4 estimate as defined by the Association for the Advancement of Cost Engineering International, with an expected accuracy range of -30% to +50%. The capital and annual costs were used to develop a net present value cost for each alternative. The projected capital, annual operating and maintenance, and net present value costs are presented in the following table. Annual operation and maintenance costs for the current operating condition (2.6 MGD annual average flow) and for the peak operating condition (15 MGD) are included in Section 7.0.

Conceptual Chloride Compliance Cost Projections

Chloride Compliance Alternative		Capital Cost	Annual O&M Cost Future Condition 7.3 MGD Average Flow	Net Present Value
Source Water Softening				
1A	Wellhead softening (22 well sites)	$91,512,000	$10,854,000	$287,800,000
1B	Centralized softening (50 MGD firm capacity)	$75,300,000	$10,094,000	$386,000,000
	Allowance for distribution system upgrades (135 miles at $1,000,000 per mile)	$135,000,000		
	Subtotal, centralized softening	$210,300,000		
UF/RO Treatment at NSWTP				
2A	UF/RO with recovery RO	$86,833,000	$136,678,000	$2,348,800,000
2B	UF/RO with recovery RO and evaporator	$170,731,000	$26,272,000	$619,000,000
2C	UF/RO with recovery RO, evaporator and crystallizer	$193,483,000	$15,492,000	$464,400,000
EDR Treatment at NSWTP				
3A	EDR	$80,824,000	$135,331,000	$2,319,100,000
3B	EDR with evaporator	$164,722,000	$24,835,000	$589,300,000
3C	EDR with evaporator and crystallizer	$187,474,000	$14,054,000	$434,800,000

The District requested that a rough projection be made of the costs for treatment of all of the effluent from the NSWTP. Removal of chloride from all of the NSWTP effluent would result in an effluent that would contain a very low concentration of dissolved solids, which could be detrimental for discharge to the receiving streams. The cost and challenges associated with management and disposal of the waste stream produced by the chloride treatment system would also be significantly increased, and the treatment system would need to include equipment for reducing the volume of waste brine prior to off-site disposal or beneficial use. Capital and annual operation and maintenance costs for treatment of all of the NSWTP effluent were estimated by factoring the conceptual costs for the 15 MGD chloride treatment systems. The capital cost for a chloride treatment system sized for a capacity of 50 MGD is projected to range from $500,000,000 to $600,000,000; the annual operation and maintenance cost is projected to range from $75,000,000 to $150,000,000, depending on the extent of brine minimization and assuming off-site disposal of brine.

Data sheets were prepared for each alternative to provide input for the TBL analysis. Information was included for each of the 17 criteria selected by the District. The data sheets and the results of the TBL analysis are provided in **Appendix E**. A summary of the TBL analysis is shown below. An enlarged version of the TBL analysis is provided at the end of this Executive Summary.



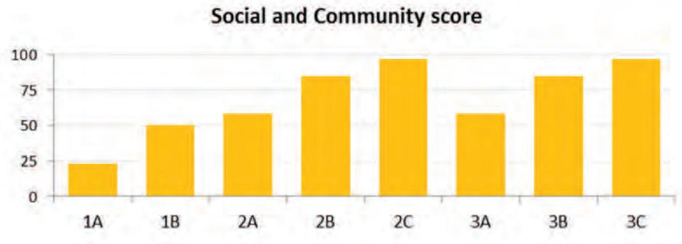
	Social & Community	
S1	Leadership/Community Ima	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
	Environmental	
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
	Financial & Operational	
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficienc	4
F5	Process Complexity	3
F6	Operational Risk	4

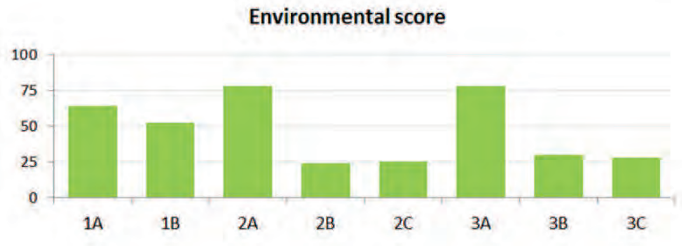
	Alternative 1A	Alternative 1B	Alternative 2A	Alternative 2B	Alternative 2C	Alternative 3A	Alternative 3B	Alternative 3C
	Source water softening - Wellhead treatment for hardness (50 well sites)	Source water softening - Centralized treatment for hardness (50 MGD)	Treatment at NSWTP using RO	Treatment at NSWTP using RO and brine minimization using evaporation	Treatment at NSWTP using RO and brine minimization using evaporation/crystallization	Treatment at NSWTP using EDR	Treatment at NSWTP using EDR and brine minimization using evaporation	Treatment at NSWTP using EDR and brine minimization using evaporation/crystallization
M1 Life-cycle Costs Net Present Value ($M) :	$287.8 M	$386.0 M	$2,348.8 M	$619.0 M	$464.4 M	$2,319.1 M	$589.3 M	$434.8 M
M2 Total Capital Cost ($M) :	$91.5 M	$210 M	$87 M	$171 M	$193 M	$81 M	$165 M	$187 M
M3 Annual O&M Cost ($M/yr) :	$10.9 M/yr	$10.1 M/yr	$136.8 M/yr	$26.3 M/yr	$15.4 M/yr	$135.3 M/yr	$24.8 M/yr	$14.0 M/yr
M4 Chloride Removal Efficiency (lb/$1000) :	953	710	48	183	244	49	192	261
M5 Total Energy Use (Mwh/yr) :	31,100	33,000	8,500	66,600	80,000	6,100	64,100	77,600
M6 Carbon Footprint (MT CO2e/yr) :	22,700	28,400	16,500	41,000	46,500	14,800	39,200	44,700
M7 By-product Quantity :	None	None	730,000 gpd	73,000 gpd	36.8 CYDS/day	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8 Truck Hauling Distance (miles/yr) :	71,250	30,000	21,900,000	2,550,000	135,000	21,900,000	2,550,000	135,000

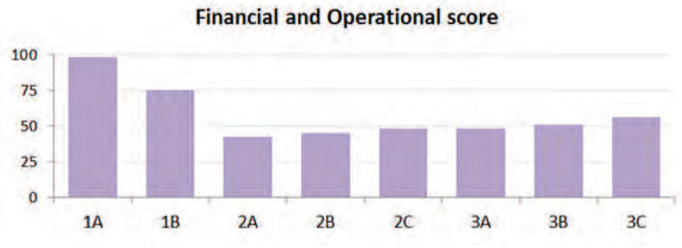
Each of the 17 criteria is color-coded by degree of positive and negative impacts on the criteria. The thickness of each slice is represented by the relative weights assigned by the District, thereby visually limiting or expanding the area of the circle represented by each criterion. A list of key performance metrics is included below each chart to provide quantified indicators such as total net present value cost, total energy use and carbon footprint.

The TBL analysis indicates that Alternatives 1A, 1B, 2A, 3A, and 3C rank the highest among the alternatives, with 1A achieving the highest overall score. However, each of these alternatives scores differently across the financial and operational, environmental, and social and community categories, making a single recommendation base on the analysis not immediately obvious.

A comparison of overall scores in the social, environmental, and financial categories is displayed in the adjacent graphs.

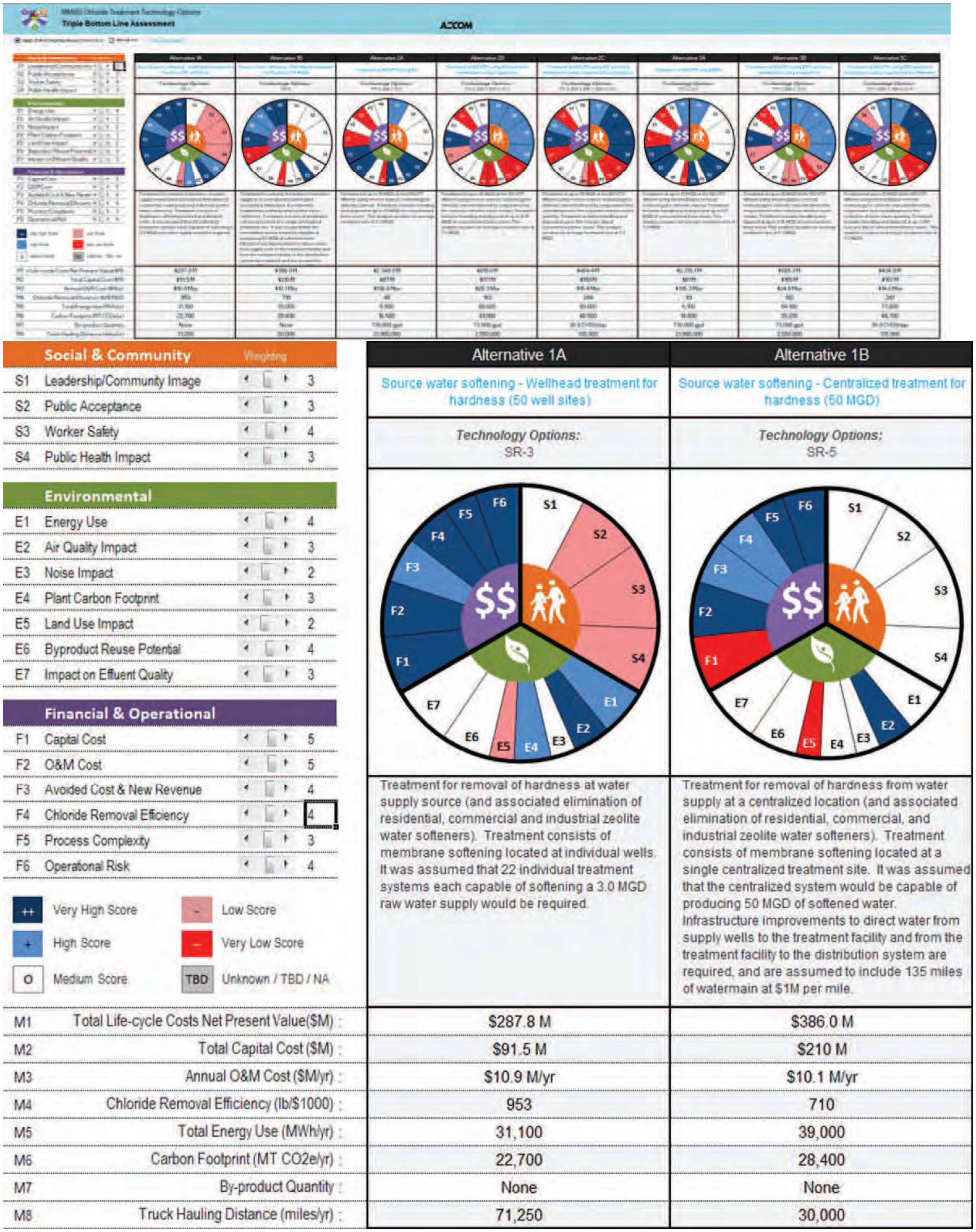






Alternative 1A had the strongest performance in the financial category, but scored the lowest of the alternatives in the social category. Alternatives 2A and 3A had strong overall performance in the environmental category, but have far higher costs and poorer performance in the financial and operational category. Within the social category, 2A and 3A have positive impacts with leadership/innovation and worker safety, but significantly negative impacts on public health. Alternatives 2C and 3C had the highest overall scores in the social category. When interpreting the results of the TBL analysis, note that the analysis is sensitive to the type of scoring and weighting factors selected by the AECOM and District review team. Some inputs to the TBL analysis rely on judgment as exercised by the evaluators.

The chloride compliance study provides information that can be used by the District, including chloride compliance alternatives and associated costs, to help determine an appropriate strategy for future compliance with the expected chloride discharge requirements at the NSWTP. The TBL analysis highlights the positive and negative impacts of the project alternatives with respect to financial, environmental and social externalities. Ultimately, the District and public representatives will need to weigh the negative consequences against the positive attributes of each alternative to select an optimum strategy for the greater Madison community. The strategy may require the cooperation of the District's customers, as well as other municipal agencies, to achieve the overall chloride compliance objectives in a manner that best meets the needs of the community.



Social & Community		Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3

Environmental		
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3

Financial & Operational		
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++ Very High Score	- Low Score
+ High Score	– Very Low Score
o Medium Score	TBD Unknown / TBD / NA

	Alternative 1A	Alternative 1B
	Source water softening - Wellhead treatment for hardness (50 well sites)	Source water softening - Centralized treatment for hardness (50 MGD)
	Technology Options: SR-3	*Technology Options:* SR-5
	Treatment for removal of hardness at water supply source (and associated elimination of residential, commercial and industrial zeolite water softeners). Treatment consists of membrane softening located at individual wells. It was assumed that 22 individual treatment systems each capable of softening a 3.0 MGD raw water supply would be required.	Treatment for removal of hardness from water supply at a centralized location (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at a single centralized treatment site. It was assumed that the centralized system would be capable of producing 50 MGD of softened water. Infrastructure improvements to direct water from supply wells to the treatment facility and from the treatment facility to the distribution system are required, and are assumed to include 135 miles of watermain at $1M per mile.
M1 Total Life-cycle Costs Net Present Value($M) :	$287.8 M	$386.0 M
M2 Total Capital Cost ($M) :	$91.5 M	$210 M
M3 Annual O&M Cost ($M/yr) :	$10.9 M/yr	$10.1 M/yr
M4 Chloride Removal Efficiency (lb/$1000) :	953	710
M5 Total Energy Use (MWh/yr) :	31,100	39,000
M6 Carbon Footprint (MT CO2e/yr) :	22,700	28,400
M7 By-product Quantity :	None	None
M8 Truck Hauling Distance (miles/yr) :	71,250	30,000

	Social & Community	Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
	Environmental	
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
	Financial & Operational	
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++	Very High Score	–	Low Score
+	High Score	–	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

		Alternative 2A	Alternative 2B	Alternative 2C
		Treatment at NSWTP using RO	Treatment at NSWTP using RO and brine minimization using evaporation	Treatment at NSWTP using RO and brine minimization using evaporation/crystallization
		Technology Options: TP-2, BM-1, D-3	*Technology Options:* TP-2, BM-1, BM-3, D-3	*Technology Options:* TP-2, BM-1, BM-3, BM-4, D-4
				
		Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.
M1	Total Life-cycle Costs Net Present Value($M)	$2,348.8 M	$619.0 M	$464.4 M
M2	Total Capital Cost ($M)	$87 M	$171 M	$193 M
M3	Annual O&M Cost ($M/yr)	$136.8 M/yr	$26.3 M/yr	$15.4 M/yr
M4	Chloride Removal Efficiency (lb/$1000)	48	183	244
M5	Total Energy Use (MWh/yr)	8,500	66,600	80,000
M6	Carbon Footprint (MT CO2e/yr)	16,500	41,000	46,500
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

	Social & Community	Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
	Environmental	
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
	Financial & Operational	
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++	Very High Score	–	Low Score
+	High Score	–	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

		Alternative 3A	Alternative 3B	Alternative 3C
		Treatment at NSWTP using EDR	Treatment at NSWTP using EDR and brine minimization using evaporation	Treatment at NSWTP using EDR and brine minimization using evaporation/crystallization
		Technology Options: TP-3, D-3	*Technology Options:* TP-3, BM-3, D-3	*Technology Options:* TP-3, BM-3, BM-4, D-4
				
		Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.
M1	Total Life-cycle Costs Net Present Value($M)	$2,319.1 M	$589.3 M	$434.8 M
M2	Total Capital Cost ($M)	$81 M	$165 M	$187 M
M3	Annual O&M Cost ($M/yr)	$135.3 M/yr	$24.8 M/yr	$14.0 M/yr
M4	Chloride Removal Efficiency (lb/$1000)	49	192	261
M5	Total Energy Use (MWh/yr)	6,100	64,100	77,600
M6	Carbon Footprint (MT CO2e/yr)	14,800	39,200	44,700
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

1.0 Introduction

The Madison Metropolitan Sewerage District (District) has undertaken a proactive evaluation of alternatives to comply with the future weekly average mass and concentration limits for chloride at the Nine Springs Wastewater Treatment Plant (NSWTP). The future chloride limits are expected to reflect the Water Quality Based Effluent Limit (WQBEL) of 395 mg/L on a weekly average basis for effluent discharges to Badger Mill Creek and Badfish Creek.

1.1 Background

The District is a municipal corporation created for the purpose of collecting and treating wastewater from the Madison metropolitan area. The District provides service to over 40 municipal customers and serves a population of 360,000 people. All wastewater generated in the District's 180 square mile service area is treated at the NSWTP. The current design flow rate for the NSWTP is 50 million gallons per day (MGD).

The NSWTP employs screening and grit removal, primary clarification, and a biological phosphorus removal activated sludge process for removal of suspended solids, organic matter (measured as 5-day biochemical oxygen demand, or BOD_5), ammonia-nitrogen and phosphorus from the influent raw wastewater. An ultraviolet (UV) process is used to disinfect treated wastewater prior to discharge. Biosolids are stabilized in an advanced anaerobic digestion process, including mesophilic and acid-phase digestion. Thermophilic digestion is also used for a portion of the biosolids produced by the NSWTP. Digester gas is used in hot water boilers, steam boilers and three reciprocating engines equipped with heat recovery equipment. Struvite is harvested from the biosolids for use as a fertilizer product. Treated biosolids are recycled to agricultural lands as a liquid.

Final effluent from the NSWTP is pumped to two effluent-dominated streams. Badger Mill Creek receives approximately 8 percent (up to 3.6 MGD) of treated effluent, and the remaining treated effluent is returned to Badfish Creek.

The District's Wisconsin Pollutant Discharge Elimination System (WPDES) permit contains a variance to the water quality standard for chloride. The District is required to meet several conditions relative to the variance:

- Meet interim effluent weekly average mass and concentration limitations for chloride
- Implement specific chloride source-reduction measures
- Submit annual progress reports to the Wisconsin Department of Natural Resources (WDNR)

It is anticipated that the interim chloride limits for the NSWTP will be reduced in future permits with the ultimate goal of meeting the WQBEL. Because Badfish Creek and Badger Mill Creek provide minimal dilution, the WQBEL is expected to be the instream water quality standard of 395 mg/L on a weekly average basis.

Chloride concentrations in wastewater received by the NSWTP have been generally increasing, and are inversely correlated to the plant flow rate. While annual average chloride concentrations are near the WQBEL limit, weekly average chloride concentrations exceed 395 mg/L during some parts of the year.

1.2 Purpose

The purpose of this evaluation is to identify and rank alternatives for compliance at the NSWTP with the future chloride WQBEL of 395 mg/L on a weekly average basis. Impacts of the chloride compliance alternatives, including effect on treatment of other wastewater constituents and wastewater characteristics, and handling of residuals, were also identified. Technology options and compliance alternatives were compared using a Triple Bottom Line (TBL) analysis tool specifically developed for the District to reflect the District's critical evaluation criteria and associated weighting for each criterion. Criteria included social, environmental, and financial considerations. Chloride compliance alternatives and TBL criteria were developed in conjunction with District staff to ensure District preferences and priorities were incorporated into the evaluation.

This report provides a summary of the following elements of the chloride compliance evaluation:

- Chloride mass balance scenarios constructed for the NSWTP
- Preliminary options identified for compliance with the future chloride discharge limit at the NSWTP
- TBL criteria used for evaluating chloride compliance options and alternatives
- Selection of chloride compliance alternatives
- Development of conceptual design information and cost projections
- TBL analysis of chloride compliance alternatives

2.0 Chloride Mass Balance

The District has developed an Excel workbook to describe the mass balance of various wastewater constituents for current operations and for future years. The mass balance is used by the District to define future conditions for capital planning purposes. The mass balance and associated calculations were used to evaluate several design conditions for chloride contributions at the NSWTP. A flow diagram was prepared for the NSWTP to graphically depict the mass loads and concentrations of chloride at various locations in the treatment plant, and for various mass balance scenarios.

The District selected the design year of 2030 for chloride compliance planning purposes. Both current and future year 2030 chloride loads were calculated for the mass balance scenarios. Input parameters, including plant flows and chloride loads, were reviewed with District staff for the average and maximum day loads. The District provided direction regarding future hydraulic loads and chloride concentrations to establish the future design condition.

Chloride loads to the NSWTP include:

- Collection system (influent wastewater)
- Septage
- Hauled waste (to digesters)
- Plant chemicals

Based on discussions with District personnel, it was determined that the maximum chloride loads often occur during periods of average flow rather than peak day flows when chloride concentrations are typically reduced. Additional mass balance scenarios were therefore constructed to reflect maximum day chloride loads associated with current and year 2030 average day flows. The mass balance scenarios are summarized in **Table 2-1**. **Figures 2-1 through 2-6** in the Figures section of this document illustrate the chloride mass balance flow diagrams for the various scenarios.

Table 2-1:
Summary of Chloride Mass Balance Scenarios

Figure	Influent Flow Rate	Influent Chloride Load	Effluent Chloride Load
2-1	Current annual average (40.50 MGD)	Current annual average 140,000 lbs/day (414 mg/L)	141,958 lbs/day (420 mg/L)
2-2	Current annual average (40.50 MGD)	Current maximum day 169,400 lbs/day (502 mg/L)	170,958 lbs/day (509 mg/L)
2-3	Current maximum day (56.70 MGD)	Current maximum day 169,400 lbs/day (358 mg/L)	171,303 lbs/day (363 mg/L)
2-4	2030 annual average (44.55 MGD)	2030 annual average 169,400 lbs/day (456 mg/L)	173,050 lbs/day (466 mg/L)
2-5	2030 annual average (44.55 MGD)	2030 maximum day 204,974 lbs/day (552 mg/L)	206,883 lbs/day (562 mg/L)
2-6	2030 maximum day (62.37 MGD)	2030 maximum day 204,974 lbs/day (394 mg/L)	207,546 lbs/day (402 mg/L)

The current annual average chloride load to the NSWTP is approximately 140,000 pounds per day. The chloride load is primarily comprised of three sources: background chloride concentrations from the potable water supply wells, chloride contributions from residential, commercial and industrial customers of the District, and runoff/infiltration from road de-icing activities. The relative contribution from each source was reviewed to help inform decisions related to potential reductions in chloride loads to the NSWTP.

It was assumed that typical domestic wastewater (without zeolite softening) contributes approximately 35 mg/L of chloride over background concentrations ("Wastewater Engineering: Treatment and Resource Recovery," Metcalf & Eddy/AECOM, Fifth Edition provides a range of 20 to 50 mg/L of chloride contributed by domestic water use). Based on the current annual average flow rate of 40.5 MGD, domestic wastewater contributes an annual average baseline quantity of 11,829 pounds of chloride.

Chloride is present in the ground water supplies which service the municipal water systems that contribute to the NSWTP. Chloride concentrations in ground water from supply wells were found to range from approximately 3 to 120 mg/L at various wells throughout the District service area. Production rates for individual wells were evaluated to estimate a blended weighted average chloride concentration of 34 mg/L. At the annual average current daily flow of 40.5 MGD, the annual average chloride load to the NSWTP is estimated to be 11,491 lbs/day attributable to background concentrations from the water supply.

The contribution of chloride to the NSWTP from industrial sources was estimated by District staff to be 25,000 lbs/day, on an annual average basis. Additional estimated inputs at the NSWTP include chemicals used for biosolids conditioning, odor control and water treatment (2,232 lbs/day), septage received (200 lbs/day) and hauled wasted received (706 lbs/day) for a total of 3,138 lbs/day.

Analysis of NSWTP effluent chloride data from October 2010 through April 2014 reveals that chloride concentrations increase during winter months when road salt is used for de-icing purposes. The timing and magnitude of the increased chloride concentrations appear to be dependent on and highly correlated to weather conditions. The mass of chloride in the NSWTP effluent is approximately 130,000 pounds per day, absent the influence of road de-icing. Winter chloride mass loads are shown to average 150,000 to 160,000 pounds per day for extended periods, with some occurrences exceeding 200,000 pounds per day. Therefore, approximately 10,000 pounds per day of chloride (140,000 pounds per day average load – 130,000 pounds per day background load) on an annual average basis are attributable to road de-icing activities.

It was assumed the annual average chloride loads described above account for all chloride inputs with the exception of zeolite water softeners. Therefore, by subtracting the total of the above individual chloride contributions from the total average chloride load at the NSWTP, the chloride load attributable to zeolite water softeners can be determined. This calculation results in an annual average chloride load of 80,500 lbs/day attributable to zeolite water softeners, as summarized in **Table 2-2**.

Table 2-2:
Summary of NSWTP Annual Average Wastewater Chloride Contributions

Chloride Source	Annual Average Chloride Mass (lbs/day)	Annual Average Percent of Total
Background from potable water supply wells	11,491	8 %
Typical contribution from domestic wastewater	11,829	8 %
Zeolite water softener contribution	80,500	57 %
Industrial input	25,000	18%
NSWTP chemicals, septage and hauled waste	3,138	2 %
Road de-icing	10,000	7 %
TOTAL	**141,958**	**100 %**

3.0 Chloride Compliance Options

Chloride compliance options were identified for reducing the chloride input to the NSWTP, removal of chloride from the effluent of the NSWTP, as well as for addressing the residuals that would be produced as a result of implementing many of the identified options.

3.1 Source Reduction

Options for reducing chloride concentrations in the water supply and/or wastewater influent to the NSWTP are summarized in **Table 3-1**, located in the Tables section of this document. The source reduction options are identified as options SR1 through SR8.

3.1.1 Reducing Chloride Concentrations in Well Water Supplies

Under option SR1, existing wells that supply potable water with higher chloride concentrations (greater than 50 mg/L) would be replaced with new wells that are screened within aquifers that have lower chloride concentrations. Under options SR2 and SR4, treatment for removal of chloride from the well water supply would be provided either at the well head or in a centralized treatment facility prior to distribution. Technologies for removal of chloride include reverse osmosis, electrodialysis reversal, and anion exchange. These technologies are described in further detail in subsequent sections.

The concentration of chloride in blended source water from individual production wells typically averages less than 35 mg/L. Therefore, reduction of chloride concentrations in the water supply wells is expected to have minimal impact (less than 10 percent reduction) on the total chloride concentrations observed in the influent to the NSWTP.

3.1.2 Softening of Well Water Supplies to Eliminate Need for Residential Zeolite Softeners

Options SR3 and SR5 involve treatment of ground water pumped from supply wells to remove concentrations of ions that contribute to hardness (calcium and magnesium). Under these options, water at individual wells or centralized locations would be treated to reduce hardness. By reducing the concentrations of calcium and magnesium in the water supply prior to distribution, the need for residential, commercial and industrial zeolite softening systems will be reduced or eliminated. The contribution of chloride which results from regeneration of the ion exchange media in individual zeolite softeners will also be reduced or eliminated.

Several technologies are commonly applied for softening of water supplies:

- Lime softening is a chemical process in which calcium hydroxide and sodium carbonate are mixed with the water to precipitate calcium carbonate and magnesium hydroxide. The precipitated solids are removed via settling in clarifiers and are typically disposed off-site.

- Ion exchange takes place in filtration vessels containing engineered resin that exchanges calcium and magnesium ions contained in the water for sodium ions contained on the ion exchange resin. When the capacity of the media to exchange ions has been exhausted, it is regenerated using a mineral acid (typically sulfuric acid). The waste chemical regenerant must be neutralized and appropriately disposed.

- Nanofiltration is a membrane process that separates divalent ions such as calcium and magnesium as the water is passed through an engineered membrane under pressure. A similar process, reverse osmosis, provides separation of both monovalent and divalent ions, and can also be used for water softening applications. Ions which are not able to pass through the membrane form a concentrated waste stream which requires handling and disposal.

Challenges associated with source water softening include:

- Some water uses, such as irrigation, do not require softened water. Therefore, more water would be softened than is required for certain uses.

- Option SR3 would require maintenance of multiple individual softening systems, along with the handling of residuals from multiple locations.

- Separation of the distribution systems would be complex, under scenarios where only a portion of the source water is softened. If areas of softened water are not separated from non-softened waters, the blended water quality will be inconsistent and may lead to customer complaints.

- Significant infrastructure upgrades would be required to provide transmission to and distribution from centralized softening systems under option SR5.

- Action would be required by the District and customer communities to ensure removal of residential water softeners in areas to which softened water would be provided. Removal of residential water softeners may be difficult to enforce, and the resulting reduction in chloride load may be less than expected if some portion of residential water softeners continue to be used.

- Water quality and fees for water would vary significantly among the District's customer communities, depending on whether the community is served by softened or unsoftened water.

Softening of the source water supply under options SR3 or SR5 is appealing because it reduces or eliminates a major source of chloride, sodium and potassium that currently originates from residential, commercial and industrial water softeners to the NSWTP, as well as to the watershed as a whole. However, implementation of a softening alternative is complex due to the requirement for numerous softening systems located at individual water supply wells, or significant modifications to the well water transmission and distribution systems to facilitate centralized water softening.

3.1.3 Reducing Chloride Load from Industrial/Commercial Sources and Zeolite Softeners

Options SR6, SR7 and SR8 involve reducing the chloride load attributable to industrial/commercial sources and residential water softeners. These initiatives are currently being undertaken by the District. Under option SR6, the chloride load from industrial and commercial facilities would be reduced by treatment or source elimination at the individual sources. The chloride contribution from commercial/industrial customers, as reported by the District, is approximately 12% of the chloride load to the NSWTP.

Options SR7 and SR8 relate to the use of residential zeolite softeners. Initiatives to educate residential customers regarding the impact of zeolite softeners on the chloride load to the watershed (option SR7), and benefits associated with use of more efficient softeners (option SR8), are expected to reduce the overall chloride load to the system. However, even under the best circumstances, it is likely that chloride from these sources will continue to be the single largest contributor to the NSWTP. The District is currently conducting studies in a defined area to better quantify the potential impact of these chloride reduction measures.

3.2 Chloride Treatment at NSWTP

Options for reducing chloride concentrations in the effluent from the NSWTP are summarized in **Table 3-2**, located in the Tables section of this document. The chloride treatment options are identified as options TP1 through TP4.

3.2.1 Minimize or Eliminate Chemicals that Contribute Chloride at NSWTP

Option TP1 involves minimizing the use of chloride-containing chemicals at the NSWTP. Several chemicals are used to enhance odor control and sludge dewatering, and to facilitate recycle water disinfection and nutrient recovery. These chemicals contribute approximately 2 percent of the chloride load in the NSWTP wastewater, and include:

- Ferric chloride ($FeCl_3$) at digester and solids handling processes
- Sodium hypochlorite (NaOCl) for W-4 water disinfection
- Calcium hypochlorite ($CaOCl_2$) for W-4 water disinfection
- Muriatic acid (HCl) for aeration diffuser stone cleaning
- Magnesium chloride ($MgCl_2$) for nutrient recovery in the Ostara process
- Sodium chloride (NaCl) for domestic and boiler water treatment

The plant staff has worked diligently to minimize these sources while maintaining effective overall treatment. While minor reductions in the chloride contribution from these chemicals may be possible, the impact to the overall plant chloride load would not be significant.

3.2.2 Treatment of NSWTP Effluent to Remove Chloride

There are a limited number of technologies used to remove chloride and other dissolved solids (TDS) from wastewater. The selection of an appropriate technology is based on the specific inorganic constituents that make up the TDS, as well as other wastewater characteristics and design considerations. Reverse osmosis (RO), electrodialysis reversal (EDR) and ion exchange (IX) technologies are commonly employed for TDS removal from water and wastewater to achieve various water quality objectives. Since the removal efficiency for these technologies is high, it is likely that only a portion of the NSWTP effluent would require treatment, and the treated and untreated effluent would be blended to achieve the target water quality objective for chloride.

3.2.2.1 Reverse Osmosis

In the reverse osmosis (RO) process (option TP2), dissolved solids such as chloride are removed by passing the wastewater under pressure through a semi-permeable membrane. The RO membrane provides a barrier to all dissolved salts and inorganic molecules, as well as organic molecules with a molecular weight greater than approximately 100. Water molecules, however, are able to pass through the membrane. Dissolved inorganic compounds are typically removed at an efficiency of 95% to greater than 99%, depending on the RO membrane and the system operating conditions.

The RO system employs cross-flow filtration where the feed stream flows under pressure parallel to the membrane surface. As the water molecules pass through the membrane by diffusion, the rejected constituents remain in the concentrated feed stream. The continuous flow across the membrane surface allows the rejected particles to be swept away from the membrane surface. The resulting stream containing rejected inorganic and organic compounds is referred to as the “concentrate” or “reject.” The water which passes through the membrane is referred to as “permeate.” Expected permeate recovery from a RO system under this application is expected to be in the range of 80 to 85 percent. Approximately 15 to 20 percent of the wastewater stream is rejected by the RO membrane, and requires additional concentration through a second stage of RO treatment, or management as a waste stream. The most common RO membrane configuration is spiral wound, although newer membrane configurations are available to reduce membrane fouling potential and are reported to require less pretreatment.

Several design and operating factors affect the performance of the RO membrane system, as described below.

- The feed water pressure affects the water flux, or rate of permeate flow per unit of membrane area, as well as the degree of rejection. With increasing feed pressure, the rejection rate and permeate flux will also increase. Since RO membranes are imperfect barriers to dissolved constituents, however, there will always be some transfer of these materials through the membrane, and there is an upper limit to the amount of inorganic compounds that can be excluded from the permeate via increasing feed pressure.

- As the feed water temperature increases, the water flux increases almost linearly due to the higher diffusion rate of water through the membrane. Increased temperature also results in lower rejection, or higher passage of wastewater constituents to the permeate stream.

- The concentration of dissolved salts affects the osmotic pressure of the feed water, and therefore impacts the amount of pressure required to drive the water through the membrane. As the concentration of dissolved salts increases, the permeate flux decreases, as does the rejection of dissolved salts.

- The recovery rate is the ratio of permeate to feed flow. With increasing recovery, the permeate flux decreases to the point where the osmotic pressure of the concentrate is as high as the applied feed pressure. The rejection of wastewater constituents also decreases with increasing recovery.

The main operational concern associated with RO technology relates to fouling of the membranes. Fouling occurs when the membrane pores become clogged with salts or obstructed by particulate matter, which limits the amount of water that can pass through the membranes. RO membrane fouling is controlled by selection of the appropriate pretreatment process and chemical addition, as well as by cleaning the membranes when necessary. The clean-in-place operation is a manually controlled function that is usually required infrequently. As the membrane fouling increases and recovery of flux rates decreases with cleanings over time, it will become necessary to replace the RO membrane units. The frequency of membrane replacement is dependent upon the feed water quality, but in wastewater applications is usually required once every one to three years.

The effluent from the NSWTP contains low concentrations of suspended solids and organic matter. Therefore pretreatment is required to protect the RO membranes from these fouling materials. Typical pretreatment would include ultrafiltration (UF) for removal of particulate matter, possibly followed by granular activated carbon adsorption or advanced oxidation for removal of dissolved organics. This equipment would be installed downstream of the existing secondary treatment process, and prior to the RO system. The UF system provides low pressure filtration through membranes with a nominal pore size around 0.01 microns. The UF membrane system operates in a similar manner to the RO system, and generates the following waste streams:

- Reject (concentrated wastewater that does not pass through the membranes)
- Clean-in-place (CIP) waste
- Backwash

Granular activated carbon filtration or advanced oxidation could be used to remove organic compounds from the wastewater which could cause biological or other organic fouling within the RO system. The activated carbon filter system would also generate a backwash waste stream. The waste streams from the UF and activated carbon filter systems would likely be recycled to the head of the treatment plant.

3.2.2.2 Electrodialysis Reversal

In the electrodialysis reversal (EDR) process (option TP3), dissolved solids are removed as ions migrate through selective semipermeable membranes. The ions migrate as a result of their attraction to two electrically charged electrodes.

Typically an EDR system can remove 50 to 95 percent of TDS from feedwater containing TDS at concentrations up to 12,000 mg/L. The configuration of the EDR system, including the number of stages and applied power, dictates the ultimate removal efficiency of the system. As the various ions pass through EDR membranes they are concentrated in a recycle stream. Similar to the RO system, the concentrated waste stream requires further concentration and/or disposal.

The polarity of the electrodes is regularly reversed in the EDR system, hence the name electrodialysis *reversal*. Polarity reversal provides for control of scaling and fouling by freeing ions which have accumulated on the membrane surface. During reversal of ion flow through the EDR system, the inlet becomes the outlet and vice versa. The reversal process increases membrane life but does require additional plumbing and electrical controls compared with a standard electrodialysis system. An EDR system typically requires only minimal chemical addition to control membrane fouling.

Similar to the RO treatment alternative, pretreatment is required to protect the EDR system and extend the membrane life. However, because the EDR system attracts and passes only ions through the membrane and does not rely on pressure to force all the clean water through the membrane, the EDR process is somewhat less susceptible than the RO process to membrane fouling. Therefore, pretreatment for the EDR system may be less extensive than for an RO system. At a minimum, scale inhibiting chemicals and sodium hypochlorite can be dosed to the feed water to prevent precipitation of divalent cations and biological growth. In addition, it is recommended that the equivalent of a 10 to 20 µm cartridge filtration system (or alternately, an ultrafiltration or microfiltration system), be installed upstream of the EDR to protect the overall system and improve its efficiency.

EDR systems typically provide slightly better recovery of treated water in comparison to the RO process. EDR system permeate recovery under this application is expected to be in the range of 90 percent. Therefore, approximately 10 percent of the wastewater stream would need to be further concentrated and/or managed as a waste stream.

3.2.2.3 Ion Exchange

In the ion exchange (IX) process (option TP4), dissolved solids are removed by replacing ions in a dissolved state with ions in a solid phase using specially-engineered ion exchange resin. The process is similar to the zeolite softening process used by many residential, commercial and industrial customers within the District. However, for this application a different ion exchange resin and regeneration solution would be used to avoid introducing chloride from the regenerant waste stream. Various solids or resins can be used depending on the specific ion of interest to be removed from the wastewater. Individual resins are charge specific and attract certain anions or cations depending on the resin. For chloride removal, an anionic resin would be used to attract the negatively charged chloride ion.

Individual resins have a greater affinity for removal of certain ions, but other similarly-charged ions may also be removed and may be preferentially removed over the target ion. This affinity may result in poor removal efficiency of target ions if ions with greater affinity are present in the wastewater stream. In this case, ions with greater affinity preferentially occupy the exchange sites on the resin and the resin requires more frequent regeneration to maintain removal of the target ion. It is also possible that once all of the exchange sites have been used, the target ion could be released from the resin in favor of the higher affinity ion.

Regeneration of the resin is required when the exchange sites on the resin have been occupied by ions from the wastewater. The IX unit is then taken off line and a regenerant is used to replace the ions that were removed with ions contained in the regenerant solution. Spent regeneration wastewater, containing the removed ions, is produced from the regeneration process and must be managed as a waste stream. Ion exchange units may operate at 98 percent efficiency when the wastewater to be treated contains primarily the target ion, or minimum concentrations of ions which have greater affinity for the resin in comparison to the target ion. Therefore, only 2 percent of the forward flow would need to be handled as a waste stream. However, since the NSWTP effluent contains competing ions such as nitrate, the efficiency of the IX process is expected to be much lower. Regeneration chemicals may include large quantities of sodium hydroxide for resin regeneration and sulfuric acid for neutralization of the spent regenerant waste. These chemicals can pose operational and handling hazards.

IX systems typically require some form of pretreatment system to improve their overall efficiency and prevent fouling or blinding of the IX resin by particulate matter and dissolved organic compounds. Typical pretreatment would include membrane or granular media filtration. Backwash from the filtration pretreatment system can typically be recycled back to the head of the plant.

3.3 Brine Minimization

Each of the chloride reduction technologies considered for implementation at the NSWTP are expected to produce significant volumes of liquid waste, and some form of brine minimization will be required to achieve volumes that can be more cost-effectively stored, hauled, disposed and/or beneficially used. Various alternatives for brine minimization are summarized in **Table 3-3,** located in the Tables section of this document and are described below. The brine minimization options are identified as options BM1 through BM7.

3.3.1 Microfiltration / Reverse Osmosis

Option BM1 involves membrane filtration, which is routinely utilized to concentrate brine waste, and typically includes a microfiltration (MF) system for pretreatment followed by an RO system. The MF membranes with a nominal pore size of approximately 0.1 microns serve as a protective barrier to the RO system. The reject stream from the RO system would need to be beneficially used or disposed off-site, or the volume could be further reduced with an evaporator system as described below. The membrane system achieves further concentration of the reject from the primary chloride removal system and may increase the overall recovery to approximately 90 to 95 percent or greater, depending on the specific chemistry of the wastewater.

3.3.2 Softening with Microfiltration / Reverse Osmosis

Option BM2 is similar to option BM1, with the addition of a softening process for removal of hardness ions prior to membrane treatment. The water recovery efficiency of RO systems is dictated by concentrations of dissolved ions in the wastewater, among other factors. As the concentration of dissolved ions increases in the concentrate stream, some combinations of ions exceed their solubility limit and precipitate, contributing to membrane fouling. This is frequently true for hardness-contributing ions including calcium and magnesium. If hardness is a limiting factor, the water recovery efficiency can be increased by providing hardness removal, or softening, ahead of the RO system. By substituting monovalent ions (sodium) for hardness ions (calcium and magnesium), the RO membrane can be operated at a higher recovery rate with reduced risk of membrane fouling. As a tradeoff, calcium carbonate and magnesium hydroxide solids are generated which may require off-site disposal or handling with the NSWTP solids process. An evaporator system could be used to further reduce the brine volume.

3.3.3 Evaporator

Evaporators, described under option BM3, make use of direct or indirect heat to boil and evaporate water from the waste stream, reducing its volume. Evaporated water can be condensed and reused in many cases. Evaporators are very effective in reducing the waste volume and are typically operated to produce wet salt which requires off-site disposal or may be suitable for beneficial use. However, evaporators are energy-intensive, and both capital and operating costs may be higher in comparison with other volume minimization techniques. Therefore, MF/RO brine concentrator systems, as described above, are routinely installed for volume reduction prior to evaporator systems to minimize the load and associated cost.

A significant consideration relative to the capital cost of evaporator systems is associated with the corrosivity of the waste stream and required materials of construction. Material selection for evaporators is critical because the concentrated inorganic materials in the reject stream become further concentrated through evaporation of the water. These inorganic materials, especially chloride, attack the evaporator surfaces and can quickly deteriorate the equipment. The base evaporator material of construction is typically 316 stainless steel but exotic materials such as titanium are often used.

3.3.4 Brine Concentrator Crystallizer

Option BM4 includes a brine concentrator followed by a crystallizer to produce a solid product for beneficial use or disposal. A brine concentrator is similar to an evaporator but includes seeded slurry to overcome the limitation imposed on conventional evaporators by the saturation limits of low solubility scaling compounds. Total water recovery from a brine concentrator is typically 95 to 99% with the brine concentrated to approximately 17% total solids. After the concentrator stage, the reduced-volume brine is fed to a crystallizer which produces a solid, crystallized product. This option would result in the lowest volume of waste brine material for disposal or beneficial use.

3.3.5 Freeze / Thaw

Under option BM5, the brine waste stream would be stored during warmer months for treatment when outside temperatures fall below freezing. Chloride separation occurs via freeze crystallization. Water in the brine solution freezes at 32° F and forms relatively pure ice crystals. The remaining brine solution contains the dissolved ions from the brine, has a lower freezing point, and therefore maintains a liquid form. Since the brine solution has a higher density than the formed ice crystals, the concentrated brine waste can separate and flow away from the ice.

Repeated exposure to freeze / thaw promotes the formation of larger ice crystals and allows the brine to flow more readily through the ice. Control of the liquid discharge from these freezing operations can allow for collection of concentrated brine waste, recycle of brine waste for further concentration in the freeze / thaw cycle, or discharge of purified water upon melting of the ice pack.

Equipment associated with this alternative is minimal compared to other alternatives. However, significant space is required to store the brine waste for processing during freezing temperatures as well as space dedicated to the freezing process and to concentrated brine storage. Additional storage may be required for treated water to control the rate of discharge when the ice pack returns to liquid form. Alternatively, the ice pack could potentially be transported to a disposal location but would result in significant handling costs.

This alternative is highly dependent upon winter temperatures to provide sufficient freezing for the purification process. The technology appears to have had success in purifying drinking water from brackish well sources but is not known to have been applied to wastewater chloride issues.

3.3.6 Natural Treatment Systems

Constructed wetlands, as described under option BM6, are an established technology and can theoretically be used for brine removal/concentration from a brine waste stream. In this application the constructed wetland would include high-salt-tolerant salt plants. These plants would remove or concentrate constituents in the root zone or sediments and allow evapotranspiration to reduce the volume of flow.

Constructed wetlands require significant land area and appropriate liner systems. The constructed wetlands would need to be periodically taken out of service for removal of the sediments to restore capacity to the system. Sediments would likely require landfill disposal. The wetland could then be reconstructed. Constructed wetlands may not provide a reasonable approach for brine minimization at the NSWTP due to space requirements, climate and ultimate disposal requirements for both the liquid discharge and the resulting sediments.

3.3.7 Evaporation Ponds

Evaporation ponds are shallow ponds used to eliminate liquid volume from concentrated wastewater through passive evaporation during warm, dry weather conditions. After water has been sufficiently evaporated from the ponds, the remaining solids and salts are removed from the ponds for off-site disposal via landfill or other means. Evaporation ponds require large tracts of land to maximize the surface area and overall evaporation rate. Typical construction includes a liner system to prevent the migration of the brine waste into the underlying soils. Evaporation ponds are best suited for arid geographies and can be utilized more effectively in the southwest United States. Evaporation ponds are not expected to be a feasible alternative for the NSWTP, due to climatic conditions in the Madison area.

3.4 Brine Disposal or Beneficial Use

Concentrated residuals which remain from technologies applied for chloride removal will require disposal or can potentially be beneficially used. Without application of brine minimization technologies, the volume of the concentrated waste stream could range from 10 to 15 percent of the treated flow. Use of brine minimization technologies, including evaporation, may result in a concentrated waste stream less than 5 percent of the treated flow. Option BM4, including a brine concentrator crystallizer, would result in production of a dry material that would require disposal off-site in a landfill or could potentially be beneficially used. Disposal or beneficial use of the brine waste would be regulated by federal, state and local laws. Characterization of the residuals using analytical methods would be required to determine the presence of toxic or hazardous substances that may limit the options for disposal and/or beneficial use. Alternatives for disposal or beneficial reuse of the chloride treatment residuals are summarized in **Table 3-4,** located in the Tables section of this document. The brine disposal and reuse options are identified as options D1 through D4.

3.4.1 Beneficial Reuse

Under the beneficial reuse option D1, it may be possible that the waste product could be used for a beneficial purpose. The opportunity for beneficial use, suitability for market, and identifying potential markets would require detailed characterization of the material and further evaluation.

3.4.2 Storage and Use for Winter Road De-icing

If the waste brine solution could be considered for winter use as an alternative road de-icing material, as described under option D2, the brine waste would need to be stored until it could be used. Further investigation and characterization would be required to determine the feasibility of utilizing the brine waste for de-icing purposes, along with determining the demand for the brine waste and storage requirements.

3.4.3 Deep Well Injection

Deep well injection, described under option D3, has been used for decades throughout the United States for disposal of waste fluids. This method is highly regulated by Federal and State entities to ensure that potential drinking water sources are not affected. Regional geology is not conducive for either below grade storage or deep well injection. In addition, deep well injection waste disposal is not permitted by the State of Wisconsin. Therefore, this option would require hauling of waste brine to another state for disposal.

3.4.4 Off-site Disposal

Option D4 involves off-site disposal of the waste brine by means of landfill or industrial waste disposal facility. Waste characterization would be required to assure the material conforms to specific landfill or industrial waste disposal facility requirements. Landfill disposal is best suited to solids or wet sludge disposal; solidification and stabilization may be required if the brine is in a liquid form.

4.0 Overview of Triple Bottom Line Analysis

The Triple Bottom Line is an evaluation process that assesses a project’s value in terms of financial, social, and environmental criteria. The determination of ‘value’ is carried out through a system of measurement that has two main aspects – the first is a set of **Indicators** that are designed to measure certain attributes of value, and second is a **Rating System** that applies a consistent set of rules that can normalize, interpret, classify, aggregate and represent the measured indicator values in order to make them useful for decision-making. The TBL assessment process uses multi-criteria decision-making (MCDM) methods as a foundation.

AECOM’s TBL Assessment process has been adapted for application in comparing and evaluating the conceptual alternatives for the chloride compliance strategy as a simple, interactive tool. In evaluating the alternatives, the TBL tool has three primary objectives:

1. To inform and support the analytical process for **developing alternatives** by considering social and environmental impacts in the process alongside operational performance and financial considerations;

2. To provide **decision-making support** for the District review team;

3. To increase **project selection transparency.**

Characteristics of a robust TBL rating system include:

- Simple (easily understood but logically sound)
- Comprehensive (by topic/criteria and indicators)
- Consistent (across indicator types, project types)
- Structurally unbiased between indicators as a model (unless explicitly weighted)
- Computable/measurable
- Scalable (expandable by number of indicators; can work at local, watershed, community scales)
- Aggregation capable (group indicators into indices etc.)
- Visually representable (in a compelling, easy to grasp way)

4.1 TBL Categories

The TBL tool compares proposed alternatives across three different categories:

1. **Financial and Operational** – compares financial impact to project and operational considerations

2. **Environmental** – compares impacts on local environment

3. **Social and Community** – compares impacts and risks on local residents and their acceptance of proposed strategies as well as the project's role in shaping the District's image as a leader in innovative environmental technologies.

Each category is made up of multiple criteria, which are in turn built on measurable indicators. AECOM worked with the District review team to select and define the criteria used in the TBL analysis.

4.1.1 Financial and Operational Category

Six financial and operational criteria were identified to be important to this evaluation, as described below.

F1 Capital Costs

This criterion reflects the overall capital investments required for the proposed project. The TBL analysis compares the capital cost across the various alternatives. In the absence of any specific allocated construction budget for the project, the comparison methodology considers the average cost across all alternatives as the benchmark to which each alternative is compared.

F2 Operation and Maintenance Costs (Including Staffing Impact)

This criterion reflects the overall annual operational and maintenance (O&M) costs required for the proposed project, including the annual salaries for key new staff required for operating the plant. Similar to the capital costs criterion, the comparison methodology considers the average O&M cost as the benchmark to which each alternative is compared.

F3 Avoided Costs and New Revenues

This criterion considers any avoided costs and new revenues from sale of by-products, or supply of generated energy associated with the proposed project. Avoided costs and new revenues are considered as positive impacts for a project alternative, serving to reduce the overall life-cycle costs.

F4 Chloride Removal Efficiency

This criterion measures the chloride removal efficiency of the proposed project in terms of quantity of chloride removed per $ spent. The efficiency indicator uses an annualized 20-year life cycle cost (NPV) for the project and the annual quantity of chloride removed by the plant.

F5 Process Complexity

This criterion considers a series of factors that contribute to the complexity of the proposed process operations. A higher complexity for the process(es) denotes a higher probability of complications in maintenance /management challenges and is therefore considered a negative impact. The factors considered for measuring the complexity are:

- Ease of operation (scale 1-5) (5 is the easiest)
- Number of other processes impacted (#)
- Process reliability/proven effectiveness (H/M/L)
- Pretreatment requirements (y/n)
- Sole-source technology

F6 Operational Risk
This criterion considers risks and tolerances of proposed processes with respect to probability of failure. The factors considered are:

- Tolerance to highly variable wastewater volume (H/M/L)
- Tolerances to variable dilution / concentration of chemicals (H/M/L)
- Tolerance to temperature sensitivity (H/M/L)

4.1.2 Environmental Category

Seven environmental criteria were identified for use in the TBL analysis of options and alternatives.

E1 Energy Use
This criterion measures the impact of the proposed alternative to the total purchased energy use relative to the current NSWTP operation as a baseline.

E2 Air Quality Impact
This criterion considers impacts to air quality, specifically tracking whether any process generates criteria pollutants outside of regulated limits.

E3 Noise Impact
This criterion considers whether the proposed alternative generates noise levels greater than 80 decibels (dB) as part of the normal daily operations.

E4 Plant Carbon Footprint
This criterion tracks and compares the overall carbon footprint or greenhouse gas (GHG) emissions resulting from the proposed project. The emissions tracked include indirect emissions due to energy use and as the result of hauling materials to and from the treatment facility.

E5 Land Use Impact
This criterion considers any land use changes resulting from the proposed project. Reductions in land requirements (e.g. due to reduced disposal in landfills) are considered positive impacts, while additional land required for treatment, storage, construction or disposal are considered negative impacts.

E6 By-product Reuse Potential
This criterion considers the waste reduction potential for the proposed project by considering the reuse potential for any by-products produced.

E7 Impact on Effluent Quality
This criterion considers any changes to the NSWTP effluent that may cause adverse or beneficial impacts to the receiving stream due to the proposed project process. The criterion tracks whether the process results in additional removal of nutrients (phosphorus and nitrogen), changes in the effluent temperature, and removal of any other effluent constituents which may result due to the chloride treatment process.

4.1.3 Social and Community Category

Four criteria were identified as important to the evaluation of options and alternatives relative to social and community impacts.

S1 Leadership and Community Image

This criterion ranks project alternatives based on level of innovation and environmental leadership that may inspire a positive community image. The criterion rank is based on three indicators :

- Whether the project includes state-of-the-art technology that would project the District as a leader in the field.
- Whether the project uses any innovative process that would be a model for other communities.
- Whether the project includes progressive actions/behavior changes on the part of the community.

S2 Public Acceptance

This criterion ranks project alternatives based on the likely acceptance by the Madison community due to unfavorable project characteristics. It tracks the following potential impacts that the public may react negatively to :

- Odors and visual aesthetics
- Public nuisance
- Behavior change requirement by residents that is perceived as a burden

S3 Worker Safety

This criterion measures the level of risk to workers within the new treatment facilities as a result of specific components and processes. It includes risks due to:

- Physical and mechanical safety hazards
- Chemical hazards

S4 Public Health Impact

This criterion considers public health risks due to activities and processes of the new treatment facilities. It includes risks (ranked as High, Medium, Low) for the following conditions:

- Public health risks due to storage and transportation of raw materials
- Public health risks due to disposal of by-products and wastes
- Potential risk for catastrophic accident (leakage/explosion/flooding etc.)

4.2 Criteria and Indicator Data for Project Alternatives

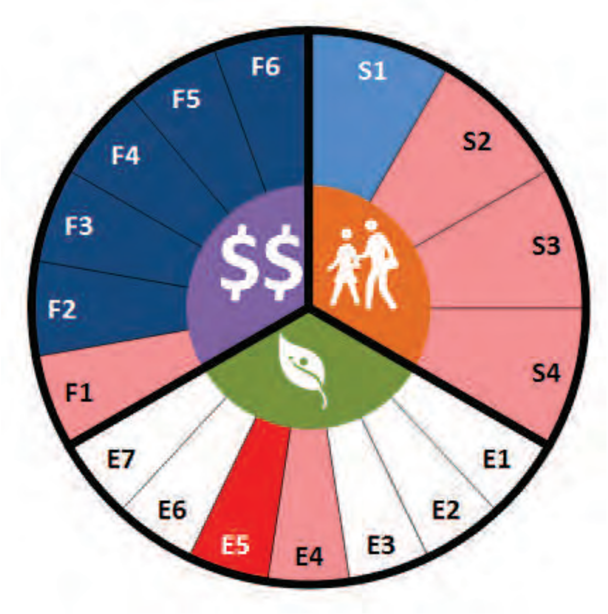
A project data form was used to capture details about each project alternative being developed. Data from these forms was read by the TBL model, which calculated TBL rankings and scores and generated the visual outputs.

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

4.2.1 TBL Representation and Scoring System

The TBL assessment uses an ordinal ranking system to denote the level of positive or negative impacts to financial, environmental, and social/community externalities reflected by the criteria selected. In order to keep the outputs simple and easy to understand, a 5-level ranking system was used:

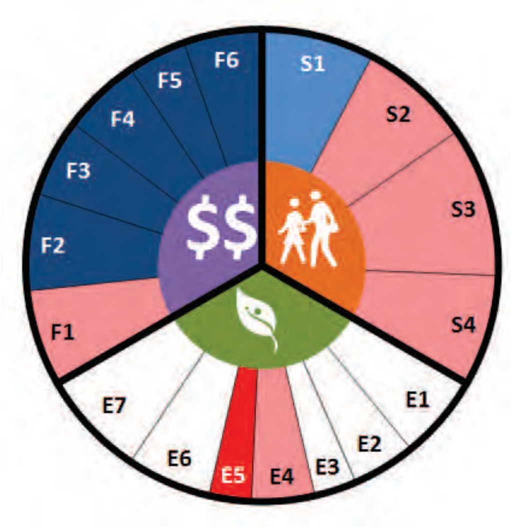
- Significantly positive (++)
- Positive (+)
- Neutral (0)
- Negative (-)
- Significantly negative (--)



++	Significantly Positive
+	Positive
O	Neutral
-	Negative
--	Significantly Negative
N/A	Not Applicable

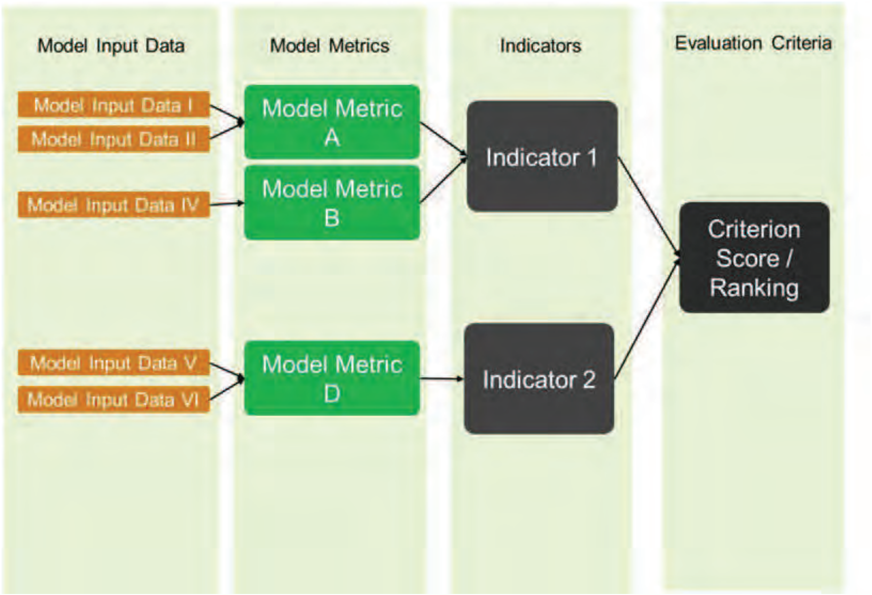
The TBL Radial Chart is by default represented with each of the three TBL categories of Social and Community, Environmental, and Financial and Operational equally weighted within the circle. The TBL approach requires that the three categories are viewed on equal terms and hold an equal area within the circle in order to represent the full picture of the TBL analysis. Within each category, the various criteria are represented by a slice, with the area in each slice showing the relative importance of the criterion and the color representing the ordinal rank. The color blue represents positive, and the color red represents negative. Therefore, the more blue area on the chart, the more favorable the alternative. More slices with red color signify more negative attributes of the project.

The TBL tool also allows the user to adjust the relative weight of the criteria within the TBL category. An example of using different criterion weights is shown below.



	Social & Community	Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
	Environmental	
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
	Financial & Operational	
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

Since many criteria are aggregations of one or more indicators, this system of ordinal rankings is also calculated at each individual indicator. Once an indicator is ranked, an aggregation method is used to “roll-up” all indicators within a criterion to calculate the criterion level ordinal rank.



4.2.2 TBL Scoring Methodology

Once the ordinal ranks are determined, the TBL model also computes a numeric score for the entire scheme based on allocating each criterion with a score range of -100 to +100 and then aggregating the overall score based on the weights assigned to each criterion. This numeric score makes it easier to compare multiple charts.

Numeric scores are calculated using three methods based on the type of indicator and the data captured for that indicator. Method 1, or the *Linear/Gradient Method,* calculates the score as the linear deviation from a performance benchmark such as an average cost. Positive impacts are calculated as a percentage of the indicator value above the benchmark, capped at a maximum score of positive 100. Similarly, negative impacts are calculated as a percentage of indicator value below the benchmark, capped at a lowest score of -100. Method 2, or *Ordinal Method,* is used for indicators that do not have a benchmark and are recorded as binary or ordinal values such as high, medium, and low categories. The ordinal scale for the impact is calculated and then the ordinal rank in converted to a numeric score using standard equivalents such as (“++” = 100, “+” = 50, “0” = 0, “—” = -50, “—” = -100). Method 3, or *Threshold Method,* compares indicator values to a range of thresholds and assigns a score to each threshold range. This method is used particularly for criteria that have multiple indicators with qualitative responses (H/M/L or Yes/No). Criterion scores for capital costs and O&M costs were originally measured using Method 1 but based on recommendations from District staff, an ordinal method (Method 2) was used for Energy Use, Carbon Footprint, Capital Costs, O&M Costs and Chloride Efficiency criteria. The performance of alternatives across these criteria was relatively compared using Very Low, Low, Medium, High, and Very High ordinal ratings. The District elected to change the method for measurement of these criteria to better distinguish among the alternatives.

The weighting and scoring methodology used for evaluation of chloride compliance alternatives is summarized in **Table 4-1**.

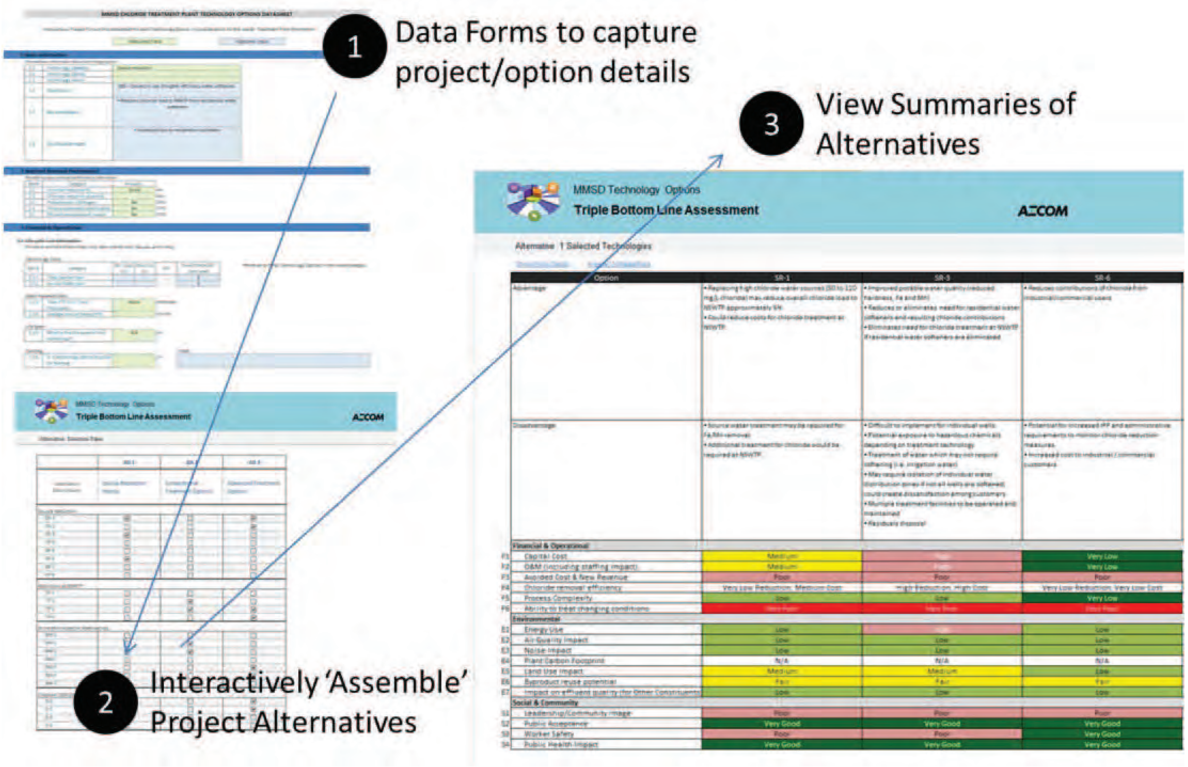
Table 4-1:
Summary of TBL Criteria Weighting and Scoring Methodology

	Financial & Operational	weighting	# Indicators	Scoring Method
F1	**Capital Cost**	5	1	Ordinal method
F2	**O&M Cost**	5	1	Ordinal method
F3	**Avoided costs**	4	1	Ordinal method
F4	**Chloride efficiency**	4	1	Ordinal method
F5	**Process complexity**	3	5	Threshold method
F6	**Operational risk**	4	4	Threshold method
	Environmental			
E1	**Energy Use**	4	1	Ordinal method
E2	**Air Quality Impact**	3	1	Threshold method
E3	**Noise Impact**	2	1	Ordinal method
E4	**Plant Carbon Footprint**	3	2	Ordinal method
E5	**Land Use Impact**	2	3	Linear/Gradient method
E6	**Byproduct reuse potential**	4	1	Ordinal method
E7	**Impact on effluent quality**	3	3	Ordinal method
	Social & Community			
S1	**Leadership/Community Image**	3	3	Linear/Gradient method
S2	**Public Acceptance**	3	3	Linear/Gradient method
S3	**Worker Safety**	4	2	Linear/Gradient method
S4	**Public Health Impact**	3	3	Linear/Gradient method

*Relative weight within each category: 1 = low; 5 = highest importance

4.3 Use of TBL Model in Selecting Technology Options and Defining Alternatives

The TBL process was used to capture conceptual details of various technology options into data forms. These data forms were then used in an interactive session with the District project advisory group to assemble three viable alternatives for consideration in this evaluation. This process allowed the team to examine preliminary advantages and disadvantages of various combinations of technologies at an early stage of the study, and then proceed with more detailed studies for three selected alternatives.



1 Data Forms to capture project/option details

2 Interactively 'Assemble' Project Alternatives

3 View Summaries of Alternatives

MMSD Technology Options

Triple Bottom Line Assessment

AECOM

Alternative 1 Selected Technologies

	Option	SR-1	SR-3	SR-6
	Financial & Operational			
F1	Capital Cost	Medium	High	Very Low
F2	O&M (including staffing impact)	Medium	High	Very Low
F3	Avoided Cost & New Revenue	Poor	Poor	Poor
F4	Chloride removal efficiency	Very Low Reduction, Medium Cost	High Reduction, High Cost	Very Low Reduction, Very Low Cost
F5	Process Complexity	Low	Low	Very Low
F6	Ability to treat changing conditions	Very Poor	Very Poor	Very Poor
	Environmental			
E1	Energy Use	Low	High	Low
E2	Air Quality Impact	Low	Low	Low
E3	Noise Impact	Low	Low	Low
E4	Plant Carbon Footprint	N/A	N/A	N/A
E5	Land Use Impact	Medium	Medium	Low
E6	Byproduct reuse potential	Fair	Fair	Fair
E7	Impact on effluent quality (for Other Constituents)	Low	Low	Low
	Social & Community			
S1	Leadership/Community image	Poor	Poor	Poor
S2	Public Acceptance	Very Good	Very Good	Very Good
S3	Worker Safety	Poor	Poor	Very Good
S4	Public Health Impact	Very Good	Very Good	Very Good

5.0 Chloride Compliance Alternatives

Several of the chloride compliance options described in Section 3.0 are currently being implemented by the District, including:

- Source reduction for industrial / commercial customers (SR6)
- Education of residential customers regarding residential water softeners (SR7)
- Conversion of residential customers to higher efficiency water softeners (SR8)
- Minimized used of chloride chemicals at the NSWTP (TP1)

These activities will be beneficial to reduce the chloride load to the NSWTP. However, additional reduction in the NSWTP chloride load is expected to be required to maintain future compliance with the chloride discharge limit at all times. The TBL screening process was used to identify three alternatives for further development and evaluation. These alternatives include:

- Source water softening (SR3 – individual wells and SR5 – centralized treatment)
- Treatment of a portion of the NSWTP effluent with RO (TP2) and brine minimization (BM1) followed by a combination of the following brine minimization and brine disposal or reuse alternatives
    - Softening (BM2) with evaporator (BM3)
    - Brine concentrator crystallizer (BM4)
    - Storage for use in road de-icing (D2)
    - Off-site disposal (D4)
- Treatment of a portion of the NSWTP effluent with EDR (TP3) followed by a combination of the following brine minimization and brine disposal or re-use alternatives
    - Softening (BM2) with evaporator (BM3)
    - Brine concentrator crystallizer (BM4)
    - Storage for use in road de-icing (D2)
    - Off-site disposal (D4)

6.0 Conceptual Design Development

Conceptual design information was developed for each of the three chloride compliance alternatives. A basis of design was defined for the source water softening alternative, and for the chloride treatment alternatives at the NSWTP, to establish a consistent level of chloride reduction to be accomplished for each alternative and facilitate comparison among the alternatives. Conceptual design information included identification and sizing of major equipment (**Appendix A**), process flow diagrams and mass balances (**Appendix B**), and site plans (**Appendix C)**. Manufacturer literature for the major treatment technologies considered in this evaluation is provided in **Appendix F**.

6.1 Source Water Softening

Softening of the source water supplies that serve the Madison community would eliminate the need for use of residential, commercial and industrial zeolite softeners, and thereby reduce a major source of chloride, sodium and potassium that is discharged to the NSWTP as a result of the zeolite softening process. On an annual average basis, it is estimated that approximately 60% of the chloride load to the NSWTP is attributable to zeolite water softeners. Two options for source water softening were evaluated: small treatment facilities located at individual wells, or a single water treatment plant located at a centralized location. The District estimates that approximately 5% of the average flow to the NSWTP comes from private wells, and any chloride load from residences with private wells will not be impacted by either wellhead or centralized softening.

Three options were identified for softening of the raw water supply:

- Lime softening
- Ion exchange
- Membrane processes (including nanofiltration and reverse osmosis)

The relative advantages and disadvantages of these water softening technologies are described in **Table 6-1**.

Table 6-1:
Summary of Source Water Softening Technologies

Softening Technology	Advantages	Disadvantages
Lime softening	• Conventional, proven process	• Significant lime sludge production; requires off-site disposal • Difficult chemical handling associated with lime storage and feed equipment • Relatively high space requirement
Ion exchange	• Relatively low capital cost • Conventional, proven process	• Requires handling of significant volumes of hazardous chemicals (sodium hydroxide and sulfuric acid) • Generates a high-TDS waste stream
Nanofiltration or reverse osmosis	• Minimum chemical requirements (membrane cleaning chemicals only) • Consistent finished water quality • Minimum space requirement • Waste stream contains primarily those constituents present in raw water	• Higher energy use • Membranes require cleaning and replacement to maintain finished water production capacity

Based on this comparison of technology options, a membrane process was selected for both wellhead and centralized softening due to the reduced space requirement, minimal chemical handling, no residuals produced for off-site disposal, and characteristics of waste stream for discharge to the sanitary sewer.

6.1.1 Source Water Softening Basis of Design

A basis of design for source water softening was developed to eliminate a sufficient mass of chloride from the NSWTP raw wastewater to ensure consistent compliance with the weekly average chloride discharge requirement of 395 mg/L.

The raw water supply that serves the Madison Water Utility is provided by multiple well sites located throughout the community. In addition, numerous neighboring communities produce their own water, a portion of which discharges to the NSWTP in the form of wastewater. It is assumed, based on the Public Service Commission of Wisconsin (PSCW) report, that in 2013 the City of Madison maintained 22 well sites and that the neighboring communities with potential to discharge to NSWTP operate 34 additional well sites.

A review of individual well information for the City of Madison shows that typical well sites include a well, reservoir and booster pump(s) with a capacity of approximately 2,100 gpm (3 MGD). On average, the wells operate 10 to 12 hours per day, producing 1.2 to 1.5 MGD of ground water which is pumped to the distribution system. For the purpose of this study, it was assumed that a softening system capable of treating up to a design feed rate of 3.0 MGD could be installed at each individual well site operated by the Madison Water Utility. It was also assumed that no additional treatment redundancy would be required at the individual well sites since redundancy is already provided by the multiple well sites.

Alternately, softening could be provided at a larger treatment system sited at a centralized location. Significant raw water and finished water distribution piping would be required to convey raw water from individual wells to the centralized location, and from the treatment system back to individual distribution system pressure zones.

Water quality data for individual wells operated by the Madison Water Utility was used to develop a basis of design for the raw source water within the City of Madison. Water quality data collected by the City in 2014, was used in conjunction with the average day demand for each of the wells to develop a weighted, blended water quality profile. The average day demand for each of the wells was based on 2008 through 2013 pumping rates, which ranged from 0.1 to 2.2 MGD at the individual well sites. The results of this evaluation are included in **Table 6-2**. For the purpose of this study it was assumed that the blended water quality data is representative across the City of Madison wells. If softening at individual wells is considered in further detail, it is recommended that the water quality for each individual well be further defined and evaluated, including parameters specific to membrane (or other) treatment technologies, for use in detailed design.

The summary of chloride contributions described in Section 2.0 showed that zeolite water softeners currently contribute 80,500 lbs/day of chloride to the NSWTP. Based on the future design condition, which include a 10% increase in flow, the mass load of chloride could increase to approximately 97,405 lbs/day of chloride from zeolite softeners. **Table 6-2** summarizes the chloride mass loads which must be removed under average and maximum chloride load conditions to maintain effluent concentrations below the 395 mg/L limit. The future design condition is based on a 10% flow increase and a 10% chloride concentration increase, as directed by District staff. The table includes the estimated percentage of zeolite softeners which must be removed from the system to achieve the 395 mg/L effluent limit at the NSWTP. The maximum day loads govern the design, as more chloride needs to be removed under this load condition.

Table 6-2:
Chloride Removal Requirements

Design Condition	Chloride load (lbs/day)	Chloride load required to meet 395 mg/L limit (lbs/day)	Chloride removal to meet discharge limit (lbs/day)	Assumed chloride load from softeners (lbs/day)	Chloride load to be removed as a % of softener load
Current design flow (40.5 MGD) with average chloride load	141,958	133,499	8,459	80,500	11%
Current design flow (40.5 MGD) with maximum chloride load	170,958	133,499	37,459	80,500	47%
Future design flow (44.6 MGD) with average chloride load	173,050	146,849	26,201	97,405	27%
Future design flow (44.6 MGD) with maximum chloride load	206,883	146,849	60,034	97,405	62%

Approximately 60% of the flow to the NSWTP is contributed by the area served by the Madison Water Utility. The balance of the flow originates from outside the City of Madison. Therefore, softening of water supplied by the Madison Water Utility and removal of zeolite softeners from this service area would eliminate approximately 60% of the chloride load attributable to zeolite softening. This would approximately meet the elimination of zeolite softeners required for the future design condition. It is anticipated that softening of water supplied by the Madison Water Utility, along with other continued chloride reduction programs, would consistently achieve the target chloride limit of 395 mg/L on a weekly average basis for the future design condition. Based on these assumptions, the source water softening alternatives were developed for softening of well water supplied by the Madison Water Utility only, and do not consider softening of water supplied by the surrounding communities and water utilities. It should be noted that this approach will result in variable water quality among communities served by softened water, and those served by unsoftened water. Residents in areas served by softened water may experience higher costs of water, due to the significant investment in community water treatment facilities and operating costs, but would avoid the costs of zeolite softening systems. Residents in areas not served by softened water may have concerns that they are not provided the same level of service as areas served by softened water.

The source water softening basis of design is summarized in **Table 6-3**.

Table 6-3:
Source Water Softening Basis of Design

Parameter	Units	Value
Individual well treatment capacity (individual treatment systems located at 22 wells)		
Production rate, firm capacity	MGD	2.55
Production rate, average	MGD	1.5
Centralized treatment capacity (single facility for treatment of water from 22 wells)		
Production rate, firm	MGD	50
Production rate, average	MGD	23.8
Raw water characteristics		
Hardness ($CaCO_3$)	mg/L	341
Chloride	mg/L	34
Alkalinity (CaCO3)	mg/L	302
Aluminum	µg/L	1.0
Antimony	µg/L	<0.206
Arsenic	µg/L	0.26
Barium	µg/L	24
Beryllium	µg/L	<0.206
Cadmium	µg/L	<0.103
Calcium	mg/L	72
Chromium	µg/L	1.0
Conductivity	µmhos / cm	690
Copper	µg/L	12
Fluoride	mg/L	0.83
Iron	mg/L	0.068
Lead	µg/L	0.24
Magnesium	mg/L	39
Manganese	µg/L	11
Mercury	µg/L	<0.206
Nickel	µg/L	1.3
Nitrogen-Nitrate	mg/L	1.6
Nitrogen-Nitrite	mg/L	<0.0400
pH (Lab)	s.µ.	7.5
Selenium	µg/L	0.50
Silver	µg/L	<0.206
Sodium	mg/L	12
Strontium	µg/L	74
Sulfate	mg/L	19
Thallium	µg/L	0.09
Total Solids	mg/L	418
Zinc	µg/L	7.5
Finished water characteristics		
Hardness as $CaCO_3$	mg/L	100

6.1.2 Wellhead Softening

Under this alternative, individual water softening systems would be constructed at each of the 22 well sites operated by the Madison Water Utility. Note that the conceptual design information for the wellhead softening alternative was developed in somewhat less detail than those alternatives developed for implementation at the NSWTP, as treatment of chloride at the NSWTP was the main focus of this study. Additional evaluation of individual well sites, water quality, and site-specific treatment capacity, among other considerations, would be required if this alternative is further developed.

At each well, the existing well pump would transfer raw water to the new nanofiltration (NF) or reverse osmosis (RO) softening treatment system. Approximately 76% of the water from the well would enter one of two 24,000 gallon (minimum) NF/RO feed tanks. The balance of the well water would bypass the softening treatment equipment and would be blended with permeate from the membrane system prior to distribution to achieve the desired water quality goal of 100 mg/L hardness as $CaCO_3$.

Ground water to be softened would be pumped from the NF/RO feed tanks through two treatment trains, each consisting of a prefilter system and a membrane system skid housing either NF or RO membranes. Each membrane system skid would be sized for 50% of the design flow rate. Ancillary equipment would include chemical storage and dosing equipment for membrane clean-in-place (CIP) operations.

Each membrane treatment system would produce a reject stream that contains the dissolved constituents removed from the water. The concentrated reject stream volume is estimated to be approximately 22% of the treated raw water volume, or approximately 0.5 MGD based on a treated raw water volume of 2.3 MGD (76% of assumed well capacity of 3.0 MGD). It is anticipated that the reject waste stream would be discharged to the sanitary sewer. If source softening is implemented at all well head sites operated by the Madison Water Utility, and the reject stream is discharged to the sanitary sewer, the rate of raw water pumping and the rate of wastewater pumping and treatment at the NSWTP could increase by up to 18%.

Permeate from the membrane treatment system and raw water which bypasses the softening process would be blended in the existing reservoir at each well head site, and chemical additives would be dosed similar to current practice. Existing booster pump(s) at each well site would continue to be utilized to pump the softened water to the distribution system.

The NF or RO membranes would require routine chemical cleaning, and the wastewater generated by these CIP procedures would require disposal. Chemicals used during cleaning usually include sodium hypochlorite, citric acid and sodium hydroxide. It was assumed that the chemical cleaning wastewater would be directed to the sanitary sewer. If needed, the pH of the chemical cleaning waste stream could be neutralized prior to discharge to the sewer.

Variable frequency drives should be installed for the existing well and booster pumps to allow for continuous operation of the pumping systems and allow the softening system to modulate in flow rate to match system demand.

An equipment list for the wellhead softening alternative is provided in **Appendix A**, and a conceptual process flow diagram is provided in **Appendix B**.

6.1.2.1 Wellhead Softening Materials of Construction

The NF/RO feed tanks were assumed to be of fiberglass reinforced plastic (FRP) construction. Membrane skids are typically constructed of epoxy coated steel frame skids fitted with a combination of PVC and stainless steel piping, membrane cartridges and ancillary equipment. Prefilters and chemical cleaning vessels were assumed to be of stainless steel construction. Chemicals will be contained in totes or containers as appropriate.

6.1.2.2 Wellhead Softening Space Requirements

The NF or RO equipment would be housed within a building with approximate dimensions of 70 feet by 40 feet. A conceptual layout of the wellhead softening treatment system is provided in **Appendix C**.

6.1.3 Centralized Softening

The centralized softening alternative is similar to the wellhead softening alternative, but would be at a larger scale. Similar to the wellhead softening alternative, the conceptual design information for the centralized softening alternative was developed in somewhat less detail than those alternatives developed for implementation at the NSWTP, as treatment of chloride at the NSWTP was the main focus of this study. Additional evaluation of potential centralized softening facility sites, raw water transmission and distribution piping requirements, water quality, storage and treatment capacity, among other considerations, would be required if this alternative is further developed.

Under this option it is assumed that the firm treatment capacity to be achieved by the Madison Water Utility is 50 MGD with an average design flow of 23.8 MGD. Centralized treatment would require transmission of raw water to, and finished water from, the centralized softening location. Raw water from each of the individual wells operated by the Madison Water Utility would be routed via new transmission lines to the centralized softening site. The distribution system would require modification to effectively distribute the softened water from the centralized treatment system throughout the service areas. The scope of this study does not include detailed evaluation of the necessary water distribution system improvements to bring water to or from the centralized treatment site, and support in estimating the magnitude of these improvements has been provided by the Madison Water Utility.

Raw water from the existing wells would be pumped via new transmission lines to a new centralized softening treatment system, including NF or RO membrane skids and ancillary equipment. Approximately 76% of the water from the wells would be softened by the treatment system. The balance of the well water would bypass the softening treatment system and would be blended with permeate from the membrane softening system prior to distribution to achieve the desired water quality goal of 100 mg/L hardness as $CaCO_3$.

The centralized softening treatment system would include two, 510,000 gallon (minimum) feed tanks, constructed of cast-in-place concrete. Raw water would be pumped from the feed tanks through 34 individual treatment trains. Each train would include a prefilter system and either a NF or RO membrane skid. The 34 membrane skids would be sized to provide a firm blended finished water capacity of 50 MGD with an average design flow of 23.8 MGD. Ancillary equipment would include chemical storage and feed equipment for membrane CIP operations, with a single CIP system serving multiple membrane skids.

Similar to the individual wellhead softening systems, the centralized membrane treatment system would produce a reject stream that contains the dissolved constituents that were removed from the raw water. It is expected that approximately 9.0 MGD of reject would be produced by the centralized softening system at full design capacity of 50 MGD, and it was assumed that the reject waste stream would be discharged to the sanitary sewer. Softening of the raw water and discharge of the reject stream would result in an increased rate of raw water pumping and wastewater pumping and treatment at the NSWTP of up to 18%.

At design capacity, permeate from the membrane system trains would be produced at a rate of 36 MGD and blended with 14 MGD of raw water that bypasses the softening process prior to being discharged to a clear well. Chemicals that are currently dosed to the potable water, including sodium hypochlorite and fluoride, would be dosed to the clearwell. New finished water pumps would transfer the finished water from the clearwell to the distribution system.

The NF or RO membranes would require routine chemical cleaning, and the wastewater generated by these CIP procedures would require disposal. Chemicals used during cleaning usually include sodium hypochlorite, citric acid and sodium hydroxide. It was assumed that the chemical cleaning wastewater would be directed to the sanitary sewer. If needed, the pH of the chemical cleaning waste stream could be neutralized prior to discharge to the sewer.

An equipment list for the centralized softening alternative is provided in **Appendix A**, and a conceptual process flow diagram is provided in **Appendix B**.

6.1.3.1 Centralized Softening Materials of Construction

The NF/RO feed tanks were assumed to be of cast-in-place concrete construction. Membrane skids are typically constructed of epoxy coated steel frame skids fitted with a combination of PVC and stainless steel piping, membrane cartridges and ancillary equipment. Prefilters and chemical cleaning vessels were assumed to be of stainless steel construction. Chemicals will be contained in totes and bulk storage tanks fabricated of appropriate materials compatible with each individual chemical.

6.1.3.2 Centralized Softening Space Requirements

The NF or RO equipment would be housed within a building with approximate dimensions of 330 feet by 200 feet. A conceptual layout of the centralized softening treatment system is provided in **Appendix C**.

6.2 Treatment for Removal of Chloride at NSWTP

Two membrane treatment alternatives, reverse osmosis (RO) and electrodialysis reversal (EDR), were developed and evaluated to achieve the target chloride effluent limit of 395 mg/L at the NSWTP. Ion exchange technology was not carried through to the alternatives analysis, due to the expected high operating costs associated with frequent regeneration of the ion exchange media and resulting high volumes of waste that would be generated due to the presence of numerous competing ions in the NSWTP effluent. Several additional processes were evaluated for concentrating and disposing of the liquid waste stream or brine that is generated from the membrane treatment processes.

6.2.1 Chloride Removal Basis of Design

A basis of design was developed to remove a sufficient mass of chloride from the NSWTP effluent wastewater to ensure consistent compliance with the weekly average chloride discharge requirement.

RO and EDR technologies are capable of removing over 90% of the chloride contained in the NSWTP effluent. Therefore, only a percentage of the NSWTP secondary effluent requires treatment to achieve the effluent chloride discharge concentration limit. The portion of secondary effluent that is treated for chloride removal would be blended with the balance of the secondary effluent to meet the chloride discharge goal of 395 mg/L.

An analysis of recent flow and chloride data from October 2010 through April 2014 was used to determine the required capacity of the chloride treatment system. It was assumed that membrane treatment technology would achieve 92% removal of chloride, and 90% of the wastewater treated could be recovered as treated permeate. Based on chloride concentrations and wastewater flows documented for the period of October 2010 through April 2014, and treatment technology assumptions, it was determined that a 10 MGD chloride removal treatment system would be required to avoid exceedances of the 395 mg/L chloride target on a 7-day rolling average basis. It was noted that the daily average chloride concentrations would have exceeded the 395 mg/L limit on nine occasions during the October 2010 through April 2014 data period.

As directed by District staff, the year 2030 future design condition for the chloride treatment system incorporated a 10% increase over the current flow and a 10% increase in chloride concentration. Using the membrane technology assumptions for chloride removal efficiency and permeate recovery described above, it was determined that a 15 MGD treatment system would be required to avoid exceedances of the 395 mg/L chloride target discharge limit on a 7-day rolling average basis. It was estimated that daily average chloride concentrations would exceed the 395 mg/L limit on six occasions during simulation of the future design condition.

Since NSWTP flow rates and effluent chloride concentrations vary seasonally, data for the period from October 2010 through April 2014 was also evaluated to determine the annual average flow rate through the chloride treatment system required to maintain compliance with the 395 mg/L chloride limit. The evaluation resulted in a current annual average flow requirement to maintain compliance of 2.6 MGD, and a future annual average flow requirement of 7.3 MGD. The maximum daily flow through the chloride treatment system would be approximately 15 MGD. The future design capacity of 15 MGD was used as a basis for developing conceptual design information and capital cost projections, and the annual average flows were used for estimating annual operation and maintenance costs.

NSWTP effluent characteristics were determined from historical monitoring data, as well as sampling and analysis of the NSWTP effluent for constituents that impact the design of membrane treatment systems. It is recommended that a more extensive monitoring program be considered prior to detailed design of any chloride removal technology. The basis of design used for evaluation of chloride treatment technologies at the NSWTP is summarized in **Table 6-4.**

Table 6-4:
NSWTP Chloride Removal Basis of Design

Parameter	Units	Value
Chloride treatment system capacity		
Chloride treatment, firm capacity	MGD	15
Average operating capacity, current	MGD	2.6
Average operating capacity, future	MGD	7.3
Secondary effluent characteristics		
Aluminum	mg/L	<0.24
Barium	mg/L	0.033
Cadmium	mg/L	0.00005
Calcium	mg/L	76.9
Chromium	mg/L	0.00018
Copper	mg/L	0.00629
Parameter		
Iron	mg/L	<0.164
Magnesium	mg/L	43.0
Manganese	mg/L	0.015
Mercury	mg/L	0.00111
Nickel	mg/L	0.00151
Potassium	mg/L	12.9
Sodium	mg/L	237
Strontium	mg/L	0.110
Zinc	mg/L	0.0501
Ammonia	mg/L	0.30
Bicarbonate	mg/L	291
Sulfate	mg/L	39.7
Chloride*	mg/L	402 - 562
Nitrate	mg/L	18.7
Fluoride	mg/L	0.75
Total Phosphorus	mg/L	0.30
Ortho Phosphorus	mg/L	0.174
Silica/Silicate (filtered)	mg/L	8.5
Silica/Silicate (unfiltered)	mg/L	12
Silt Density Index	5 min. basis	17.5
Total Dissolved Solids	mg/L	1,100
Total Suspended Solids	mg/L	5.6
Total Organic Carbon	mg/L	6.0
Chemical Oxygen Demand	mg/L	30
Oil & Grease	mg/L	2.2
Temperature	ºC	9 min / 27 max
Conductivity	mhos/cm	1,785
pH	standard units	7.2
Color	C.P.U.	40
Turbidity	NTU	2.9
Fecal Coliform	CFU/100 ml	82
Blended effluent characteristics		
Chloride, 7-day average	mg/L	<395

*Chloride concentration varies seasonally

6.2.2 Integration of the Chloride Removal Process at the NSWTP

It is assumed that a portion of the secondary effluent flow will be intercepted in an existing or new channel prior to the existing ultraviolet (UV) disinfection process. Secondary effluent to be treated for removal of chloride will be pumped from the channel to the chloride removal process. The remainder of the secondary effluent will continue to flow through the channel to the UV process. Low chloride effluent from the treatment process will be returned to the secondary effluent stream downstream of the withdrawal point for blending with the untreated portion of the secondary effluent.

The current configuration of the UV system and the pumping systems for Badfish Creek (BFC) and Badger Mill Creek (BMC) does not allow for discharge of higher quality effluent to one discharge point or the other. In the current configuration, the effluent for both discharges comes from a common well following the UV system, and DNR effluent monitoring parameters for both discharges are reported from a single sampling point. If the ratio of flows from the chloride removal system and secondary effluent could be separately controlled in the two discharges, then it may be possible to use the existing UV system for the BFC discharge, and bypass undisinfected effluent around the UV system to the suction of the BMC return pumps, blend the proper chloride treatment flow with the BMC flow, and provide a new in-pipe UV disinfection system for the BMC return. The remaining flow from the chloride removal system would go to the BFC discharge. Separate sampling points would be required for DNR permit monitoring. This alternative would need to be considered along with future UV system upgrades and hydraulic improvements.

6.2.3 Reverse Osmosis

The RO treatment alternative for removal of chloride includes pretreatment for removal of low concentrations of suspended solids present in the NSWTP secondary effluent followed by RO membrane treatment for removal of chloride and other dissolved constituents.

6.2.3.1 RO Process Description

RO membranes are susceptible to fouling by particulate matter and organic constituents, which can increase the required cleaning frequency and impact membrane performance. Therefore, to minimize the presence of particulate matter in the secondary effluent, ultrafiltration (UF) was selected for pretreatment upstream of the RO membranes. Seven new secondary effluent pumps (six duty and one standby) would be used to transfer wastewater to one of two UF feed tanks, each with a minimum capacity of 320,000 gallons. The effluent transfer pumps will be equipped with variable frequency drives (VFDs) to enable flow-pacing to achieve a target treatment rate selected by the operator.

The UF feed tanks will provide a minimum of 30 minutes of detention at the design flow rate of 15 MGD. Under normal conditions the feed tanks will operate as a single combined tank. One tank can be taken out of service for maintenance or cleaning while the full wastewater flow is directed through the remaining tank. The UF system configuration is dependent on the selected equipment supplier, but for the purposes of this evaluation it was assumed to include 14 UF treatment trains (12 duty, and 2 standby). Each UF treatment train would include a UF feed pump for wastewater transfer from the UF feed tank to the UF treatment process, a prefilter system used to protect the UF membranes from damage by large solids, and the UF membrane skid. Individual treatment trains would be staged to control the flow to meet the target treatment rate selected by the operator. Permeate from the UF system would be transferred to two RO feed tanks, each sized for a minimum capacity of 320,000 gallons, with a minimum of 30 minutes detention at the design flow rate. The RO feed tanks would operate in a similar manner to the UF feed tanks, and one tank could be taken out of service at any given time for maintenance or cleaning while maintaining full treatment capacity. A portion of secondary effluent containing concentrated suspended solids that do not pass through the UF membrane, estimated to be approximately 5% of the forward flow, would be returned to the head of the NSWTP. The UF membranes would require periodic backwashing to dislodge solids which accumulate on the membranes. The backwash waste would also be transferred back to the head of the NSWTP.

Based on this conceptual evaluation, it is assumed that the secondary effluent is of sufficient quality such that granular activated carbon filtration or advanced oxidation would not be required to remove organic material prior to the RO membranes. This assumption should be confirmed through additional wastewater characterization and pilot testing, if an RO system is to be evaluated in further detail.

Similar to the UF membrane system, the RO process configuration is also somewhat dependent on the specific equipment supplier. For the purposes of this evaluation the configuration was assumed to consist of 6 RO treatment trains (5 duty and 1 standby). Each RO treatment train would include a RO feed pump for wastewater transfer from the RO feed tank to the RO treatment process, a prefilter system to provide additional protection for the RO membranes, and the RO membrane skid. Similar to the UF process, individual treatment trains would be staged on and off to meet the target treatment rate selected by the operator. The RO process is best operated at a consistent treatment rate; therefore, turndown to achieve lower treatment rates is more complex than turndown of the UF process. The desired turndown ratio must be carefully considered during the detailed design process, and the treatment rate would likely require seasonal adjustment, as well as adjustment as chloride loads increase in the future. Chemicals would be dosed to permeate from the RO system to adjust the pH, if necessary. RO permeate would then be blended with the secondary effluent prior to UV disinfection and discharge. The reject or concentrate volume from the RO process would contain the concentrated chloride and other ions removed from the secondary effluent, and is expected to constitute approximately 15% of the treated flow, or 2.25 MGD at the design flow rate. The concentrate would be transferred to one of two recovery RO tanks, each with a minimum capacity of 47,000 gallons, for further concentration.

The recovery RO (RRO) feed tanks would provide a minimum of 30 minutes of detention at the design flow rate. The RRO system would function in a similar manner to the primary RO system, and would be operated to further concentrate and reduce the volume of reject from the primary RO process. It is assumed that the RRO process will consist of 6 RRO treatment trains (5 duty and standby). Each RRO would be operated in conjunction with its associated primary RO treatment train. Each train would include a RRO feed pump, prefilter system, and RRO membrane skid. Permeate from the RRO system would be combined with the main RO permeate prior to pH adjustment and blending with the secondary effluent for UV disinfection and discharge. The RRO is expected to achieve approximately 33% recovery of permeate under cold weather conditions and 50% recovery under warm weather conditions. Through operation of the RRO process, the overall recovery of permeate would be increased to 90% and 92.5% during cold and warm weather, respectively. It is assumed that the system would be operated at a higher flow rate during winter months due to higher chloride loads; therefore a conservative assumption of 90% overall recovery was assumed for comparison of alternatives and cost projections. Therefore, the estimated total volume of reject or concentrate from the primary and recovery RO processes is estimated to comprise 10% of the treated flow rate, or 1.5 MGD at design capacity. The concentrate stream would be transferred to two primary brine waste holding tanks for storage prior to transportation to disposal or further concentration. These tanks would each have a capacity of 2.25 million gallons to provide 36 hours of detention at the design flow rate.

The UF pretreatment system, primary RO and RRO would each include clean-in-place (CIP) systems which would be operated periodically to provide chemical cleaning of the membranes to restore membrane flux rates and treatment capacity when the membranes become fouled. Chemicals used in the CIP process typically include sodium hypochlorite, citric acid and sodium hydroxide. A specific CIP system will be dedicated to the UF, RO and RRO processes. Each CIP system will include sufficient redundancy to maintain the effectiveness of the overall treatment process.

An equipment list for the proposed RO treatment system is provided in **Appendix A**. A conceptual process flow diagram and mass balance is provided in **Appendix B**.

6.2.3.2 RO Process Materials of Construction

Materials of construction for the membrane skids are assumed to include epoxy coated steel frames fitted with a combination of PVC and stainless steel piping. Membrane cartridges and other pressure vessels are typically constructed of fiberglass reinforced plastic (FRP). CIP vessels will be of stainless steel construction. Chemicals would be contained in bulk storage tanks constructed of appropriate materials for compatibility with each specific chemical.

Brine waste is expected to be highly corrosive, due to the high concentration of dissolved solids (TDS). Brine waste holding tanks would be constructed of specific epoxy coated steel, and pumps and piping materials would be constructed of corrosion-resistant materials.

6.2.3.3 RO Process Space Requirements

The membrane system feed tanks, membrane systems, and ancillary equipment would be housed within a building with a footprint of approximately 290 feet by 350 feet. The brine waste holding tanks would be located outside of the RO treatment building and are assumed to have approximate dimensions of 115 feet in diameter by 32 feet high. The tanks would be covered to prevent the accumulation of precipitation within the tanks. The expected overall foot print for the tanks is 270 feet by 125 feet.

A conceptual layout for the RO process equipment is provided in **Appendix C**.

6.2.3.4 RO Process Removal of Other Wastewater Constituents

In addition to providing effective removal of chloride, the RO process would remove other dissolved constituents from the NSWTP secondary effluent. UF pretreatment upstream of the RO process would also provide nearly complete removal of particulate constituents. It is expected that significant removal of the following constituents would be achieved for the portion of secondary effluent that is treated by the RO process:

- Total and soluble phosphorus
- Total and soluble nitrogen (TKN, ammonia and oxidized nitrogen)
- Organic chemicals, including endocrine disrupting chemicals, pharmaceuticals and personal care products
- Mercury

Daily mass quantities of phosphorus and total nitrogen that would be projected to be removed by the RO and associated processes were estimated and summarized on a monthly basis for three scenarios:

- The current wastewater loads with the chloride removal system operating at an annual average flow of 2.6 MGD
- Future wastewater loads with the chloride removal system operating at an annual average flow of 7.3 MGD
- Future load with the system operating at its design capacity of 15 MGD.

The mass removal quantities and projected effluent concentrations are provided in **Tables 6-5** and **6-6** for phosphorus and total nitrogen, respectively.

Table 6-5:
Projected Mass Removals of Total Phosphorus by RO Process

Month	Total Phosphorus at Current Annual Average Chloride Treatment Rate of 2.6 MGD		Total Phosphorus at Future Annual Average Chloride Treatment Rate of 7.3 MGD		Total Phosphorus at Maximum Chloride Treatment Rate of 15 MGD	
	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*
January	305	0.27	609	0.24	1,125	0.20
February	296	0.27	585	0.24	1,025	0.20
March	167	0.28	459	0.26	1,125	0.20
April	61	0.29	303	0.27	1,089	0.21
May	49	0.30	295	0.28	1,125	0.21
June	69	0.29	286	0.27	1,089	0.21
July	75	0.29	302	0.27	1,125	0.21
August	96	0.29	377	0.27	1,125	0.20
September	110	0.29	367	0.27	1,089	0.20
October	50	0.29	276	0.27	1,125	0.20
November	57	0.29	267	0.27	1,089	0.20
December	213	0.28	502	0.25	1,125	0.19

*average total phosphorus effluent concentration, after combining effluent treated for chloride removal and effluent that bypasses the chloride treatment system; annual average total phosphorus concentration without chloride treatment projected to be 0.30 mg/L

Table 6-6:
Projected Mass Removals of Total Nitrogen by RO Process

Month	Total Nitrogen at Current Annual Average Chloride Treatment Rate of 2.6 MGD		Total Nitrogen at Future Annual Average Chloride Treatment Rate of 7.3 MGD		Total Nitrogen at Maximum Chloride Treatment Rate of 15 MGD	
	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*
January	15,907	17.38	31,733	16.06	58,594	13.55
February	15,410	17.32	30,450	16.01	53,397	13.76
March	8,721	18.16	23,878	16.94	58,594	14.05
April	3,159	18.69	15,775	17.66	56,704	14.34
May	2,539	18.76	15,338	17.73	58,594	14.23
June	3,579	18.62	14,881	17.64	56,704	14.13
July	3,888	18.61	15,744	17.61	58,594	14.09
August	5,001	18.50	19,606	17.24	58,594	13.75
September	5,733	18.40	19,100	17.19	56,704	13.65
October	2,597	18.74	14,368	17.70	58,594	13.74
November	2,942	18.68	13,894	17.66	56,704	13.62
December	11,112	17.86	26,151	16.56	58,594	13.48

*average total nitrogen effluent concentration, after combining effluent treated for chloride removal and effluent that bypasses the chloride treatment system; annual average total nitrogen concentration without chloride treatment projected to be 19.0 mg/L

6.2.3.5 RO Process Considerations

Relatively high pressure is required to drive secondary effluent through the RO membranes, and significant energy is required to power the RO feed pumps. Membranes are susceptible to membrane fouling without sufficient pretreatment. Membrane system suppliers estimate that the UF membranes may require replacement every 7 years of operation and the RO and RRO membranes may require replacement every 3 years.

There are multiple manufacturers of UF and RO equipment, and the specific equipment configuration will be dependent upon the selected manufacturer, desired turndown ratio, and other site requirements.

6.2.4 Electrodialysis Reversal

Electrodialysis reversal (EDR) is less susceptible to fouling by the presence of low concentrations of suspended solids present in the NSWTP secondary effluent. Therefore, it was assumed that pretreatment for removal of suspended solids would not be required upstream of the EDR process.

6.2.4.1 EDR Process Description

Seven new pumps (6 duty and 1 standby) would transfer secondary effluent to two EDR feed tanks. The effluent transfer pumps would be equipped with VFDs to enable flow-pacing to achieve a target treatment rate selected by the operator.

The EDR feed tanks would each have a minimum capacity of 320,000 gallons to provide a minimum of 30 minutes detention at the design flow rate. Under normal operation these tanks would perform as a single combined tank. When maintenance or cleaning is required, one tank could be taken out of service and the full wastewater flow could be directed through the remaining tank.

The EDR process utilizes electrically charged plates to induce the transfer of ions (including chloride) through a membrane for separation from the treated water. The EDR system would consist of 12 EDR treatment trains (10 duty and 2 standby). Each train would include an EDR feed pump for transfer of wastewater from the EDR feed tank to the EDR process, a prefilter system for removal of any large solids and protection of the EDR membranes, and the EDR membrane system. The operation of individual treatment trains would be staged on and off to control the treatment flow rate as selected by the operator. Each of the 12 EDR systems would include 8 treatment lines, each consisting of 3 stages or passes. This equates to 24 stages per treatment train, and 288 total stages for the system. Chemicals would be automatically dosed to the EDR permeate, if necessary, prior to blending with the remaining untreated portion of the secondary effluent and transfer to UV disinfection and discharge. The reject or concentrate waste stream from the EDR process is expected to constitute approximately 10% of the treated flow, or 1.5 MGD at the design flow rate. The expected recovery of permeate is similar to that expected from the RO alternative with a RRO system. Concentrate waste produced by the EDR system, containing concentrated ions removed from the NSWTP secondary effluent, would be transferred to two brine waste holding tanks for storage prior to transportation and disposal or further concentration. Each tank would have a capacity of 2.25 MG to provide 36 hours of detention at the design flow rate.

The EDR system would include a minimum of two CIP systems to provide periodic cleaning of membranes when needed to restore treatment capacity. Each CIP system would utilize totes for storage of CIP chemicals, chemical feed pumps and a tank for mixing, heating and recirculation of the CIP solution through the membranes. Each CIP system would be dedicated to multiple EDR trains.

An equipment list for the proposed EDR treatment system is provided in **Appendix A**. A conceptual process flow diagram and mass balance is provided in **Appendix B**.

6.2.4.2 EDR Process Materials of Construction

The EDR process skids will be constructed of epoxy coated steel frames fitted with a combination of PVC and stainless steel piping. CIP vessels will be of stainless steel construction. Chemicals will be contained in bulk storage tanks constructed of appropriate materials for compatibility with each specific chemical.

Brine waste is expected to be highly corrosive, due to the high concentration of dissolved solids (TDS). The brine waste holding tanks will be constructed of specific epoxy coated steel, and pumps and piping materials will be constructed of corrosion-resistant materials.

6.2.4.3 EDR Process Space Requirements

The EDR feed tanks, treatment equipment and ancillary processes would be housed within a building with approximate dimensions of 190 feet by 370 feet. The primary brine waste holding tanks would be located outside of the EDR treatment building. Each tank would have approximate dimensions of 115 feet in diameter by 32 feet high. The tanks would be covered to prevent the accumulation of precipitation within the tanks. The expected overall foot print for both tanks is estimated to be 270 feet by 125 feet.

A conceptual layout of the EDR treatment system is provided in **Appendix C**.

6.2.4.4 EDR Process Removal of Other Wastewater Constituents

Similar to the RO process, the EDR process would remove dissolved and particulate constituents from the NSWTP secondary effluent, in addition to chloride. It is expected that significant removal of the following constituents would be achieved for the portion of secondary effluent that is treated by the EDR process:

- Total and soluble phosphorus
- Total and soluble nitrogen (TKN, ammonia and oxidized nitrogen)
- Organic chemicals that have a sufficient ionic charge to be impacted by the EDR process
- Mercury

Daily mass quantities of phosphorus and total nitrogen that would be projected to be removed by the EDR process were estimated and summarized on a monthly basis for three scenarios: the current wastewater loads with the chloride removal system operating at an annual average flow of 2.6 MGD; future wastewater loads with the chloride removal system operating at an annual average flow of 7.3 MGD; and future load with the system operating at its design capacity of 15 MGD. The mass removal quantities and projected effluent concentrations are provided in **Tables 6-7 and 6-8** for phosphorus and total nitrogen, respectively.

Table 6-7:
Projected Mass Removals of Total Phosphorus by EDR Process

Month	Total Phosphorus at Current Annual Average Chloride Treatment Rate of 2.6 MGD		Total Phosphorus at Future Annual Average Chloride Treatment Rate of 7.3 MGD		Total Phosphorus at Maximum Chloride Treatment Rate of 15 MGD	
	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*
January	274	0.27	546	0.25	1,009	0.21
February	265	0.27	524	0.25	919	0.21
March	150	0.29	411	0.26	1,009	0.21
April	54	0.29	272	0.28	976	0.22
May	44	0.30	264	0.28	1,009	0.22
June	62	0.29	256	0.28	976	0.22
July	67	0.29	271	0.28	1,009	0.22
August	86	0.29	338	0.27	1,009	0.21
September	99	0.29	329	0.27	976	0.21
October	45	0.30	247	0.28	1,009	0.21
November	51	0.29	239	0.28	976	0.21
December	191	0.28	450	0.26	1,009	0.20

*average total phosphorus effluent concentration, after combining effluent treated for chloride removal and effluent that bypasses the chloride treatment system; annual average total phosphorus concentration without chloride treatment projected to be 0.30 mg/L

Table 6-8:
Projected Mass Removals of Total Nitrogen by EDR Process

Month	Total Nitrogen at Current Annual Average Chloride Treatment Rate of 2.6 MGD		Total Nitrogen at Future Annual Average Chloride Treatment Rate of 7.3 MGD		Total Nitrogen at Maximum Chloride Treatment Rate of 15 MGD	
	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*	Pounds per Month Removed	Average Effluent Conc. (mg/L)*
January	17,908	17.17	35,726	15.69	65,967	12.86
February	17,349	17.11	34,282	15.63	60,115	13.10
March	9,818	18.06	26,883	16.68	65,967	13.43
April	3,557	18.65	17,759	17.49	63,839	13.75
May	2,858	18.72	17,268	17.57	65,967	13.63
June	4,029	18.57	16,754	17.47	63,839	13.51
July	4,377	18.56	17,725	17.44	65,967	13.47
August	5,631	18.43	22,073	17.02	65,967	13.09
September	6,454	18.32	21,503	16.96	63,839	12.98
October	2,924	18.71	16,175	17.53	65,967	13.08
November	3,313	18.64	15,642	17.49	63,839	12.94
December	12,510	17.72	29,441	16.25	65,967	12.79

*average total nitrogen effluent concentration, after combining effluent treated for chloride removal and effluent that bypasses the chloride treatment system; annual average total nitrogen concentration without chloride treatment projected to be 19.0 mg/L

6.2.4.5 EDR Process Considerations

The EDR system is expected to require less energy than an RO system, since it operates at a lower pressure compared to the RO process. The EDR treatment system may be less complex in comparison to the RO process, due to reduced pretreatment requirements for removal of suspended solids. EDR membranes are not as susceptible to membrane fouling because the waste stream is not filtered through the membrane, and only ions pass through the membranes as a result of the electric charge induced within the EDR system. It is estimated by the EDR manufacturer that membranes may require replacement every 10 years.

There are fewer EDR systems in operation compared to RO systems. The City of San Diego, California, operates an EDR system for removal of TDS from reclaimed wastewater. The performance of the EDR system was reviewed with Albert Sohikish, an engineer with the City of San Diego. Mr. Sohikish reported that San Diego has had a good experience with its EDR system. A summary of AECOM's conversation with Mr. Sohikish is included in **Appendix F**.

EDR technology is currently available from only a single manufacturer, GE Water & Process Technologies.

6.2.5 Brine Minimization Alternatives

A significant disadvantage of RO and EDR treatment processes is the large potential volume of concentrate or brine waste generated as a result of treatment. It is not practical to reuse or transport the expected volume of brine waste for off-site disposal without further concentration. Multiple processes can be used to reduce the volume of brine for transportation and disposal, or potential reuse. Two common alternatives evaluated for brine volume reduction are evaporation and crystallization. Evaporation can be used to concentrate the brine waste by approximately a factor of 10, reducing the brine waste volume to 0.15 MGD at the design flow rate. A crystallizer can then be used to reduce the brine waste from the evaporator to a solid form.

6.2.5.1 Evaporator Process Description

Concentrated brine waste would be produced from the UF/RO or EDR processes at a rate of approximately 1,500,000 gpd at the design flow rate. An evaporation process can be used to reduce the volume of brine that must be handled by approximately 90%.

Due to the presence of calcium, magnesium and other constituents at relatively high concentrations in the brine waste, potential exists for precipitation of these minerals within the evaporation equipment. Significant precipitation and scale-formation can limit the process efficiency, leading to frequent downtime for cleaning. To achieve effective evaporation and reliable operation, the concentration of scale-forming minerals in the brine waste must be reduced. Lime softening is a common technology used for precipitation of scale-forming minerals, including calcium and magnesium.

Two cold lime softening systems, each sized to process 0.75 MGD, would be provided to remove scale-forming minerals from the brine waste prior to evaporation. The lime softening systems were sized without major process equipment redundancy; however, three days of upstream storage would be provided by the primary brine waste storage tanks, at design flow, allowing evaporator down time for cleaning and maintenance activities. Brine from the primary brine waste storage tanks would be transferred to the cold lime softening system by two transfer pumps. Lime and/or soda ash would be dosed upstream of two solids contact clarifiers to precipitate calcium carbonate and magnesium hydroxide. Lime and soda ash would be stored in silos from which the chemicals would be made-down in local mix-tanks for dosing into the process. It is likely that recarbonation and pH adjustment of the effluent from the lime softening process would be required. Recarbonation and pH adjustment can be achieved utilizing carbon dioxide (CO_2). Sulfuric acid can also be used to reduce the pH of the softened brine waste.

Precipitated solids would be pumped from the solids contact clarifiers and discharged to a lime sludge holding tank. Lime sludge would be pumped from the holding tank to a belt filter press for dewatering. Dewatered lime sludge would need to be disposed off-site. It may be possible to combine lime sludge from the holding tank with the NSWTP biological solids for processing.

The softened brine waste would be pumped to two evaporator systems, each sized for a capacity of 750,000 gpd. Due to the relatively high cost and space requirement for this equipment, it was assumed that equipment redundancy would not be provided to meet the anticipated brine production rate of 1.5 MGD. Upstream storage provided by the primary brine waste storage tanks would allow brine to be stored for up to three days to facilitate evaporator equipment cleaning and maintenance. One evaporator feed pump would be dedicated to each evaporator.

Water evaporated from the brine waste would be condensed, cooled to a moderate temperature (approximately 108°F), and combined with the permeate stream of the chloride removal treatment system. The pH of the condensate would be adjusted, if necessary, along with membrane process permeate, and then blended with the remaining secondary effluent prior to UV disinfection and discharge. The concentrate produced by the evaporator process is expected to comprise 10% of the influent brine flow, or approximately 150,000 gpd at the design flow rate. Concentrate would be transferred to two secondary brine waste holding tanks for transportation and off-site disposal or further concentration. The secondary brine waste holding tanks would each have a capacity of 225,000 gallons to provide 36 hours of detention at the design flowrate.

An equipment list for the evaporation process is provided in **Appendix A**. A conceptual process flow diagram and mass balance is provided in **Appendix B**.

6.2.5.2 Evaporator Process Materials of Construction

The corrosive characteristics of the high TDS brine waste are further magnified by the high temperatures maintained within the evaporation process. Corrosion-resistant materials of construction, including specialty steels or other metals, are required for surfaces that contact the high-temperature brine. These materials, including titanium grade 12 tubes, Hastelloy tube sheets and product contact areas, duplex stainless steel shells, and duplex and super duplex stainless steel fan components, contribute significantly to the capital cost of equipment. The secondary brine waste tanks would be constructed of 304 stainless steel.

6.2.5.3 Evaporator Process Space Requirements

The evaporator process and ancillary equipment would be housed within a building with approximate dimensions of 80 feet by 260 feet. Due to the height of the evaporators (approximately 85 feet), it is expected that the upper portions of the evaporators would be designed to extend above the roof of the evaporator building and would require insulation of the exposed areas. Much of the mechanical components associated with the evaporators are located near the bottom of the systems and would be protected from the elements within the building

The secondary brine waste holding tanks would be located outside of the evaporator treatment building. Each tank would have approximate dimensions of 36 feet in diameter by 32 feet high. The expected overall foot print for secondary brine waste holding tanks is 50 feet by 90 feet. A conceptual layout of the evaporator process is provided in **Appendix C**.

6.2.5.4 Evaporator Process Attributes

The evaporation process is expected to concentrate and reduce the volume of brine produced by the membrane systems by a factor of 10. Although evaporator equipment design advances make use of heat recovery and other energy-saving features, the process requires significant amounts of heat (steam) and electrical energy. It is expected that the majority of ions removed by the membrane processes would be further concentrated by the evaporation process. Condensate produced by the process would be expected to contain only minimum concentrations of these constituents, and could be blended with the secondary effluent to further reduce chloride concentrations.

Due to the high temperature operation of the evaporator process, condensate and cooling tower blowdown are expected to increase the temperature of the NSWTP by a small amount.

6.2.5.5 Crystallizer Process Description

Concentrated brine waste will be produced from the evaporator process at a rate of approximately 150,000 gpd at the design flow rate. A crystallization process can be used to further reduce the volume of brine that must be handled, resulting in production of a solid material.

Two pumps (one duty and one standby) would be used to transfer concentrated brine from the secondary brine waste holding tanks waste to a single crystallization system. No redundancy in equipment, other than the feed pumps, was included for the conceptual design. Brine can be temporarily stored in the secondary brine waste storage tanks for short-term cleaning and maintenance activities. The crystallization system would be sized to process 150,000 gpd of concentrated brine waste to meet the anticipated design flow condition.

The proposed crystallization system would include a single effect, three stage, multiple vapor recompression system with heated forced circulation. Similar to the evaporation process, water evaporated from the crystallization process would be condensed, cooled to a moderate temperature (assumed to be 108°F) and combined with permeate from the chloride removal treatment system. The pH of the combined condensate and permeate would be adjusted, if necessary, and then blended with the secondary effluent prior to UV disinfection and discharge. The volume of condensate produced by the crystallization process is expected to be approximately 109,000 gpd (37,500 PPH * 0.1209 gal/lb * 24 hrs/day) at the design concentrated brine flow rate of 150,000 gpd.

Crystallized brine waste is anticipated to be generated at a rate of 102 tons/day (8,500 PPH * 24 hrs/day * 1 ton / 2,000 lbs) at the design flow condition. The crystallized brine is expected to have a moisture content of approximately 15%, and will be discharged to roll-off dumpsters or trucks for hauling off-site for disposal or reuse. For the purposes of this evaluation it was assumed that the crystallized brine waste would be disposed in a landfill. If testing of the end product deems it acceptable, some beneficial reuse opportunities may exist which could offset the disposal costs.

An equipment list for the crystallization process is provided in **Appendix A**. A conceptual process flow diagram and mass balance is provided in **Appendix B**.

6.2.5.6 Crystallizer Process Materials of Construction

The significant corrosion characteristics of the high TDS brine waste are further magnified by the high temperatures within the crystallization process. Similar to the evaporator system, exotic materials of construction are required which significantly increase the capital costs of the equipment. These materials include titanium grade 12 tubes, Hastelloy tube sheets and product contact areas, duplex stainless steel shells, and duplex and super duplex stainless steel fan components.

6.2.5.7 Crystallizer Process Space Requirements

The crystallizer equipment and ancillary processes would be housed within a building with approximate dimensions of 55 feet by 90 feet. Due to the height of the crystallizer system, it is expected that the top portion of the equipment would extend above the roof of the crystallizer building and would require insulation. Most of the mechanical components associated with the crystallizer are located near the bottom of the system and would be protected from the elements within the building.

6.2.5.8 Crystallizer Process Attributes

The crystallization process can reduce the volume of concentrated brine waste to produce a solid material, significantly reducing handling and disposal requirements. However, the crystallizer requires large quantities of heat (steam) and electrical energy. A small quantity of high-quality condensate would be produced, which could be blended with secondary effluent to reduce chloride concentrations. Similar to the evaporator process, the elevated temperature of condensate produced by the crystallizer, as well as cooling tower blowdown, will result in an increase in the NSWTP effluent temperature.

6.2.6 Brine Handling Alternatives

Handling of the waste brine produced by removal of chloride from the NSWTP secondary effluent poses a significant challenge due to relative high volumes. Disposal options vary depending on the volume and characteristics of the final brine product. For this evaluation, it was assumed that liquid brine waste produced by the membrane processes or the evaporation process would be disposed via deep well injection. Landfill disposal was evaluated for crystallized brine waste. Potential may also exist for reuse of the concentrated or crystallized brine for road de-icing. **Table 6-9** summarizes the expected volume of waste generated by each alternative and associated trucking requirements for the varying levels of brine minimization at the design flow condition.

Table 6-9:
Brine Disposal Volumes and Trucking Requirements

Alternative	Brine Form	Volume produced at design flow	Assumed volume per haul	Total hauls per day
UF/RO or EDR	Liquid	1,500,000 gpd	5,000 gallons	300
UF/RO or EDR + Evaporation	Liquid	150,000 gpd	5,000 gallons	30
UF/RO or EDR + Evaporation + Crystallization	Solid	75.6 CYDS/day[1]	20 CYDS	3.7
[1]Based on 20 CYDS per dumpster and 1.35 tons per CYD				

6.2.6.1 Liquid Waste Disposal – Deep Well Injection

Deep well injection is not permitted within the State of Wisconsin. Therefore, waste would need to be hauled out of state to a permitted deep well injection site. A waste disposal company was contacted to determine requirements and fees for deep well injection at a disposal site in Vickery, Ohio. The disposal capacity of this site would be limited to 50,000 gpd of brine waste, but it was assumed that disposal costs would be representative. It may be possible to contract with a waste disposal company to permit, develop and operate a deep well injection system at a closer location for disposal of the liquid brine waste under a long-term contracting scenario.

The potential for up to 300 tanker trucks arriving and departing from the NSWTP per day for removal of 1,500,000 gallons of brine from the UF/RO or EDR process would have a significant impact on the plant and the surrounding community. It is expected that hauling and disposal of brine waste directly from the UF/RO or EDR system does not appear to be a viable alternative due to the high volumes of brine that would be produced. Hauling and disposal of 150,000 gpd of brine waste produced by the evaporation process would require approximately 30 tanker truck loads per day, and would also have a significant impact on the plant and community. These alternatives may require multiple deep well injection sites due to the significant brine volumes which would be disposed.

6.2.6.2 Solid Waste Disposal - Landfill

It was assumed that the crystallized brine waste could be disposed in a solid waste landfill. The Madison Prairie Landfill, operated by Waste Management, was contacted to review the feasibility and requirements for disposal of the crystallized brine waste.

The crystallized brine waste results in the minimum waste volume which can be achieved for this waste stream. Approximately 102 tons per day of solid material with 15% moisture content would be produced at the design flow condition, or approximately 75.6 cubic yards per day at an assumed density of 1.35 tons per cubic yard. Madison Prairie Landfill can provide 30 cubic yard containers for solid waste hauling. If each container is filled with approximately 20 cubic yards of waste, less than 4 loads would be removed from the site per day.

6.2.6.3 Beneficial Reuse

There is potential that the concentrated brine or crystallized brine waste could be utilized for beneficial reuse, such as for road de-icing. However, the final characteristics and presence of constituents which are concentrated within the waste stream would need to be evaluated for individual reuse opportunities. Beneficial reuse of a portion or all of the brine waste could reduce the cost of disposal. Transportation costs may also be borne by the end user of the product. Storage of the brine waste would need to be provided, and significant storage may be required for seasonal reuse options. Due to the volume and properties of the crystallized brine waste, storage requirements would be reduced in comparison with storage of liquid brine.

6.3 Alternatives Summary

For purposes of developing cost projections, as well as the TBL analysis, the source water softening, chloride removal, brine minimization and brine disposal options were grouped into eight alternatives as summarized in **Table 6-10**.

Table 6-10:
Summary of Chloride Compliance Alternatives

Alternative		Description
1A	Source water softening – wellhead treatment for hardness (22 wells)	Treatment for removal of hardness at water supply source (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at individual wells. It was assumed that 22 individual treatment systems each capable of softening a 3.0 MGD raw water supply would be required.
1B	Source water softening – centralized treatment for hardness (50 MGD firm capacity	Treatment for removal of hardness from water supply at a centralized location (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at a single centralized treatment site. It was assumed that the centralized system would be capable of producing 50 MGD of softened water. Infrastructure improvements to direct water from supply wells to the treatment facility and from the treatment facility to the distribution system are assumed to include 135 miles of watermain at a cost of $1,000,000 per mile.
2A	Treatment at NSWTP using RO	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
2B	Treatment at NSWTP using RO with brine minimization using evaporation	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal, followed by evaporation of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
2C	Treatment at NSWTP using RO with brine minimization using evaporation and crystallization	Treatment of up to 15 MGD of NSWTP effluent using reverse osmosis technology for chloride removal, followed by evaporation and crystallization of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.

Alternative		Description
3A	Treatment at NSWTP using EDR	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
3B	Treatment at NSWTP using EDR with brine minimization using evaporation	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal, followed by evaporation of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.
3C	Treatment at NSWTP using EDR with brine minimization using evaporation and crystallization	Treatment of up to 15 MGD of NSWTP effluent using electrodialysis reversal technology for chloride removal, followed by evaporation and crystallization of brine to reduce volume for disposal. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. Annual average treatment rate assumed to be 7.3 MGD for the future year 2030 design condition.

7.0 Projected Capital, Operating and Maintenance Costs

Projected capital, and annual operating and maintenance costs were developed at a conceptual level for the treatment alternatives described in Section 6. The estimated costs are consistent with a Class 4 estimate as defined by the Association for the Advancement of Cost Engineering International (AACE) criteria, which is defined as a Planning Level or Design Technical Feasibility Estimate. Class 4 estimates are used to prepare planning level cost scopes or to evaluate alternatives in design conditions and form the base work for the Class 3 Project Budget or Funding Estimate. Expected accuracy for Class 4 estimates typically ranges from -30% to +50%, depending on the technological complexity of the project, appropriate reference information, and the inclusion of an appropriate contingency determination. In unusual circumstances, ranges could exceed +50/-30%.

It was assumed that most tanks and equipment would be installed above grade for accessibility and to avoid potential constructability issues associated with dewatering and soil conditions. However, consideration could be given to below-grade construction of some treatment and storage tanks during subsequent design phases when a final treatment site location is selected and additional details regarding site conditions are available.

Major process equipment (with the exception of the brine storage tanks) would be installed inside buildings due to concerns over potential freezing and maintenance challenges during cold temperatures. Buildings were assumed to be of brick and block construction, similar to other process buildings at the NSWTP site. Process tanks within the process buildings would be constructed of cast-in-place concrete with common wall construction. An exception to this approach is the NF/RO feed tanks for the individual well softening option. Due to their smaller anticipated capacity (24,000 gallons) these tanks were assumed to be constructed of fiberglass reinforced plastic (FRP). Smaller tanks for chemical storage would be polypropylene or FRP, unless the chemical being stored warrants a different material for improved compatibility. Primary brine waste tanks located outside of building would be constructed of epoxy coated steel, and the secondary brine waste tanks would be constructed of stainless steel.

For the 22 well sites within the Madison Water Utility system, approximately 35% are estimated to have sufficient space to construct a softening system. It is assumed the remaining 65% of the well sites would require procurement of additional real estate to allow for construction of a softening system. It was assumed that property would also need to be acquired for the new centralized softening facility.

It is expected that the NSWTP has sufficient land space available for construction of the chloride removal alternatives. The available space consists of an area east of the Effluent Building as well as an area north of the Metrogro tanks and west of the Biosolids End Use Building.

The ideal location for the chloride reduction equipment would be east of the Effluent Building due to its proximity to the secondary effluent stream. However, the approximate footprint as illustrated in the conceptual layout drawings (**Figures C-2** and **C-3** in **Appendix C**) indicates that the equipment may not fit in this area. If possible, it is recommended that the UF/RO or EDR membrane systems be located in east of the Effluent Building. Residuals minimization equipment could be constructed at another location, if necessary.

7.1 Projected Capital Costs

An estimate of probable capital cost was developed for each chloride compliance alternative. Budgetary quotes were solicited from equipment manufacturers and tank fabricators for major equipment. Other costs were estimated based on recent construction experience and published cost data, or were factored based on equipment costs.

Projected capital costs for the wastewater treatment alternatives described above are summarized in **Table 7-1**. Note that cost for any required land acquisition associated with each treatment alternative is not included in the capital costs.

Table 7-1:
Conceptual Chloride Compliance Capital Cost Projections

Chloride Compliance Alternative		Projected Capital Cost
Source Water Softening		
1A	Wellhead softening (22 well sites)	$91,512,000
1B	Centralized softening (50 MGD firm capacity)	$75,300,000
	Allowance for distribution system upgrades (135 miles at $1,000,000 per mile)	$135,000,000
	Subtotal, centralized softening	$210,300,000
UF/RO Treatment at NSWTP		
2A	UF/RO with recovery RO	$86,833,000
2B	UF/RO with recovery RO and evaporator	$170,731,000
2C	UF/RO with recovery RO, evaporator and crystallizer	$193,483,000
EDR Treatment at NSWTP		
3A	EDR	$80,824,000
3B	EDR with evaporator	$164,722,000
3C	EDR with evaporator and crystallizer	$187,474,000

Details of the capital cost projections are provided in **Appendix D**. Manufacturer information, including budgetary equipment cost estimates, is provided in **Appendix F**.

The District requested that a rough projection be made of the capital cost for treatment of all of the effluent from the NSWTP. It should be noted that removal of chloride from all of the NSWTP effluent would result in an effluent that would contain a very low concentration of dissolved solids, which could be detrimental for discharge to the receiving streams. The cost and challenges associated with management and disposal of the waste stream produced by the chloride treatment system would also be significantly increased, as the volume of brine produced by the chloride treatment system would be approximately 5 MGD at a chloride treatment rate of 50 MGD. Therefore, the treatment system would need to include equipment for reducing the volume of waste brine prior to off-site disposal or beneficial use. Capital costs for treatment of all of the NSWTP effluent were projected by factoring the conceptual capital costs for the 15 MGD chloride treatment systems. The capital cost for a chloride system sized for a capacity of 50 MGD is projected to range from $500,000,000 to $600,000,000 for chloride treatment with facilities to minimize the volume of brine that would require disposal.

7.2 Projected Annual Operation and Maintenance Costs

A projection of annual costs for operation and maintenance was developed for each chloride compliance alternative, including estimated costs for chemicals, power, liquid/solids disposal, consumables, labor and maintenance. Chemical costs were determined based on conceptual estimates of required chemical quantities and budgetary chemical prices. Power costs were estimated based on motor loads, estimated operating durations, and a unit cost for electricity of $0.09 per kW-hour. The costs for liquids and solids disposal were determined for off-site deep well injection or landfill disposal, assuming nonhazardous characteristics. Labor was estimated based on estimated labor hours for each treatment alternative, and an average labor rate of $47.38 per hour provided by District staff. Maintenance costs were estimated based on a percentage of mechanical and electrical equipment costs of 5% per year.

For chloride treatment alternatives at the NSWTP, annual operation and maintenance costs would be impacted by the volume of flow treated by the chloride removal and ancillary processes prior to blending to achieve the target chloride limit. The volume needed for treatment is expected to vary seasonally, and the full design capacity of the treatment system would not be required to be operated at all times. Therefore, annual operation and maintenance costs were projected for three operating scenarios:

- Current NSWTP flows and chloride concentrations
- Design condition flows and chloride concentrations
- Full design (firm) capacity of 15 MGD

Disposal costs for the brine waste represent a significant proportion of the estimated annual costs for alternatives that do not include treatment to reduce brine volumes. Transportation and disposal costs are significantly decreased for alternatives that include evaporation and crystallization. Brine disposal costs were estimated based on transportation to a deep well injection site in Vickery, Ohio. However, it is expected that a closer disposal site could be identified, or it may be possible to contract with a disposal company to permit, construct and operate a deep well disposal facility specifically for disposal for brine waste from the NSWTP. For the purposes of this evaluation, it was assumed that a suitable disposal site could be located within 250 miles of the NSWTP, and the estimated transportation costs were factored accordingly.

A summary of the annual operating cost projections is provided in **Table 7-2**. The cost summary takes into consideration the expected operating time and use of capacity with respect to chemicals, liquids and solids disposal, and power costs.

Table 7-2:
Conceptual Chloride Compliance Operation and Maintenance Cost Projections

Chloride Compliance Alternative		Projected Annual Operation and Maintenance Cost		
Source Water Softening				
1A	Wellhead softening (22 well sites)	$10,854,000		
1B	Centralized softening (50 MGD firm capacity, operating at 28.2 MGD average)	$10,094,000		
Chloride Compliance Alternative		**Current Condition 2.6 MGD Average Flow**	**Future Condition 7.3 MGD Average Flow**	**Design Capacity 15 MGD Firm**
UF/RO Treatment at NSWTP				
2A	UF/RO with recovery RO	$4,227,000	$5,596,000	$7,843,000
	Brine disposal	$46,719,000	$131,172,000	$269,532,000
	Subtotal	***$50,946,000***	***$136,768,000***	***$277,375,000***
2B	UF/RO with recovery RO and evaporator	$8,216,000	$13,155,000	$21,252,000
	Brine disposal	$4,672,000	$13,117,000	$26,953,000
	Subtotal	***$12,888,000***	***$26,272,000***	***$48,205,000***
2C	UF/RO with recovery RO, evaporator and crystallizer	$9,119,000	$14,590,000	$23,556,000
	Solid waste disposal	$325,000	$902,000	$1,839,000
	Subtotal	***$9,444,000***	***$15,492,000***	***$25,395,000***
Chloride Compliance Alternative		**Current Condition 2.6 MGD Average Flow**	**Future Condition 7.3 MGD Average Flow**	**Design Capacity 15 MGD Firm**
EDR Treatment at NSWTP				
2A	EDR	$3,593,000	$4,159,000	$5,087,000
	Brine disposal	$46,719,000	$131,172,000	$269,532,000
	Subtotal	***$50,312,000***	***$135,331,000***	***$274,619,000***
2B	EDR and evaporator	$7,582,000	$11,718,000	18,496,000
	Brine disposal	$4,672,000	$13,117,000	$26,953,000
	Subtotal	***$12,254,000***	***$24,835,000***	***$45,449,000***
2C	EDR, evaporator and crystallizer	$8,486,000	$13,152,000	$20,801,000
	Solid waste disposal	$325,000	$902,000	$1,839,000
	Subtotal	***$8,810,000***	***$14,054,000***	***$22,640,000***

Details of the annual operation and maintenance cost projections are included in **Appendix D**.

As requested by the District, rough annual operation and maintenance costs were projected for a chloride treatment facility sized for treatment of all of the effluent from the NSWTP. These operation and maintenance costs were developed by applying a rough factor to the conceptual operation and maintenance costs developed for the future design capacity of 15 MGD, and do not include costs associated with chemical addition that may be required to increase the concentration of total dissolved solids prior to discharge, to avoid adverse impacts to the receiving streams. In addition, due to the very high volume of waste brine produced by the chloride treatment facility, it would not be feasible to operate the system without equipment for reduction of the brine volume prior to off-site disposal or beneficial use. The annual operation and maintenance cost for treatment of chloride at an average flow rate of 50 MGD is roughly projected to range from $75,000.000 to $150,000,000, depending on the extent of treatment used to reduce the volume of brine and assuming that the brine would be disposed off-site.

7.3 Net Present Value

The net present value of each alternative was determined over a 20-year period, assuming a discount rate of 5% and an annual escalation in operation and maintenance cost of 3%. A summary of the net present value calculated for each alternative is provided in **Table 7-3.**

Table 7-3:
Conceptual Chloride Compliance Net Present Value Cost Projections

Chloride Compliance Alternative		Net Present Value
Source Water Softening		
1A	Wellhead softening (22 well sites)	$287,800,000
1B	Centralized softening (50 MGD firm capacity, operating at 28.2 MGD average)	$386,000,000
UF/RO Treatment at NSWTP		
2A	UF/RO with recovery RO	$2,348,800,000
2B	UF/RO with recovery RO and evaporator	$619,000,000
2C	UF/RO with recovery RO, evaporator and crystallizer	$464,400,000
EDR Treatment at NSWTP		
3A	EDR	$2,319,100,000
3B	EDR with evaporator	$589,300,000
3C	EDR with evaporator and crystallizer	$434,800,000

8.0 Triple Bottom Line Analysis of Chloride Compliance Alternatives

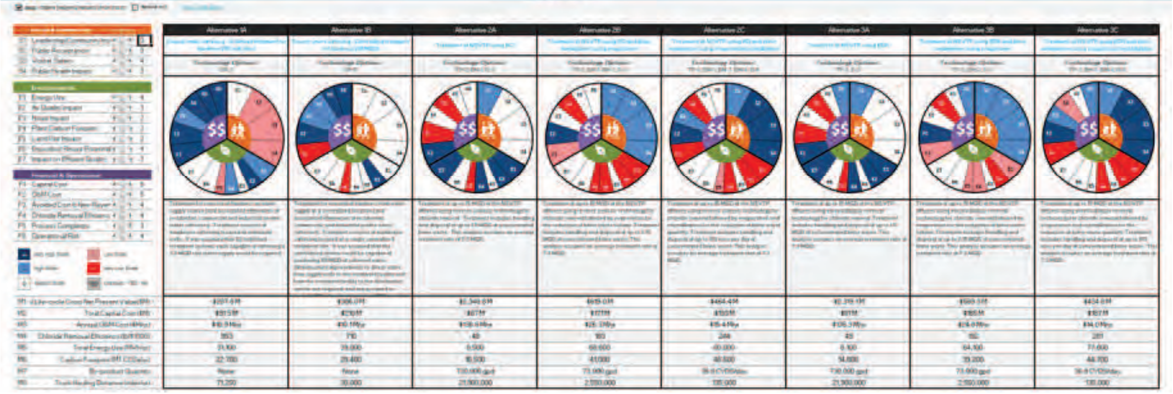
Eight chloride compliance alternatives described in Section 6 were reviewed using the TBL evaluation methodology described in Section 4 of this document. The output format includes the TBL radial chart with a circle divided into thirds representing the major categories of evaluation criteria:

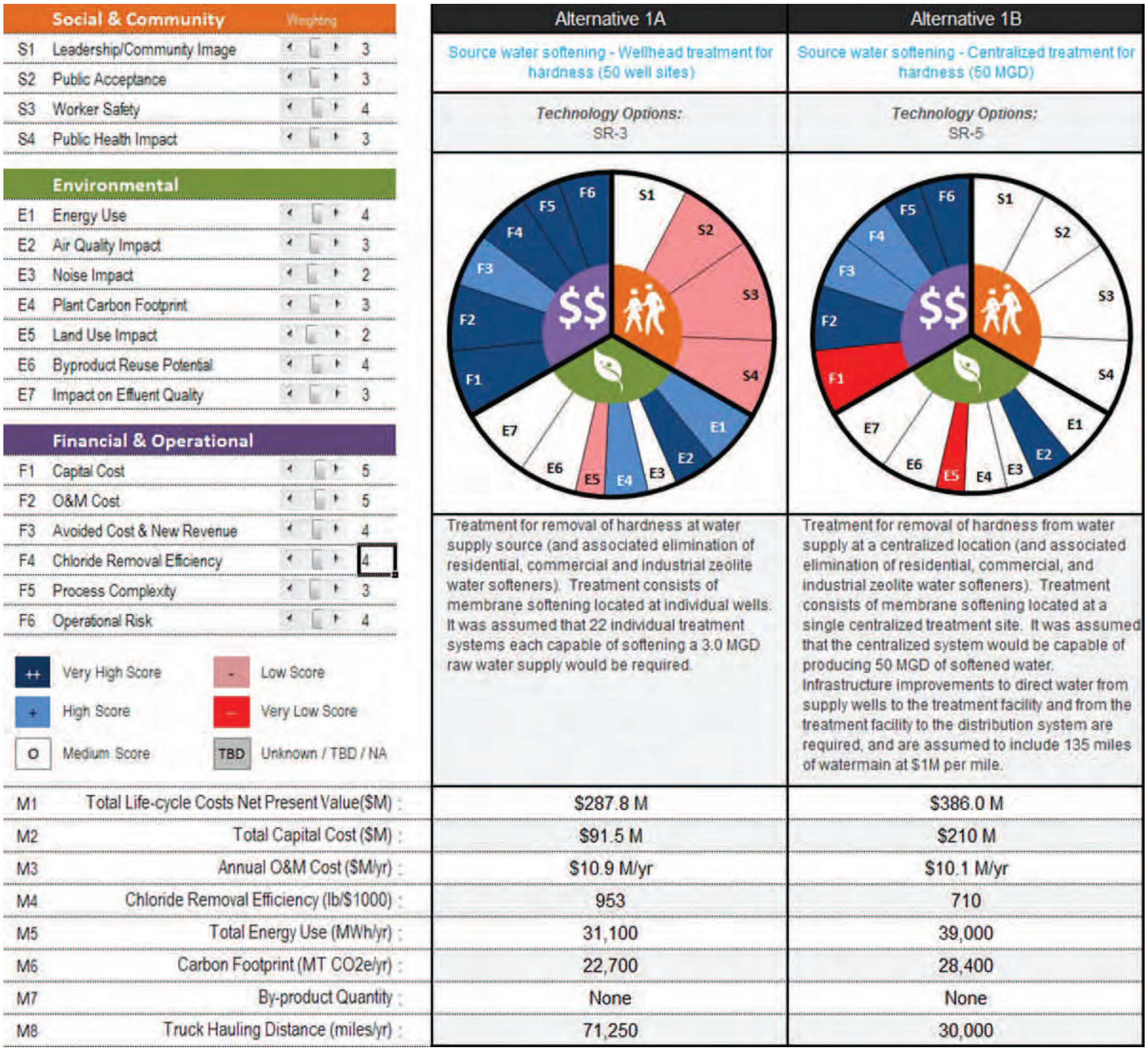
- Financial and operational
- Environmental
- Social and community

A summary of the TBL evaluation is provided in **Appendix E**. Data sheets used to provide the input for analysis of each alternative are also included in **Appendix E**. Each of the 17 criteria selected by the District is represented by a slice of the circle and is color-coded by degree of positive and negative impacts on the criteria. Furthermore, the thickness of each slice is represented by the relative weights assigned by the District, thereby visually limiting or expanding the area of the circle represented by the criterion. To complement the radial chart, a list of key performance metrics is shown below each chart. These metrics show quantified indicators such as total net present value cost, total energy use and carbon footprint, and others, that help in distinguishing alternatives from each other in additional to the visual comparison of the radial charts.

Based on the overall scores, Alternatives 1A, 1B, 2A, 3A, and 3C were determined to rank the highest among the alternatives. However, closer examination of these alternatives reveals that each of these four alternatives score differently across the financial and operational, environmental, and social and community categories, making a single recommendation based on TBL not immediately obvious. While the scores for each of the general TBL categories vary considerably for each alternative, the total scores for each alternative are relatively similar.

Comparison of 8 alternatives for the Chloride Treatment Plant





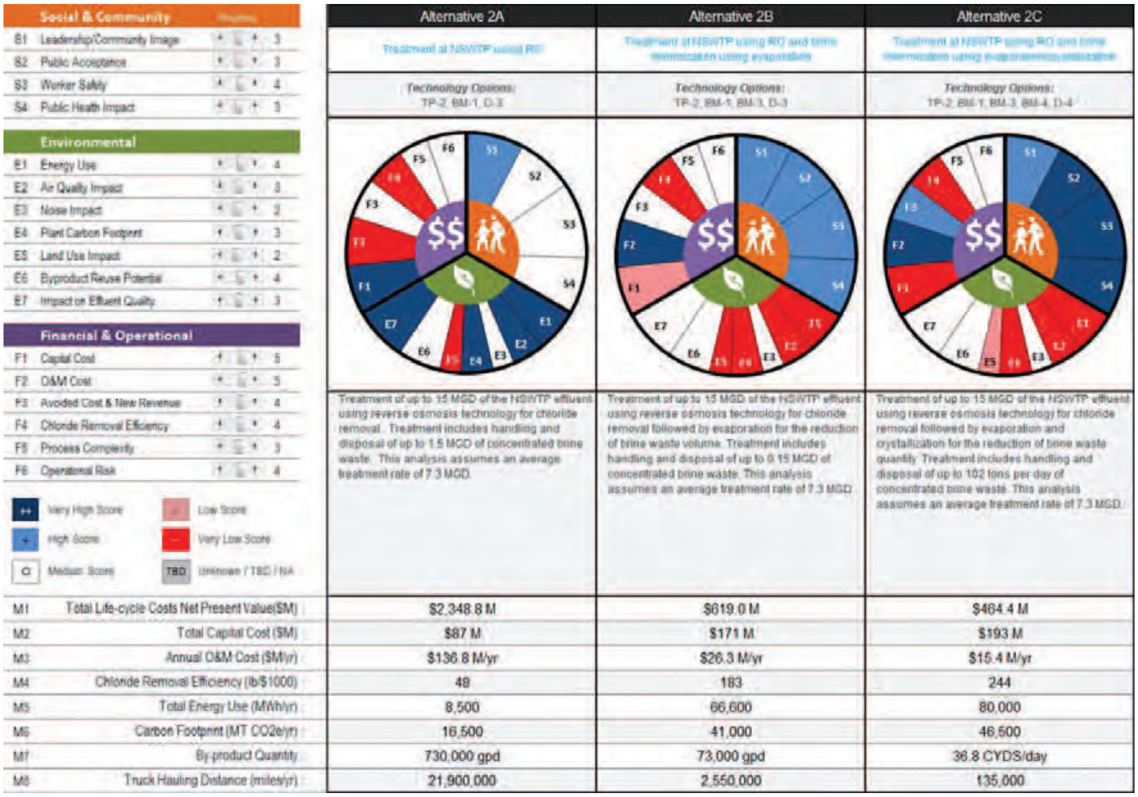
Social & Community	Weighting
S1 Leadership/Community Image	3
S2 Public Acceptance	3
S3 Worker Safety	4
S4 Public Health Impact	3

Environmental	
E1 Energy Use	4
E2 Air Quality Impact	3
E3 Noise Impact	2
E4 Plant Carbon Footprint	3
E5 Land Use Impact	2
E6 Byproduct Reuse Potential	4
E7 Impact on Effluent Quality	3

Financial & Operational	
F1 Capital Cost	5
F2 O&M Cost	5
F3 Avoided Cost & New Revenue	4
F4 Chloride Removal Efficiency	4
F5 Process Complexity	3
F6 Operational Risk	4

++	Very High Score	-	Low Score
+	High Score	—	Very Low Score
o	Medium Score	TBD	Unknown / TBD / NA

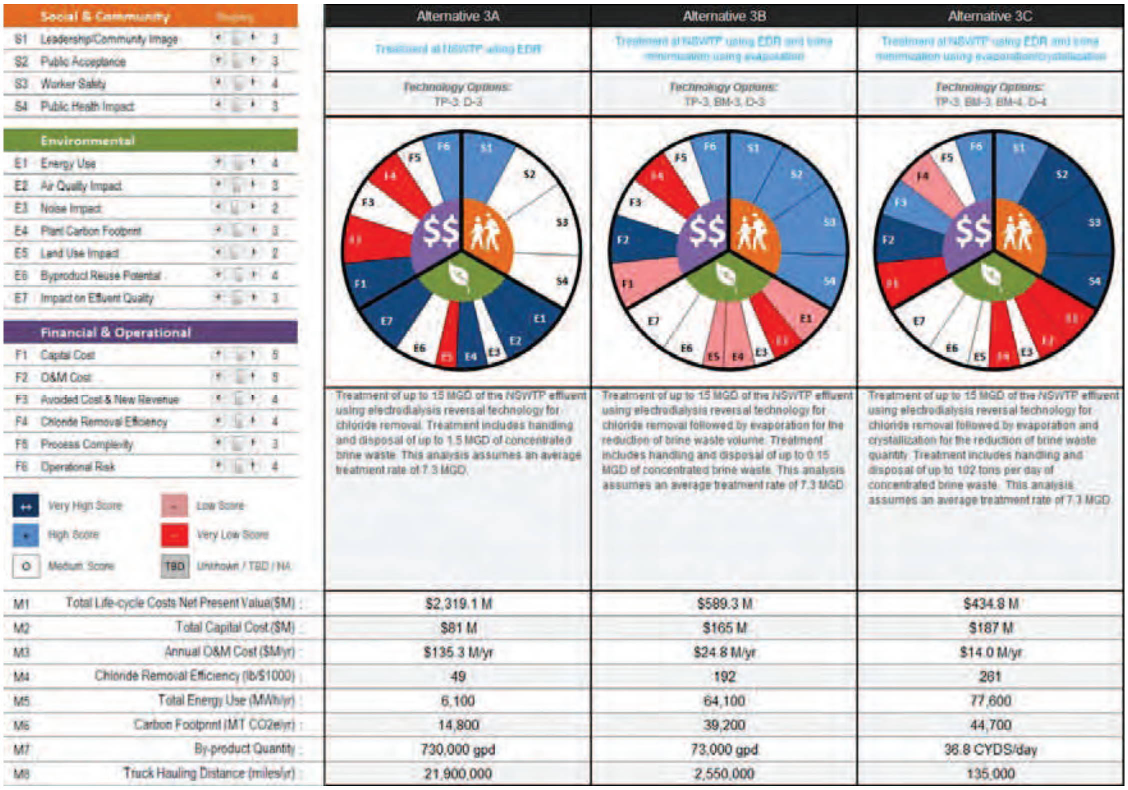
	Alternative 1A	Alternative 1B
	Source water softening - Wellhead treatment for hardness (50 well sites)	Source water softening - Centralized treatment for hardness (50 MGD)
	Technology Options: SR-3	*Technology Options:* SR-5
	Treatment for removal of hardness at water supply source (and associated elimination of residential, commercial and industrial zeolite water softeners). Treatment consists of membrane softening located at individual wells. It was assumed that 22 individual treatment systems each capable of softening a 3.0 MGD raw water supply would be required.	Treatment for removal of hardness from water supply at a centralized location (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at a single centralized treatment site. It was assumed that the centralized system would be capable of producing 50 MGD of softened water. Infrastructure improvements to direct water from supply wells to the treatment facility and from the treatment facility to the distribution system are required, and are assumed to include 135 miles of watermain at $1M per mile.
M1 Total Life-cycle Costs Net Present Value($M)	$287.8 M	$386.0 M
M2 Total Capital Cost ($M)	$91.5 M	$210 M
M3 Annual O&M Cost ($M/yr)	$10.9 M/yr	$10.1 M/yr
M4 Chloride Removal Efficiency (lb/$1000)	953	710
M5 Total Energy Use (MWh/yr)	31,100	39,000
M6 Carbon Footprint (MT CO2e/yr)	22,700	28,400
M7 By-product Quantity	None	None
M8 Truck Hauling Distance (miles/yr)	71,250	30,000



Social & Community		Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
Environmental		
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
Financial & Operational		
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++	Very High Score	-	Low Score
+	High Score	--	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

		Alternative 2A	Alternative 2B	Alternative 2C
		Treatment at NSWTP using RO	Treatment at NSWTP using RO and brine minimization using evaporation	Treatment at NSWTP using RO and brine minimization using evaporation/crystallization
		Technology Options: TP-2, BM-1, D-3	*Technology Options:* TP-2, BM-1, BM-3, D-3	*Technology Options:* TP-2, BM-1, BM-3, BM-4, D-4
		Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.
M1	Total Life-cycle Costs Net Present Value($M)	$2,348.8 M	$619.0 M	$464.4 M
M2	Total Capital Cost ($M)	$87 M	$171 M	$193 M
M3	Annual O&M Cost ($M/yr)	$136.8 M/yr	$26.3 M/yr	$15.4 M/yr
M4	Chloride Removal Efficiency (lb/$1000)	48	183	244
M5	Total Energy Use (MWh/yr)	8,500	66,600	80,000
M6	Carbon Footprint (MT CO2e/yr)	16,500	41,000	46,500
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

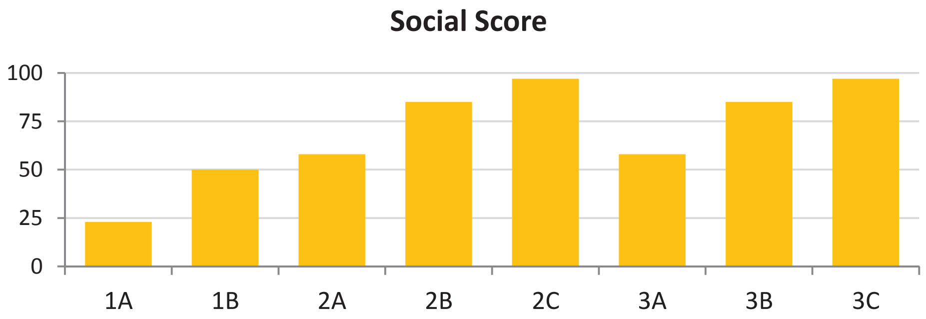


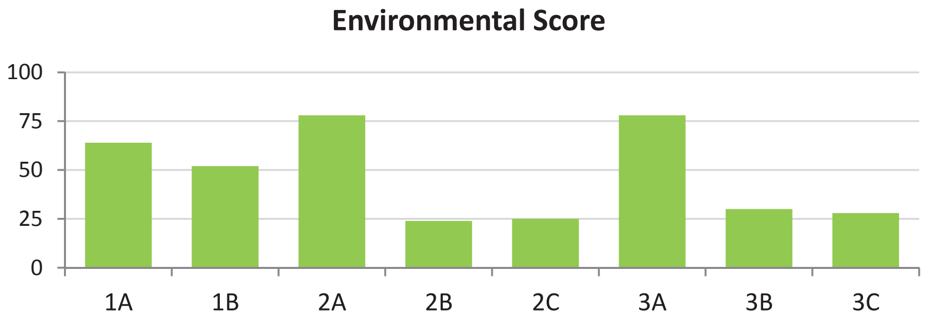
Social & Community		Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3
Environmental		
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
Financial & Operational		
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

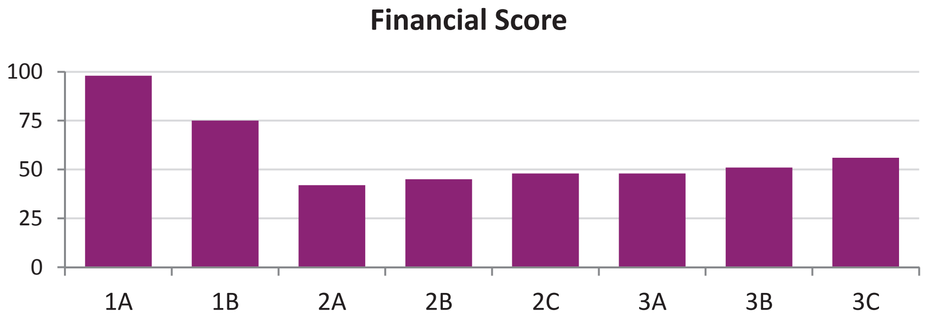
++	Very High Score	-	Low Score
+	High Score	--	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

		Alternative 3A	Alternative 3B	Alternative 3C
		Treatment at NSWTP using EDR	Treatment at NSWTP using EDR and brine minimization using evaporation	Treatment at NSWTP using EDR and brine minimization using evaporation/crystallization
		Technology Options: TP-3, D-3	*Technology Options:* TP-3, BM-3, D-3	*Technology Options:* TP-3, BM-3, BM-4, D-4
		Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.
M1	Total Life-cycle Costs Net Present Value($M)	$2,319.1 M	$589.3 M	$434.8 M
M2	Total Capital Cost ($M)	$81 M	$165 M	$187 M
M3	Annual O&M Cost ($M/yr)	$135.3 M/yr	$24.8 M/yr	$14.0 M/yr
M4	Chloride Removal Efficiency (lb/$1000)	49	192	261
M5	Total Energy Use (MWh/yr)	6,100	64,100	77,600
M6	Carbon Footprint (MT CO2e/yr)	14,800	39,200	44,700
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

A comparison of overall scores in the social, environmental, and financial categories is displayed in the following graphs.



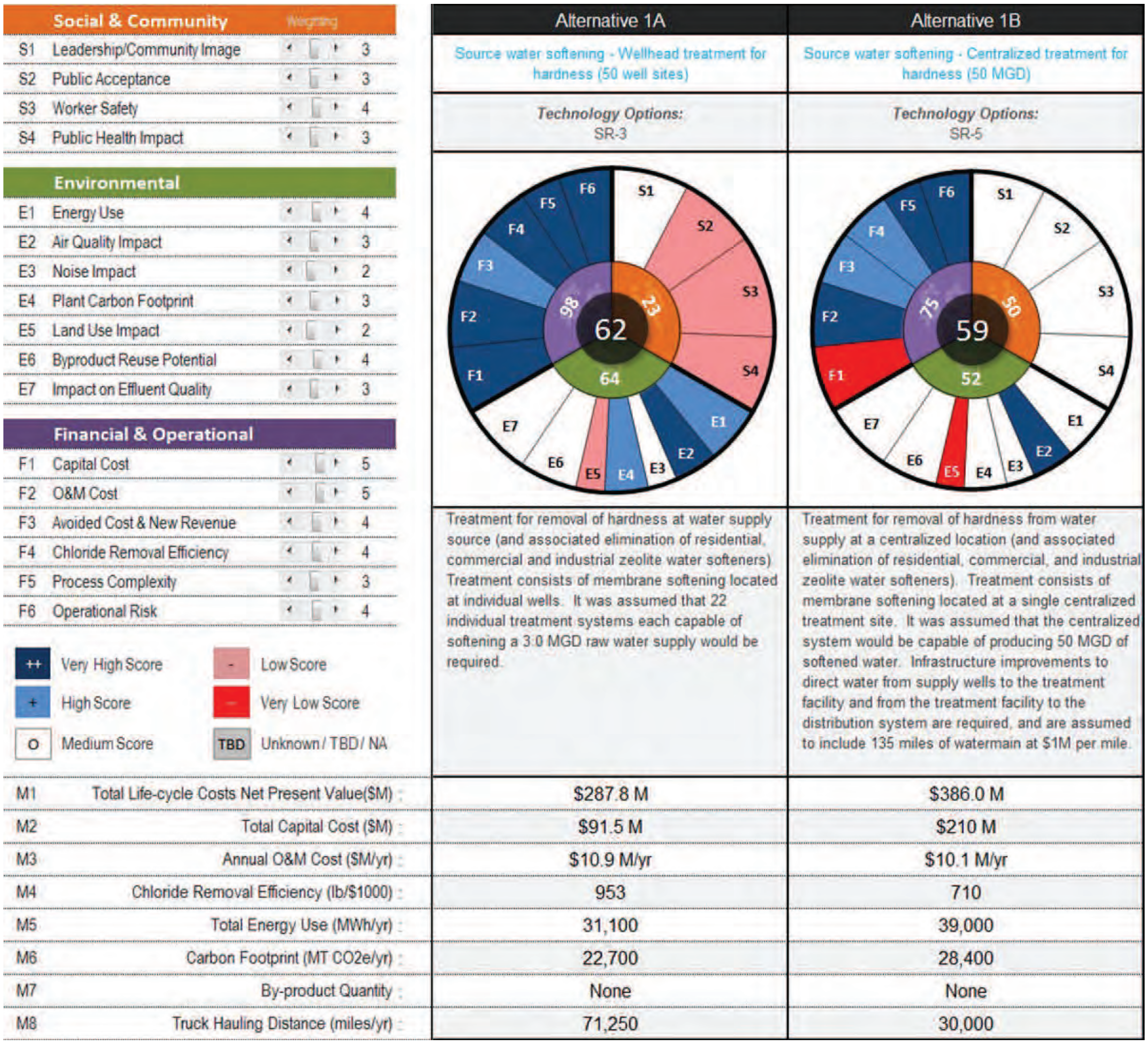




Alternative 1A achieved the highest overall score, largely due to strong performance in the financial category at the expense of poorer performance in the social category. Conversely, alternatives 2A and 3A had the strongest overall performance in the environmental category but at the expense of far higher costs and poorer performance in the financial and operational category. Even within the social category, 2A and 3A have positive impacts with leadership/ innovation and worker safety but significantly negative impacts on public health. Alternatives 2C and 3C scored the highest overall in the social category. When interpreting the results of the TBL analysis, note that the analysis is sensitive to the type of scoring and weighting factors selected by the AECOM and District review team. Some inputs to the TBL analysis rely on judgment as exercised by the evaluators.

The evaluation highlights the intended use of the TBL analysis as an advisory tool in the overall decision process. The TBL analysis merely highlights the positive and negative impacts of the project alternatives with respect to financial, environmental and social externalities. Ultimately, the District and public representatives would need to weigh the negative consequences against the positive attributes of each alternative to select an optimum strategy for the greater Madison community.

The TBL charts below show the scores for each category.



Social & Community		Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3

Environmental		
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3

Financial & Operational		
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++	Very High Score	-	Low Score
+	High Score	—	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

Alternative 1A	Alternative 1B
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M4	Chloride Removal Efficiency (lb/$1000) :	953	710
M5	Total Energy Use (MWh/yr) :	31,100	39,000
M6	Carbon Footprint (MT CO2e/yr) :	22,700	28,400
M7	By-product Quantity :	None	None
M8	Truck Hauling Distance (miles/yr) :	71,250	30,000

	Social & Community	Weighting
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	Environmental	
E1	Energy Use	4
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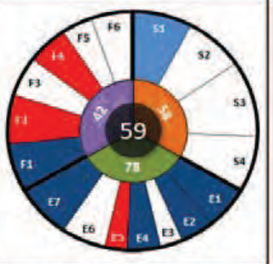
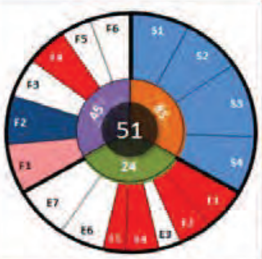
Technology Options: TP-2, BM-1, D-3	*Technology Options:* TP-2, BM-1, BM-3, D-3	*Technology Options:* TP-2, BM-1, BM-3, BM-4, D-4





Alternative 2A	Alternative 2B	Alternative 2C
Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.

		Alternative 2A	Alternative 2B	Alternative 2C
M1	Total Life-cycle Costs Net Present Value($M)	$2,348.8 M	$619.0 M	$464.4 M
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M4	Chloride Removal Efficiency (lb/$1000)	48	183	244
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M6	Carbon Footprint (MT CO2e/yr)	16,500	41,000	46,500
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

	Social & Community	Weighting
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S3	Worker Safety	4
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	Environmental	
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E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3
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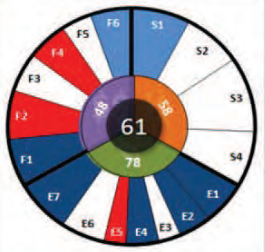
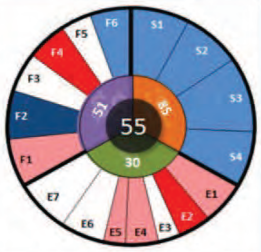
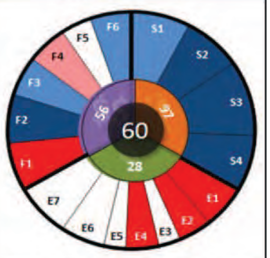
Technology Options: TP-3, D-3	*Technology Options:* TP-3, BM-3, D-3	*Technology Options:* TP-3, BM-4, D-4







Alternative 3A	Alternative 3B	Alternative 3C
Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.

		Alternative 3A	Alternative 3B	Alternative 3C
M1	Total Life-cycle Costs Net Present Value($M)	$2,319.1 M	$589.3 M	$434.8 M
M2	Total Capital Cost ($M)	$81 M	$165 M	$187 M
M3	Annual O&M Cost ($M/yr)	$135.3 M/yr	$24.8 M/yr	$14.0 M/yr
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M5	Total Energy Use (MWh/yr)	6,100	64,100	77,600
M6	Carbon Footprint (MT CO2e/yr)	14,800	39,200	44,700
M7	By-product Quantity	730,000 gpd	73,000 gpd	36.8 CYDS/day
M8	Truck Hauling Distance (miles/yr)	21,900,000	2,550,000	135,000

Tables 3-1 through 3-4

Chloride Compliance Options

Table 3-1

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Source Reduction (SR)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
SR1 – *Develop new water supply sources with lower chloride concentrations*	Individual wells	Concentrations of Fe/Mn in deeper aquifers with lower chloride concentrations may require treatment via oxidation and filtration to meet secondary drinking water standards.	Minimal (less than 10% of chloride load is from source water)	None	None	Moderate (if Fe/Mn treatment is required)	Moderate (if Fe/Mn treatment is required)	• Replacing high chloride water sources (50 to 120 mg/L chloride) may reduce overall chloride load to NSWTP approximately 5%. • Could reduce costs for chloride treatment at NSWTP.	• Source water treatment may be required for Fe/Mn removal. • Additional treatment for chloride would be required at NSWTP.
SR2 – *Treatment for chloride removal at water supply source*	Individual wells	Pretreatment: • Cartridge filters, granular media filter, and/or microfiltration or ultrafiltration Treatment: • Reverse osmosis, electrodialysis reversal, or anion exchange	Up to 99% reduction in source water chloride, but minimal reduction of chloride at NSWTP (less than 10% of chloride load is from source water)	None	2-50%	High	High	• In combination with other chloride source reduction measures, may be adequate to eliminate need for treatment at NSWTP. • Some chloride removal technologies (reverse osmosis and electrodialysis reversal) provide removal of hardness, which may eliminate need for residential zeolite softening systems and resulting discharges of chloride to NSWTP.	• Treatment of water which may not require chloride removal (i.e. irrigation water) • Relatively high cost for removal of approximately 8% of the chloride load to the NSWTP • Multiple treatment facilities to be operated and maintained • Brine disposal
SR3 –*Treatment for removal of hardness at water supply source (and associated elimination of residential zeolite water softeners)*	Individual wells	Pretreatment: • Fe/Mn removal may be required prior to ion exchange or membrane-based softening technologies. Treatment: • Lime softening, ion exchange (mineral acid regenerant), or nanofiltration	Eliminating need for residential zeolite water softeners could result in 50 to 80% reduction in chloride load to the NSWTP.	None	5-50%	High	High	• Improved potable water quality (reduced hardness, Fe and Mn) • Reduces or eliminates need for residential water softeners and resulting chloride contributions • Eliminates need for chloride treatment at NSWTP if residential water softeners are eliminated.	• Difficult to implement for individual wells. • Potential exposure to hazardous chemicals depending on treatment technology • Treatment of water which may not require softening (i.e. irrigation water) • May require isolation of individual water distribution zones if not all wells are softened; could create dissatisfaction among customers • Multiple treatment facilities to be operated and maintained • Residuals disposal

Table 3-1

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Source Reduction (SR)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
SR4 – *Treatment for removal of chloride at centralized location(s)*	One or more treatment facilities located within the water supply system	Pretreatment: • Cartridge filters, granular media filter, and/or microfiltration or ultrafiltration Treatment: • Reverse osmosis, electrodialysis reversal, or anion exchange	Up to 99% reduction in source water chloride, but minimal reduction of chloride at NSWTP (less than 10% of chloride load is from source water)	None	2-50%	High	High	• In combination with other chloride source reduction measures, may be adequate to eliminate need for treatment at NSWTP. • Some chloride removal technologies (reverse osmosis and electrodialysis reversal) provide removal of hardness, which may eliminate need for residential zeolite softening systems and resulting discharges of chloride to NSWTP.	• Treatment of water which may not require chloride removal (i.e. irrigation water) • Relatively high cost for removal of approximately 8% of the chloride load to the NSWTP. • Brine disposal • Central treatment requires substantial modifications to the distribution system and may not provide the same reliability as distributed water supply sources.
SR5 – *Treatment for removal of hardness at centralized location(s)*	One or more treatment facilities located within the water supply system	Pretreatment: • Fe/Mn removal may be required prior to ion exchange or membrane-based softening technologies. Treatment: • Lime softening, ion exchange (mineral acid regenerant), or nanofiltration	Eliminating need for residential zeolite water softeners could result in 50 to 80% reduction in chloride load to the NSWTP.	None	5-50%	High	High	• Improved potable water quality (reduced hardness, Fe and Mn) • Reduces or eliminates need for residential water softeners and resulting chloride contributions • Eliminates need for chloride treatment at NSWTP if residential water softeners are eliminated.	• Potential exposure to hazardous chemicals depending on treatment technology • Treatment of water which may not require softening (i.e. irrigation water) • Residuals disposal • Requires significant new infrastructure to convey well water to centralized treatment facility prior to distribution • Central treatment requires substantial modifications to the distribution system and may not provide the same reliability as distributed water supply sources.
SR6 - *Industrial/commercial source reduction*	Industrial and commercial sites	Treatment or elimination of chloride at individual industrial/commercial sites	Minimum impact at NSWTP	None	N/A	N/A	N/A	• Reduces contributions of chloride from industrial/commercial users	• Potential for increased IPP and administrative requirements to monitor chloride reduction measures • Increased cost to industrial / commercial customers

Table 3-1

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Source Reduction (SR)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
SR7 - ***Educate residential customers and/or control/prohibit use of residential water softeners***	Individual residential customers	N/A	Eliminating use of residential zeolite water softeners could result in 50 to 80% reduction in chloride load to the NSWTP.	None	N/A	N/A	N/A	• Reduces or eliminates largest source of chloride from the system	• Residential customers impacted by challenges associated with use of hard water
SR8 – ***Convert to use of higher efficiency water softeners***	Individual residential customers	Replace residential zeolite softeners	Data to be provided by the District	None	N/A	N/A	N/A	• Reduces chloride load to NSWTP from residential water softeners	• Increased cost to residential customers

Table 3-2

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Treatment at NSWTP (TP)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
TP1 – *Reduce or eliminate use of chemicals at NSWTP which contribute chloride*	NSWTP	N/A	Minimal	None	N/A	N/A	N/A	• Minimal reduction (2%) of chloride load to NSWTP	• Reduced or alternate chemical use may negatively impact the NSWTP performance
TP2 – *Treat a portion of NSWTP effluent using reverse osmosis technology*	NSWTP	Pretreatment: • Microfiltration or ultrafiltration, granular activated carbon adsorption, and/or advanced oxidation Chloride Treatment: • Reverse osmosis	95 to 99% in treated effluent; desired removal achieved by blending treated and untreated effluent	Removal of dissolved and particulate phosphorus and nitrogen (ammonia, nitrate, nitrite)	15-50%	High	High	• Provides barrier to microoganisms and anthropogenic organic contaminants • Numerous operating systems in similar applications	• Susceptible to membrane fouling without sufficient pretreatment • Requires high pressure to achieve high salt rejection (chloride removal) • Significant use and disposal of cleaning chemical solutions • Membranes are susceptible to damage by chlorine • High volume of brine produced
TP3 – *Treat a portion of NSWTP effluent using electrodialysis reversal technology*	NSWTP	Pretreatment: • Cartridge filters, granular media filter, microfiltration or ultrafiltration, granular activated carbon adsorption, and/or advanced oxidation Chloride Treatment: • Electrodialysis reversal	50% to 95% (dependent on number of stages) in treated effluent; desired removal achieved by blending treated and untreated effluent	Removes dissolved ions which pass through the membrane; particulate phosphorus and nitrogen may be removed by EDR pretreatment system.	10%	High	High	• Reduced pretreatment requirements compared to reverse osmosis • Operates at lower pressure than reverse osmosis • Less maintenance and longer membrane life than reverse osmosis • Lower requirements for cleaning chemicals and associated disposal • Compatible with chlorine concentrations <0.5 mg/L	• Larger foot print compared to reverse osmosis • One U.S. manufacturer • Less proven; only one full-scale wastewater treatment plant • Susceptible to membrane fouling without sufficient pretreatment • Significant power requirements • Significant volume of brine produced
TP4 – *Treat a portion of NSWTP effluent using anion exchange*	NSWTP	Pretreatment: • Granular media filter, microfiltration or ultrafiltration, granular activated carbon adsorption, and/or advanced oxidation Chloride Treatment: • Anion exchange (hydroxide based)	95 to 99% in treated effluent; desired removal achieved by blending treated and untreated effluent	Potential to remove phosphate, nitrite and nitrate ions through ion exchange process; nitrate and nitrite are preferentially removed over chloride. Particulate phosphorus and nitrogen may be removed by pretreatment system	2%	Moderate	Moderate	• Reduced pretreatment requirements compared to other technologies • Potential for lower volume of brine waste compared to other technologies • Lower power requirements compared to other technologies	• Prone to inorganic and biological fouling which may result in irreversible degradation of resins • Sensitive to influent water quality fluctuations • Large quantities of sodium hydroxide and sulfuric acid used for regeneration and pH balancing • Limited application for treatment of municipal wastewater • Other anions may be preferentially removed reducing the system capacity for chloride reduction • Brine / chemical regenerant disposal

Table 3-3

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Brine Minimization (BM)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
BM1 – *Microfiltration / reverse osmosis*	NSWTP	Concentration of primary chloride removal technology brine (reverse osmosis or electrodialysis reversal) using microfiltration and reverse osmosis	N/A	N/A	40-60%	Moderate	Moderate	• Reduces brine volume • Potential for beneficial reuse	• Significant use of chemical cleaning solutions which require disposal • Membranes are susceptible to damage by chlorine • Liquid waste produced • Potentially hazardous chemicals present at low or non-detectable concentrations in the NSWTP effluent may be concentrated into the brine or solid material
BM2 – *Lime softening followed by microfiltration / reverse osmosis*	NSWTP	Lime softening for removal of divalent cations to improve the concentration factor that can be achieved by reverse osmosis, improving overall recovery rate; microfiltration used to protect reverse osmosis membranes	N/A	N/A	10-40%	High	High	• Improves performance and recovery rate of the reverse osmosis process, resulting in a lower volume of concentrated brine • Potential for beneficial reuse	• Solids produced by lime softening process require disposal • Significant use of chemical cleaning solutions which require disposal • Membranes are susceptible to damage by chlorine • Liquid waste produced • Potentially hazardous chemicals present at low or non-detectable concentrations in the NSWTP effluent may be concentrated into the brine or solid material
BM3 - *Evaporator*	NSWTP	Use of heat to evaporate water from brine, concentrating salts and reducing volume	N/A	N/A	2-10%	Very High	Very High	• Produces less brine waste than reverse osmosis brine minimization alternatives	• Energy intensive • Corrosion potential due to high chloride concentrations • Potentially hazardous chemicals present at low or non-detectable concentrations in the NSWTP effluent may be concentrated into the brine or solid material
BM4 - *Brine concentrator/crystallizer*	NSWTP	Use of heat to evaporate water from brine, followed by further removal of water in a crystallizer	N/A	N/A	Produces solid material	Highest	Highest	• Produces solid waste or product • Potential for beneficial reuse	• Significant equipment and space requirements • Complex operation • Energy intensive • Corrosion potential due to high chloride concentrations

Table 3-3

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Brine Minimization (BM)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
									• Potentially hazardous chemicals present at low or non-detectable concentrations in the NSWTP effluent may be concentrated into the brine or solid material
BM5 - *Freeze/thaw*	NSWTP / off-site	Freezing to produce ice crystals and further concentrate brine solution	N/A	N/A	25- 50%	Moderate	Low	• Natural system • No moving parts • Simple operation	• Requires large land areas which would likely require lining • Unproven technology • Seasonal operational issues (storage required during above-freezing temperatures) • Weather-dependent • Liquid waste produced • Potentially hazardous chemicals present at low or non-detectable concentrations in the NSWTP effluent may be concentrated into the brine or solid material
BM6 - *Natural treatment systems (wetlands)*	NSWTP / off-site	Plant and soil-based treatment for limited removal of chloride from brine	N/A	N/A	Liquid and sediment residuals; no loss other than evaporation	Moderate	Low	• Limited mechanical equipment to operate and maintain • Minimizes operational cost with the exception of periodic disposal and reconstruction	• Requires large land areas • Likely requires a lined system • Unproven technology • Limited chloride removal • Seasonal • Very limited application for brine minimization • Accumulation of chlorides requires periodic removal and landfill disposal of organic materials and sub soil followed by wetland reconstruction
BM7 - *Evaporation ponds*	NSWTP / off-site	Evaporation of water from brine in a pond	N/A	N/A	N/A	High	Low	• Minimum operational cost	• Requires large surface areas • Best suited for arid climates • Requirement for liner system • Ultimate disposal of residual solids in landfill.

Table 3-4

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study

Comparison of Chloride Reduction Options – Brine/Residuals Disposal or Reuse (D)

Option	Location	Treatment Requirements	Chloride Reduction	Phosphorus & Nitrogen Removal	Residuals (Volume as percent of forward flow)	Capital Cost	Operation & Maintenance Costs	Benefits	Disadvantages
D1 - *Beneficial reuse of reduced-volume brine or solids*	Off-site	Brine or solids contain chloride and other salts which may have value for reuse	N/A	N/A	N/A	Moderate	Low	• Beneficial reuse	• Must identify and maintain markets for beneficial reuse • Storage may be needed if reuse is seasonal • Potential presence of hazardous chemicals in the brine or solid material
D2 - *Storage for winter use in road de-icing*	NSWTP / off-site	Storage of brine or solids for use in seasonal road de-icing	N/A	N/A	N/A	High	Low	• Beneficial reuse • Reduces cost for de-icing chemicals	• Significant storage capacity may be required • Chloride may be re-introduced into influent to NSWTP if used for de-icing • Potential presence of hazardous chemicals in the brine or solid material
D3 – *Deep well injection*	NSWTP / off-site	Disposal of brine via deep well injection	N/A	N/A	N/A	Low (for existing deep wells)	High	• Eliminates chloride from watershed	• Not permitted per Wisconsin code • Haul to another state for disposal • Off-site hauling poses risk and significant cost • Corrosion potential of well materials due to high chloride content
D4 - *Off-site disposal of reduced-volume brine or solids*	Off-site	Disposal of brine or solids at industrial waste facility or landfill	N/A	N/A	N/A	Low	High	• Eliminates chloride from watershed	• Waste characterization would be required to determine ultimate landfill or disposal facility requirements • Off-site hauling poses risk and significant cost

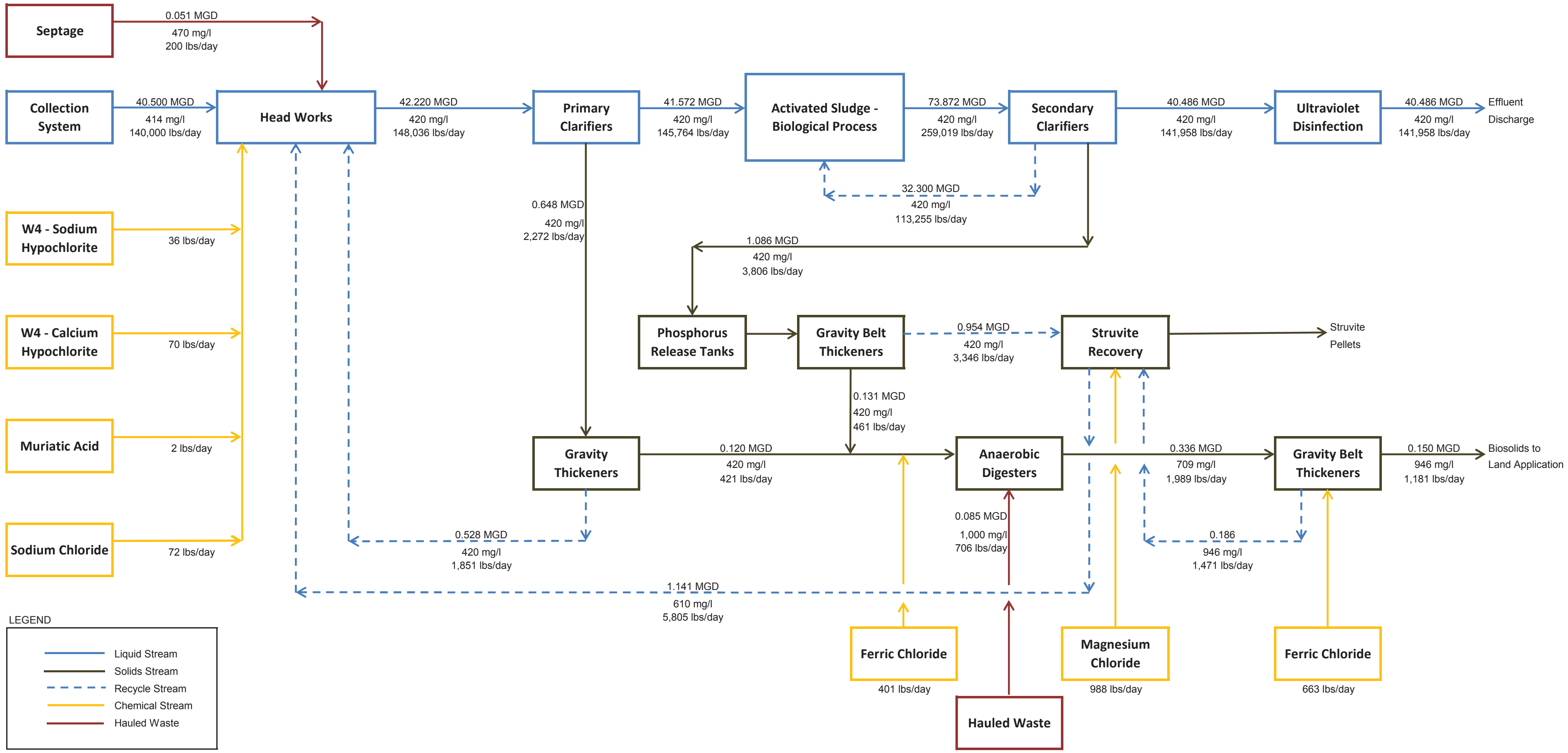
Figures 2-1 through 2-6

Chloride Mass Balance Scenarios

Figure 2-1

Chloride Mass Balance

Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Current Average Day Load

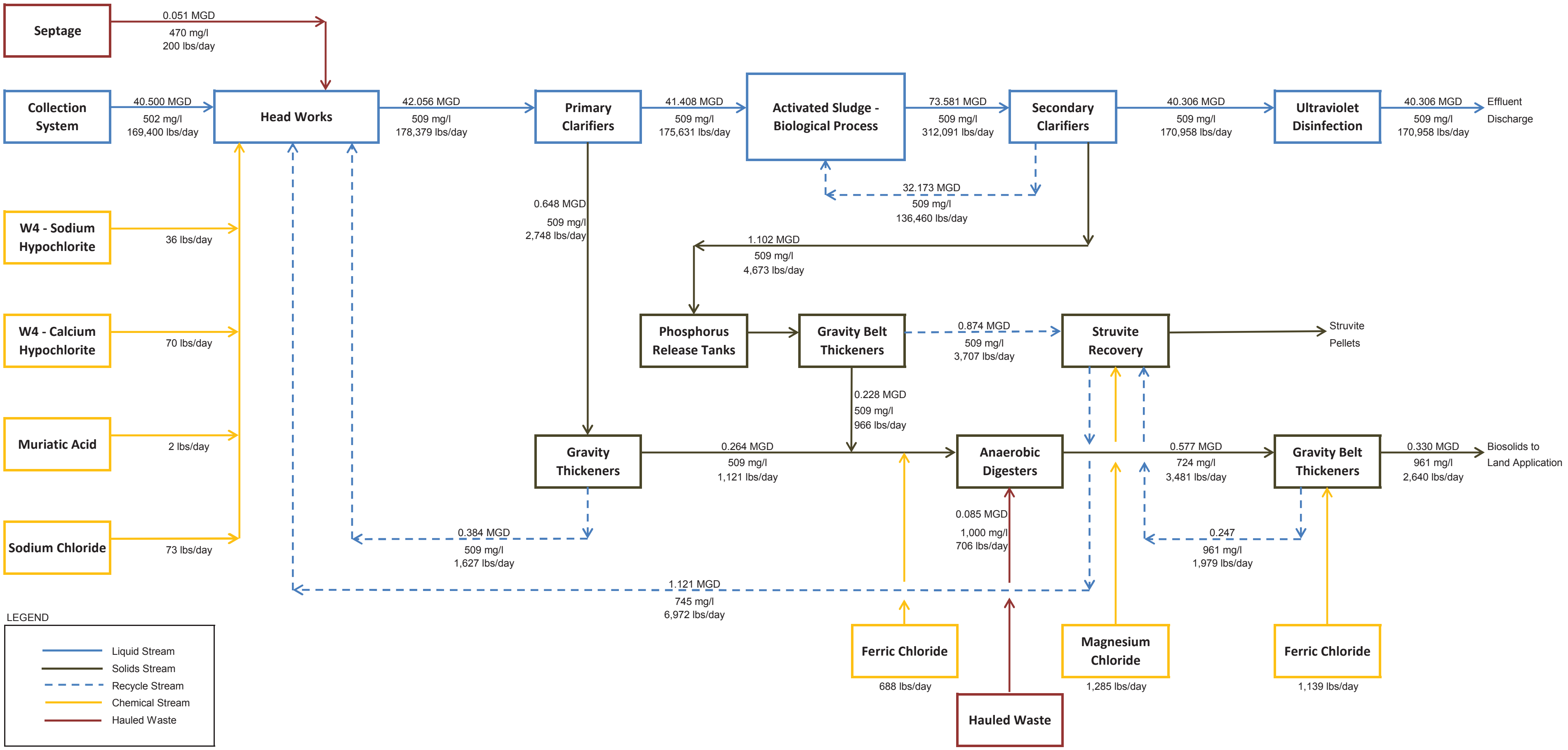


AECOM

10/15/2014

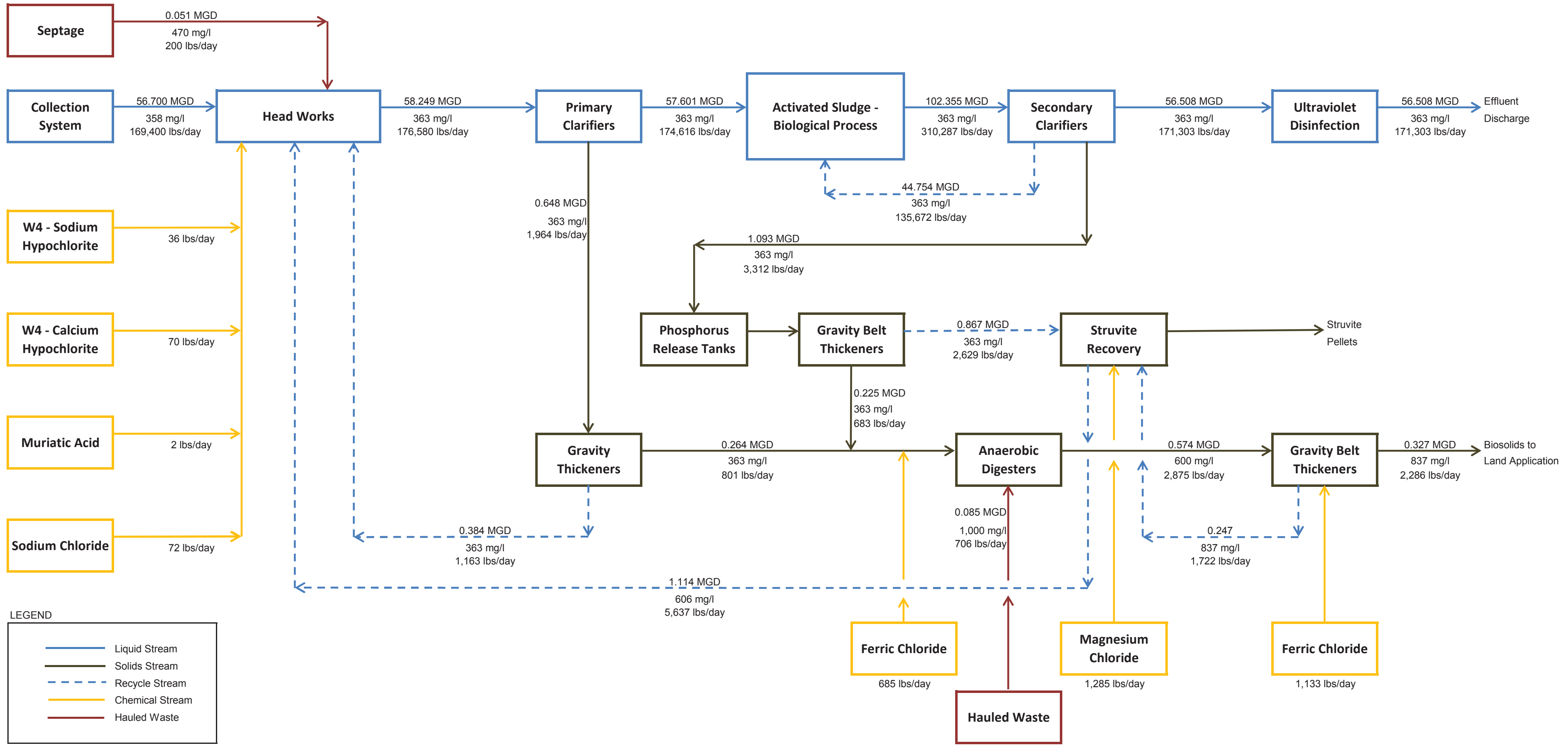
Figure 2-2
Chloride Mass Balance

Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Current Average Flow with Maximum Day Chloride



10/15/2014

Figure 2-3
Chloride Mass Balance
Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Current Maximum Day Load



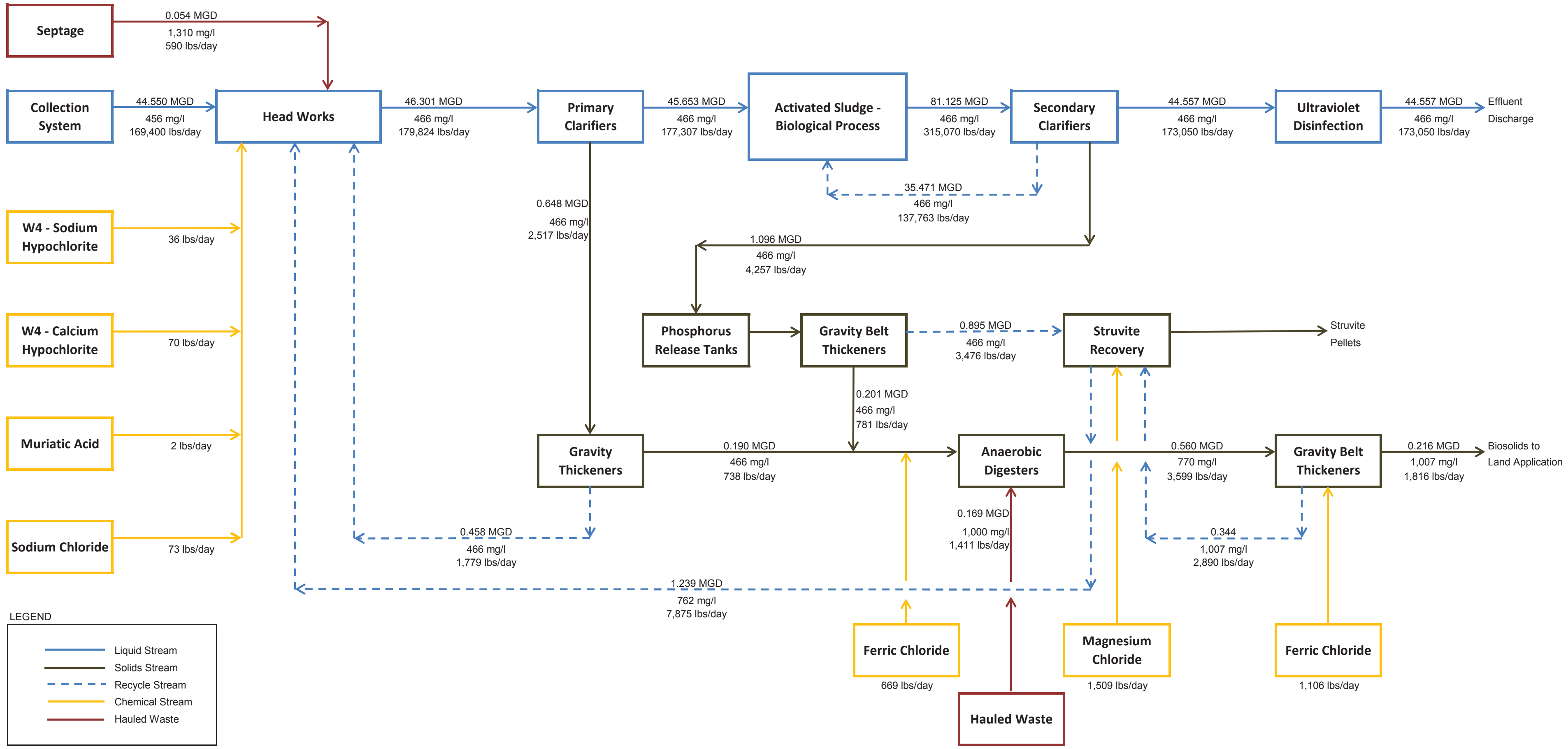
AECOM

10/15/2014

Figure 2-4

Chloride Mass Balance

Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Year 2030 Average Day Load



2/13/2015

Figure 2-5

Chloride Mass Balance

Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Year 2030 Average Flow with Maximum Day Chloride

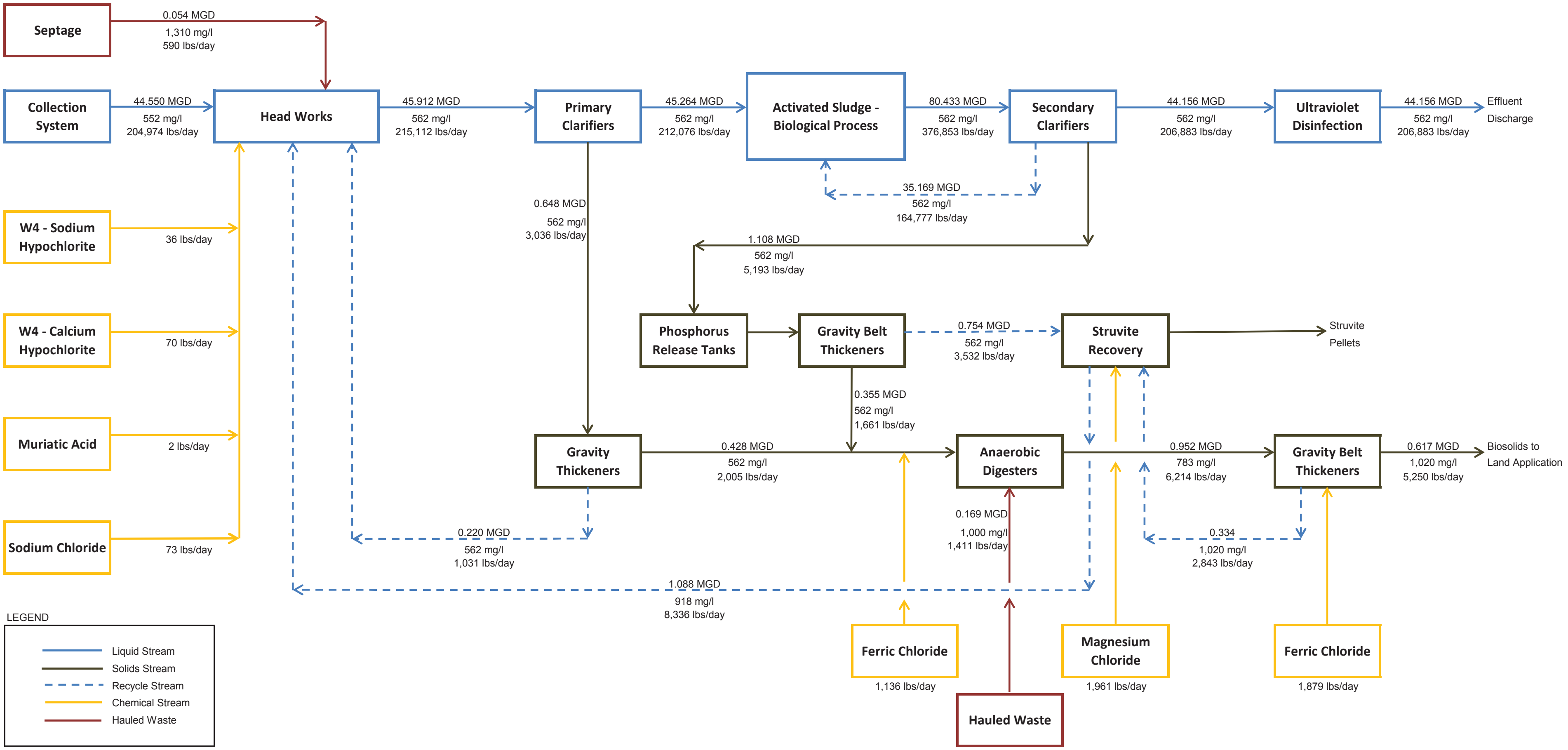


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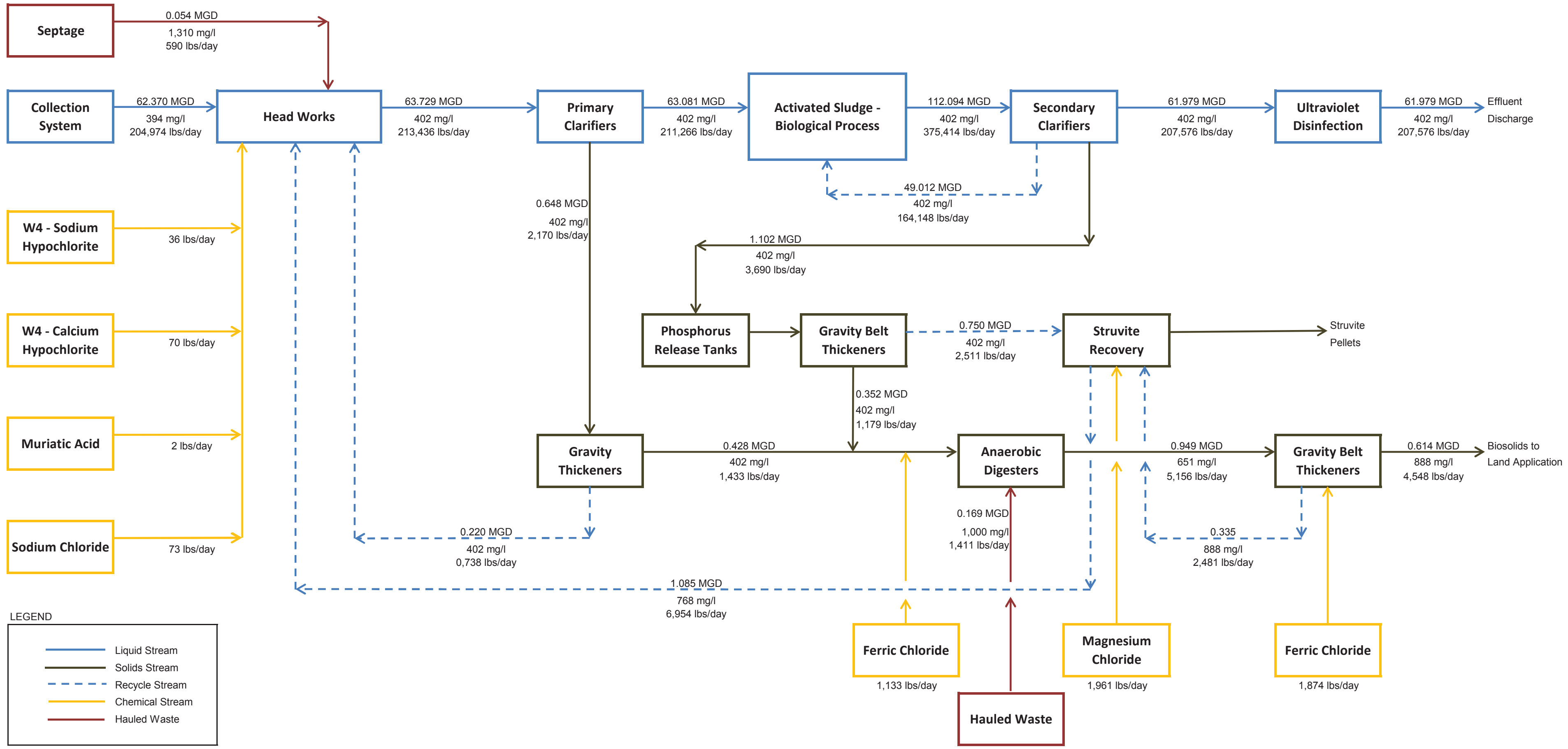
Figure 2-6

Chloride Mass Balance

Madison Metropolitan Sewerage District
Nine Springs Wastewater Treatment Plant
Year 2030 Maximum Day Load



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Appendix A

Equipment Lists

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
NF or RO Well Head Softening (2.5 MGD) Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
			Softening System			
T-201	NF/RO feed tank	15 minutes capacity at design flow	12-ft dia x 22-ft high	24,000 gallons (min)	FRP / PP	
T-202	NF/RO feed tank	15 minutes capacity at design flow	12-ft dia x 22-ft high	24,000 gallons (min)	FRP / PP	
P-301	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.15 MGD	Carbon steel	
P-302	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.15 MGD	Carbon steel	
PF-301	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.15 MGD	Stainless steel	
PF-302	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.15 MGD	Stainless steel	
NF/RO-301	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.15 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-302	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.15 MGD	FRP / PVC / SS piping; CS skid	
	NF/RO CIP					
	Acid feed system					
	Anti-scalant feed system					
	Sodium hydroxide feed system					
	Sodium hypochlorite feed system					
	Reservoir	EXISTING		Varies		
	Booster pumps	EXISTING		Varies		

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
NF or RO Centralized Softening System (50 MGD) Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
Softening System						
T-201	NF/RO feed tank	15 minutes capacity at design flow	67-ft x 52-ft x 20-ft SWD	510,000 gallons (min)	Cast-in-place concrete	
T-202	NF/RO feed tank	15 minutes capacity at design flow	67-ft x 52-ft x 20-ft SWD	510,000 gallons (min)	Cast-in-place concrete	
P-301	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-302	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-303	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-304	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-305	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-306	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-307	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-308	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-309	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-310	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-311	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-312	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-313	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-314	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-315	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-316	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-317	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-318	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-319	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-320	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-321	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-322	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-323	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-324	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-325	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-326	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-327	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-328	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-329	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-330	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-331	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-332	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-333	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
P-334	NF/RO feed pump	Horizontal centrifugal	Part of Skid	1.35 MGD	Carbon steel	
PF-301	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-302	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-303	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-304	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-305	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-306	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-307	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-308	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-309	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-310	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-311	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-312	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-313	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
NF or RO Centralized Softening System (50 MGD) Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
PF-314	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-315	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-316	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-317	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-318	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-319	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-320	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-321	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-322	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-323	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-324	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-325	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-326	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-327	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-328	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-329	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-330	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-331	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-332	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-333	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
PF-334	NF/RO pre-filter	Cartridge style filter	Part of Skid	1.35 MGD	Stainless steel	
NF/RO-301	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-302	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-303	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-304	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-305	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-306	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-307	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-308	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-309	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-310	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-311	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-312	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-313	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-314	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-315	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-316	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-317	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-318	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-319	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-320	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-321	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-322	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-323	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-324	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-325	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-326	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-327	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-328	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-329	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-330	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
NF or RO Centralized Softening System (50 MGD) Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
NF/RO-331	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-332	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-333	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
NF/RO-334	NF/RO membrane skid	Spiral wound (average 15.3 gfd)	10-ft x 26-ft	1.35 MGD	FRP / PVC / SS piping; CS skid	
	NF/RO CIP					
	Acid feed system					
	Anti-scalant feed system					
	Sodium hydroxide feed system					
	Sodium hypochlorite feed system					
T-301	Clearwell	22.5 minutes capacity at design flow	102-ft x 102-ft x 20-ft SWD	800,000 gallons (min)	Cast-in-place concrete	
T-302	Clearwell	22.5 minutes capacity at design flow	102-ft x 102-ft x 20-ft SWD	800,000 gallons (min)	Cast-in-place concrete	
P-401	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-402	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-403	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-404	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-405	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-406	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	
P-407	High Service Pump	Vertical turbine		5,800 gpm	Carbon steel	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
UF/RO Chloride Removal System Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
Secondary Effluent Pumping						
P-001	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-002	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-003	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-004	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-005	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-006	Secondary effluent transfer pump	Dry pit submersible (Standby)		3.0 MGD	Carbon Steel	
Chloride removal						
T-401	UF feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
T-402	UF feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
P-401	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-402	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-403	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-404	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-405	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-406	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-407	UF feed pump	Horizontal centrifugal (Standby)	Part of Skid	1.3 MGD	Carbon Steel	
P-408	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-409	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-410	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-411	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-412	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-413	UF feed pump	Horizontal centrifugal	Part of Skid	1.3 MGD	Carbon Steel	
P-414	UF feed pump	Horizontal centrifugal (Standby)	Part of Skid	1.3 MGD	Carbon Steel	
PF-401	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-402	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-403	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-404	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-405	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-406	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-407	UF pre-filter	Cartridge style filter (Standby)	Part of Skid	1.3 MGD	Stainless steel	
PF-408	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-409	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-410	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-411	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-412	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-413	UF pre-filter	Cartridge style filter	Part of Skid	1.3 MGD	Stainless steel	
PF-414	UF pre-filter	Cartridge style filter (Standby)	Part of Skid	1.3 MGD	Stainless steel	
UF-401	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-402	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-403	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-404	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-405	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-406	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-407	UF membrane skid	Cartridge style filter (20 gfd) (Standby)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
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Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
UF-408	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-409	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-410	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-411	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-412	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-413	UF membrane skid	Hollow fiber (20 gfd)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
UF-414	UF membrane skid	Cartridge style filter (20 gfd) (Standby)	12-ft x 21-ft x 14-ft H	1.3 MGD	PVC / SS piping; CS skid	
	UF CIP - Train #1		20-ft x 60-ft x 21-ft H			
	UF CIP - Train #2		20-ft x 60-ft x 21-ft H			
	Ammonium Hydroxide Feed System					
	Sodium Hypochlorite Feed System					
T-501	RO feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
T-502	RO feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
P-501	RO feed pump	Horizontal centrifugal	Part of Skid	3.0 MGD	Carbon Steel	
P-502	RO feed pump	Horizontal centrifugal	Part of Skid	3.0 MGD	Carbon Steel	
P-503	RO feed pump	Horizontal centrifugal	Part of Skid	3.0 MGD	Carbon Steel	
P-504	RO feed pump	Horizontal centrifugal	Part of Skid	3.0 MGD	Carbon Steel	
P-505	RO feed pump	Horizontal centrifugal	Part of Skid	3.0 MGD	Carbon Steel	
P-506	RO feed pump	Horizontal centrifugal (Standby)	Part of Skid	3.0 MGD	Carbon Steel	
PF-501	RO pre-filter	Cartridge style filter	Part of Skid	3.0 MGD	Stainless steel	
PF-502	RO pre-filter	Cartridge style filter	Part of Skid	3.0 MGD	Stainless steel	
PF-503	RO pre-filter	Cartridge style filter	Part of Skid	3.0 MGD	Stainless steel	
PF-504	RO pre-filter	Cartridge style filter	Part of Skid	3.0 MGD	Stainless steel	
PF-505	RO pre-filter	Cartridge style filter	Part of Skid	3.0 MGD	Stainless steel	
PF-506	RO pre-filter	Cartridge style filter (Standby)	Part of Skid	3.0 MGD	Stainless steel	
RO-501	RO membrane skid	Spiral wound (11 gfd)		3.0 MGD	FRP / PVC / SS	
RO-502	RO membrane skid	Spiral wound (11 gfd)		3.0 MGD	FRP / PVC / SS	
RO-503	RO membrane skid	Spiral wound (11 gfd)		3.0 MGD	FRP / PVC / SS	
RO-504	RO membrane skid	Spiral wound (11 gfd)		3.0 MGD	FRP / PVC / SS	
RO-505	RO membrane skid	Spiral wound (11 gfd)		3.0 MGD	FRP / PVC / SS	
RO-506	RO membrane skid	Spiral wound (Standby)		3.0 MGD	FRP / PVC / SS	
	Acid feed system					
	Anti-scalant feed system					
	RO CIP system					
	pH adjustment - carbon dioxide feed system					
	pH adjustment - carbon dioxide feed system					
Brine Minimization (BM1 - Microfiltration / reverse osmosis)						
T-601	Recovery RO feed tank	30 minutes capacity at design flow	22-ft x 22-ft x 15-ft SWD	47,000 gallons (min)	Cast-in-place concrete	
T-602	Recovery RO feed tank	30 minutes capacity at design flow	22-ft x 22-ft x 15-ft SWD	47,000 gallons (min)	Cast-in-place concrete	
P-601	Recovery RO feed pump	Horizontal centrifugal	Part of Skid	0.45 MGD	Stainless internals	
P-602	Recovery RO feed pump	Horizontal centrifugal	Part of Skid	0.45 MGD	Stainless internals	
P-603	Recovery RO feed pump	Horizontal centrifugal	Part of Skid	0.45 MGD	Stainless internals	
P-604	Recovery RO feed pump	Horizontal centrifugal	Part of Skid	0.45 MGD	Stainless internals	
P-605	Recovery RO feed pump	Horizontal centrifugal	Part of Skid	0.45 MGD	Stainless internals	
P-606	Recovery RO feed pump	Horizontal centrifugal (Standby)	Part of Skid	0.45 MGD	Stainless internals	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
UF/RO Chloride Removal System Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
PF-601	Recovery RO pre-filter	Cartridge style filter	Part of Skid	0.45 MGD	Stainless steel	
PF-602	Recovery RO pre-filter	Cartridge style filter	Part of Skid	0.45 MGD	Stainless steel	
PF-603	Recovery RO pre-filter	Cartridge style filter	Part of Skid	0.45 MGD	Stainless steel	
PF-604	Recovery RO pre-filter	Cartridge style filter	Part of Skid	0.45 MGD	Stainless steel	
PF-605	Recovery RO pre-filter	Cartridge style filter	Part of Skid	0.45 MGD	Stainless steel	
PF-606	Recovery RO pre-filter	Cartridge style filter (Standby)	Part of Skid	0.45 MGD	Stainless steel	
RO-601	Recovery RO membrane skid	Spiral wound (7 to 10 gfd)		0.45 MGD	FRP / PVC / SS	
RO-602	Recovery RO membrane skid	Spiral wound (7 to 10 gfd)		0.45 MGD	FRP / PVC / SS	
RO-603	Recovery RO membrane skid	Spiral wound (7 to 10 gfd)		0.45 MGD	FRP / PVC / SS	
RO-604	Recovery RO membrane skid	Spiral wound (7 to 10 gfd)		0.45 MGD	FRP / PVC / SS	
RO-605	Recovery RO membrane skid	Spiral wound (7 to 10 gfd)		0.45 MGD	FRP / PVC / SS	
RO-606	Recovery RO membrane skid	Spiral wound (7 to 10 gfd) (Standby)		0.45 MGD	FRP / PVC / SS	
	Acid feed system					
	Anti-scalant feed system					
	Recovery RO CIP system					
T-701	Brine waste holding tank - Primary	36 hour capacity at design flow	115-ft diam x 30-ft SWD	2,250,000 gallons (min)	Epoxy coated steel	
T-702	Brine waste holding tank - Primary	36 hour capacity at design flow	115-ft diam x 30-ft SWD	2,250,000 gallons (min)	Epoxy coated steel	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
EDR Chloride Removal System Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
Secondary Effluent Pumping						
P-001	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-002	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-003	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-004	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-005	Secondary effluent transfer pump	Dry pit submersible		3.0 MGD	Carbon Steel	
P-006	Secondary effluent transfer pump	Dry pit submersible (Standby)		3.0 MGD	Carbon Steel	
Chloride removal						
	Ammonium Hydroxide Feed Systen					
	Sodium Hypochlorite Feed Systen					
T-401	EDR feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
T-402	EDR feed tank	30 minutes capacity at design flow	60-ft x 60-ft x 15-ft SWD	320,000 gallons (min)	Cast-in-place concrete	
P-401	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-402	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-403	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-404	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-405	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-406	EDR feed pump	Horizontal centrifugal (Standby)		1.5 MGD	Carbon Steel	
P-407	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-408	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-409	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-410	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-411	EDR feed pump	Horizontal centrifugal		1.5 MGD	Carbon Steel	
P-412	EDR feed pump	Horizontal centrifugal (Standby)		1.5 MGD	Carbon Steel	
PF-401	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-402	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-403	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-404	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-405	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-406	Pre-filters	Cartridge style filter (Standby)	Part of Skid	1.5 MGD	Stainless steel	
PF-407	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-408	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-409	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-410	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-411	Pre-filters	Cartridge style filter	Part of Skid	1.5 MGD	Stainless steel	
PF-412	Pre-filters	Cartridge style filter (Standby)	Part of Skid	1.5 MGD	Stainless steel	
EDR-401	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-402	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-403	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-404	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-405	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-406	EDR	2020-8L-3S - (Standby)	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-407	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-408	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-409	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
EDR Chloride Removal System Alternative
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Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
EDR-410	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-411	EDR	2020-8L-3S	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
EDR-412	EDR	2020-8L-3S - (Standby)	66-ft x 23-ft x 12-ft SWD	1.5 MGD	PVC piping; carbon steel skid	
	Acid feed system					
	Anti-scalant feed system					
	EDR CIP system Train #1					
	EDR CIP system Train #2					
	pH adjustment - carbon dioxide feed system					
	pH adjustment - carbon dioxide feed system					
T-701	Brine waste holding tank - Primary	36 hour capacity at design flow	115-ft diam x 30-ft SWD	2,250,000 gallons (min)	Epoxy coated steel	
T-702	Brine waste holding tank - Primary	36 hour capacity at design flow	115-ft diam x 30-ft SWD	2,250,000 gallons (min)	Epoxy coated steel	

Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
Brine Concentrate Cold Lime Softening with Evaporation Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
Brine Minimization (BM3 - Evaporator)						
P-701	Cold lime softening feed pump	Horizontal centrifugal		0.75 MGD	Stainless steel	
P-702	Cold lime softening feed pump	Horizontal centrifugal		0.75 MGD	Stainless steel	
C-701	Solids contact clarifier internals	Brine softening (loading 0.82 gpm/ft^2)	30-ft diam x - 16 ft SWD	0.75 MGD	Carbon steel (concrete tank)	
C-702	Solids contact clarifier internals	Brine softening (loading 0.82 gpm/ft^2)	30-ft diam x - 16 ft SWD	0.75 MGD	Carbon steel (concrete tank)	
	Lime chemical feed systems					
T-711	Lime sludge holding tank	24 hours capacity at design flow	22-ft diam x - 19 ft SWD	53,000 gpd	Carbon Steel	
P-711	Lime sludge feed pump	Progessive cavity		50 gpm	Stainless/carbon Steel	
P-712	Lime sludge feed pump	Progessive cavity		50 gpm	Stainless/carbon Steel	
BFP-711	Belt filter press					
BFP-712	Belt filter press					
P-721	Evaporator feed pump	Horizontal centrifugal		0.75 MGD	Stainless steel	
P-722	Evaporator feed pump	Horizontal centrifugal		0.75 MGD	Stainless steel	
E-721	Brine waste evaporator	Vapor recompression	90-ft x 55-ft x 85-ft high	0.75 MGD	Titaneum / hastelloy / duplex	
E-722	Brine waste evaporator	Vapor recompression	90-ft x 55-ft x 85-ft high	0.75 MGD	Titaneum / hastelloy / duplex	
CT-721	Cooling tower	400 gpm @ 85 F suppy / 100 F return	12-ft x 12-ft x 14-ft high	250 ton		
CT-722	Cooling tower	400 gpm @ 85 F suppy / 100 F return	12-ft x 12-ft x 14-ft high	250 ton		
T-801	Brine waste holding tank - Secondary	36 hour capacity at design flow	36-ft diam x 30-ft SWD	225,000 gallons (min)	Stainless steel	
T-802	Brine waste holding tank - Secondary	36 hour capacity at design flow	36-ft diam x 30-ft SWD	225,000 gallons (min)	Stainless steel	

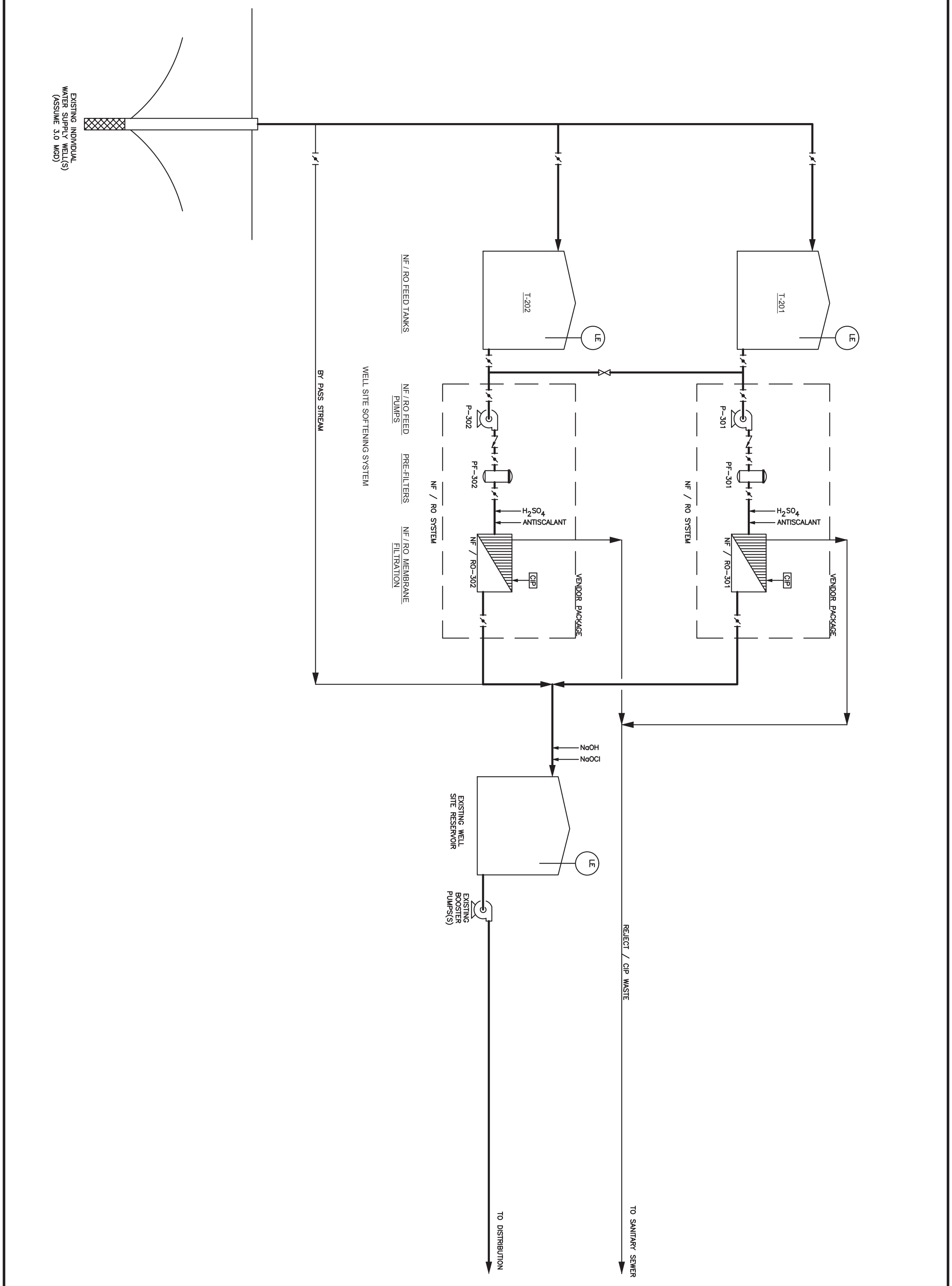
Madison Metropolitan Sewerage District
Chloride Treatment Feasibility Study
Equipment List
Brine Concentrate Crystallization Alternative
February 3, 2015

Tag #	Service	Description	Dimensions	Capacity	Materials of Construction	HP
Brine Minimization (BM4 - Concentrator/crystallizer)						
P-801	Crystallizer feed pump	Horizontal centrifugal		0.075 MGD	Stainless steel	
P-802	Crystallizer feed pump	Horizontal centrifugal		0.075 MGD	Stainless steel	
E-801	Brine waste crystallizer	One Effect (3 Stage) MVR		75,000 GPD	Titaneum / hastelloy / duplex	
CT-801	Cooling tower	600 gpm @ 85 F suppy / 100 F return		375 ton		

Appendix B

Process Flow Diagrams

Electronic Filing: Received, Clerk's Office 05/30/2019 P.C. #6

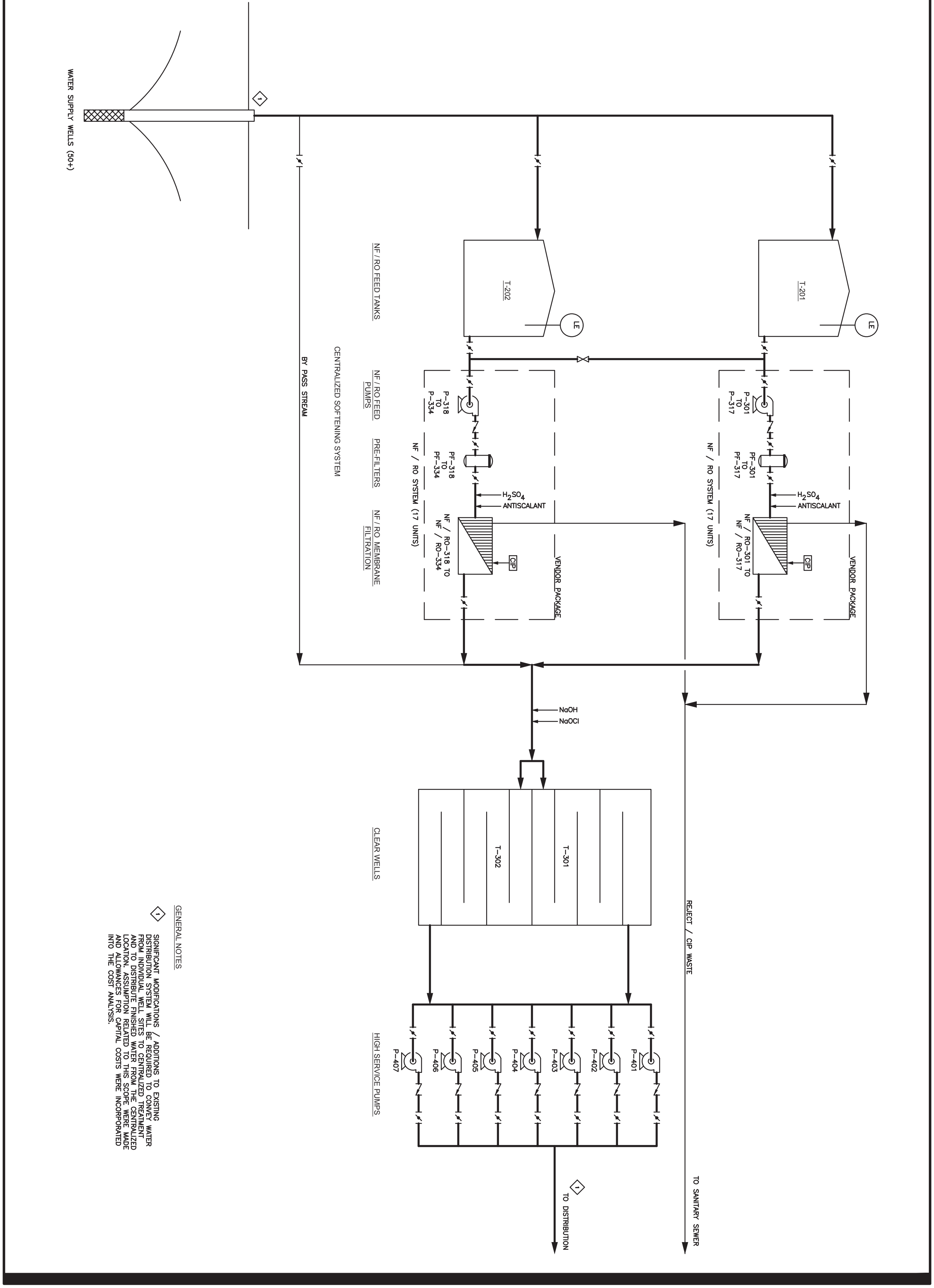


CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

NF OR RO WELL HEAD SOFTENING SYSTEM (2.5 MGD) ALTERNATIVE

AECOM

Figure: PFD-1



GENERAL NOTES

1. SIGNIFICANT MODIFICATIONS / ADDITIONS TO EXISTING DISTRIBUTION SYSTEM WILL BE REQUIRED TO CONVEY WATER FROM INDIVIDUAL WELL SITES TO CENTRALIZED TREATMENT AND TO DISTRIBUTE FINISHED WATER FROM THE CENTRALIZED LOCATION. ASSUMPTION RELATED TO THIS SCOPE WERE MADE AND ALLOWANCES FOR CAPITAL COSTS WERE INCORPORATED INTO THE COST ANALYSIS.

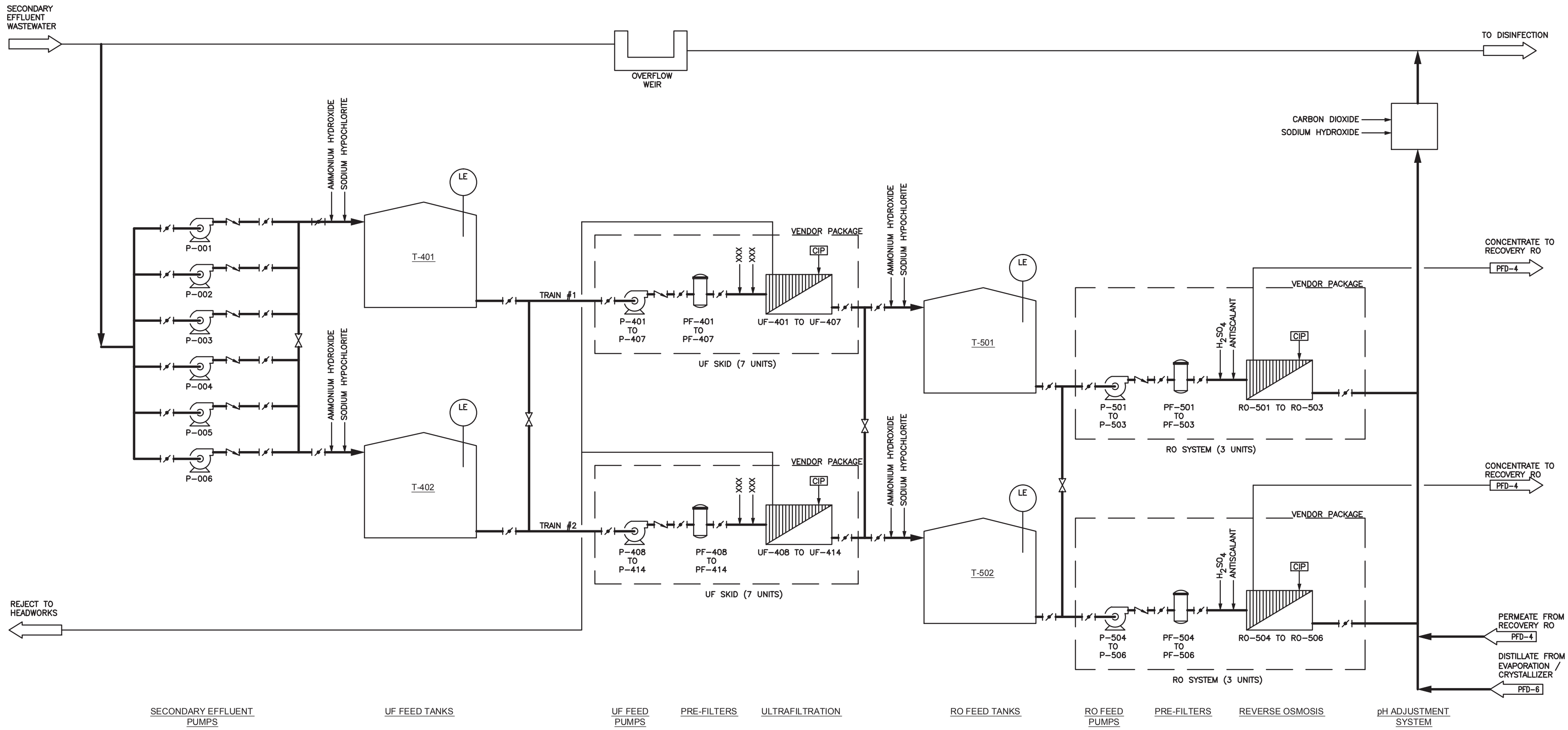
CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

NF OR RO CENTRALIZED SOFTENING SYSTEM (50 MGD) ALTERNATIVE

AECOM

Figure: PFD-2

Electronic Filing: Received, Clerk's Office 05/30/2019 P.C. #6



MASS BALANCE

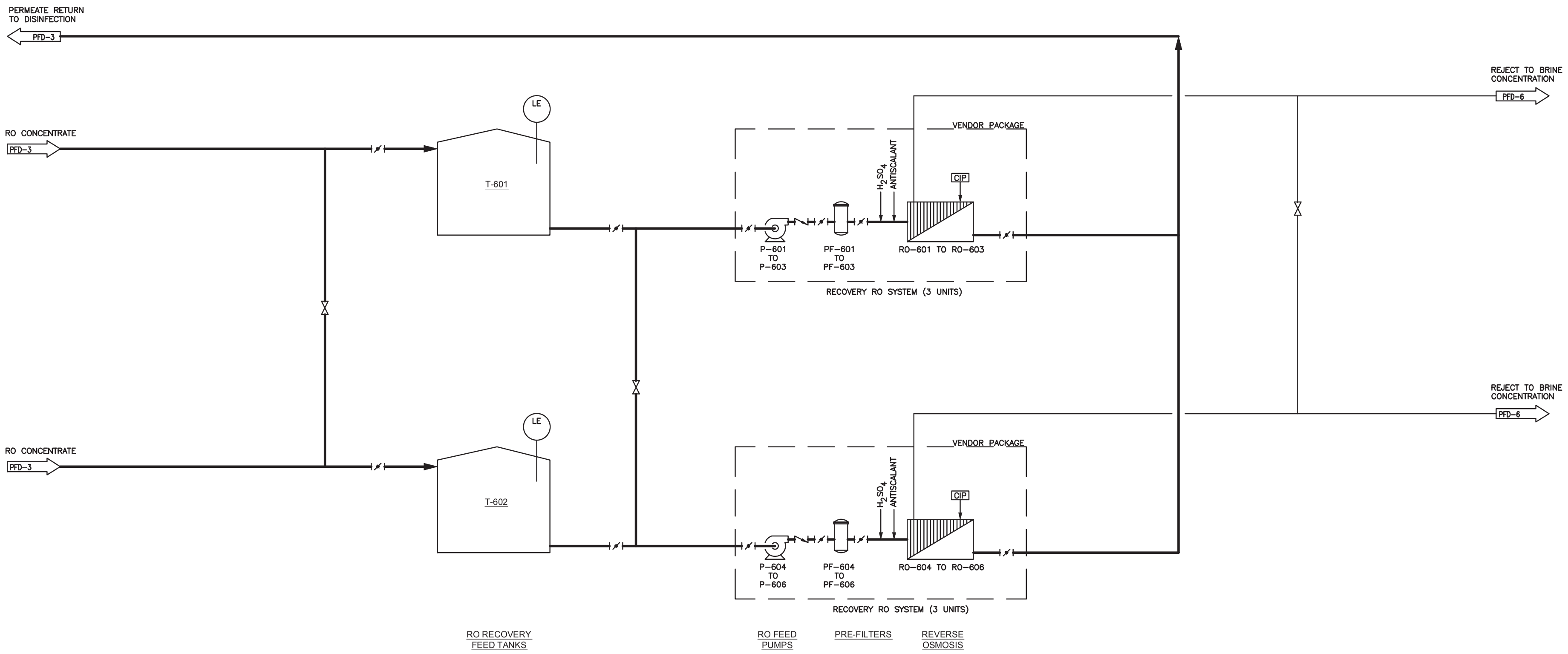
	SECONDARY EFFLUENT	SLIP STREAM	UF PERMEATE	UF REJECT	RO PERMEATE	RO CONCENTRATE	RECOVERY RO PERMEATE	EVAPORATOR DISTILLATE	CRYSTALLIZER DISTILLATE	BLENDED SECONDARY EFFLUENT
FLOW	44.6 MGD	15.5 MGD	15.0 MGD	0.5 MGD	12.8 MGD	2.3 MGD	0.79 MGD	1.3 MGD	0.132 MGD	44.1 MGD
CHLORIDE	449 mg/L	449 mg/L	449 mg/L	449 mg/L	22 mg/L	2,865 mg/L	143 mg/L	43 mg/L	429 mg/L	308 mg/L
	166,850 lbs/day	57,916 lbs/day	56,179 lbs/day	1,737 lbs/day	2,388 lbs/day	53,791 lbs/day	941 lbs/day	476 lbs/day	471 lbs/day	113,210 lbs/day
TOTAL PHOSPHORUS	0.30 mg/L	0.30 mg/L	0.17 mg/L	4.4 mg/L	0.00 mg/L	1.1 mg/L	0.02 mg/L	0.02 mg/L	0.2 mg/L	0.2 mg/L
	112 lbs/day	39 lbs/day	22 lbs/day	17 lbs/day	.4 lbs/day	21 lbs/day	.1 lbs/day	0.2 lbs/day	0.2 lbs/day	74 lbs/day
ORTHO PHOSPHORUS	0.17 mg/L	0.17 mg/L	0.17 mg/L	0.17 mg/L	0.00 mg/L	1.1 mg/L	0.02 mg/L	0.02 mg/L	0.2 mg/L	0.1 mg/L
	65 lbs/day	22 lbs/day	22 lbs/day	1 lbs/day	.4 lbs/day	21 lbs/day	.1 lbs/day	0.2 lbs/day	0.2 lbs/day	43 lbs/day
AMMONIA	0.30 mg/L	0.30 mg/L	0.30 mg/L	0.30 mg/L	0.05 mg/L	1.7 mg/L	0.28 mg/L	1.25 mg/L	6.90 mg/L	0.27 mg/L
	112 lbs/day	39 lbs/day	38 lbs/day	1 lbs/day	5 lbs/day	32 lbs/day	2 lbs/day	14 lbs/day	8 lbs/day	101 lbs/day
NITRATE	18.7 mg/L	18.7 mg/L	18.7 mg/L	18.7 mg/L	2.99 mg/L	108 mg/L	17.2 mg/L	1.56 mg/L	15.5 mg/L	13.6 mg/L
	6,952 lbs/day	2,413 lbs/day	2,341 lbs/day	72 lbs/day	318 lbs/day	2,022 lbs/day	113 lbs/day	17 lbs/day	17 lbs/day	5,005 lbs/day

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

UF/RO CHLORIDE REMOVAL SYSTEM ALTERNATE

AECOM

Figure: PFD-3



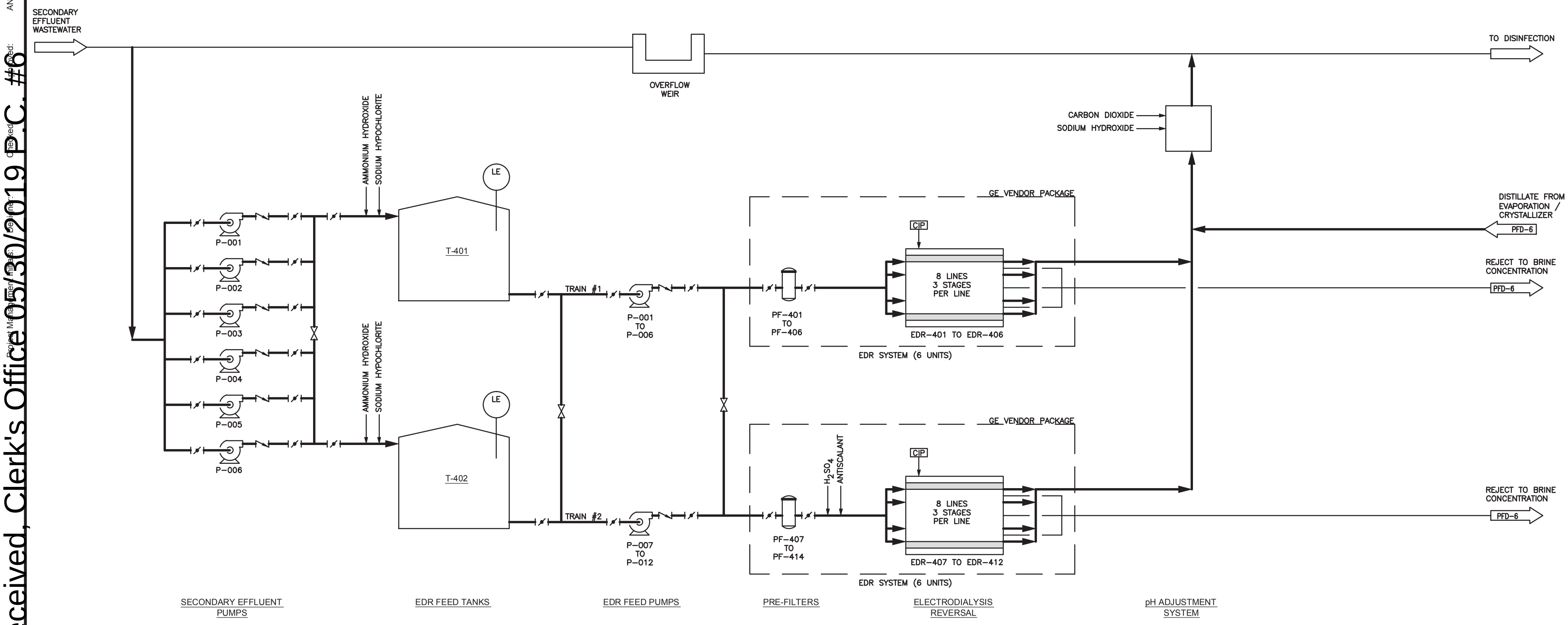
MASS BALANCE			
	RECOVERY RO FEED	RECOVERY RO PERMEATE	RECOVERY RO CONCENTRATE
FLOW	2.5 MGD	0.79 MGD	1.7 MGD
CHLORIDE	2,565 mg/L	143 mg/L	4,380 mg/L
	53,791 lbs/day	941 lbs/day	52,850 lbs/day
TOTAL PHOSPHORUS	1.0 mg/L	0.22 mg/L	1.7 mg/L
	21 lbs/day	1 lbs/day	20 lbs/day
ORTHOPHOSPHORUS	1.0 mg/L	0.22 mg/L	1.7 mg/L
	21 lbs/day	1 lbs/day	20 lbs/day
AMMONIA	1.5 mg/L	0.28 mg/L	2.5 mg/L
	32 lbs/day	2 lbs/day	30 lbs/day
NITRATE	106 mg/L	17.2 mg/L	136 mg/L
	2,018 lbs/day	113 lbs/day	1,905 lbs/day

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

RO CONCENTRATE RECOVERY FOR UF / RO
CHLORIDE REMOVAL SYSTEM ALTERNATE

AECOM

Figure: PFD-4



MASS BALANCE

	SECONDARY EFFLUENT	SLIP STREAM	EDR PERMEATE	EDR CONCENTRATE	EVAPORATOR DISTILLATE	CRYSTALLIZER DISTILLATE	BLENDED SECONDARY EFFLUENT
FLOW	44.6 MGD	15.0 MGD	13.5 MGD	1.5 MGD	1.4 MGD	0.14 MGD	44.5 MGD
CHLORIDE	449 mg/L	449 mg/L	36 mg/L	4,165 mg/L	42 mg/L	413 mg/L	311 mg/L
	166,850 lbs/day	56,179 lbs/day	4,045 lbs/day	52,134 lbs/day	469 lbs/day	465 lbs/day	115,651 lbs/day
TOTAL PHOSPHORUS	0.30 mg/L	0.30 mg/L	0.04 mg/L	2.6 mg/L	0.03 mg/L	0.26 mg/L	0.2 mg/L
	112 lbs/day	38 lbs/day	5 lbs/day	33 lbs/day	0.3 lbs/day	0.3 lbs/day	79 lbs/day
ORTHO PHOSPHORUS	0.17 mg/L	0.17 mg/L	0.02 mg/L	1.5 mg/L	0.02 mg/L	0.15 mg/L	0.1 mg/L
	65 lbs/day	22 lbs/day	3 lbs/day	19 lbs/day	0.2 lbs/day	0.2 lbs/day	46 lbs/day
AMMONIA	0.30 mg/L	0.30 mg/L	0.03 mg/L	2.8 mg/L	1.38 mg/L	7.58 mg/L	0.27 mg/L
	112 lbs/day	38 lbs/day	3 lbs/day	35 lbs/day	16 lbs/day	9 lbs/day	101 lbs/day
NITRATE	18.7 mg/L	18.7 mg/L	1.68 mg/L	172 mg/L	1.72 mg/L	17 mg/L	13.0 mg/L
	6,952 lbs/day	2,341 lbs/day	190 lbs/day	2,151 lbs/day	19 lbs/day	19 lbs/day	4,839 lbs/day

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

EDR CHLORIDE REMOVAL SYSTEM ALTERNATE

AECOM

Figure: PFD-5

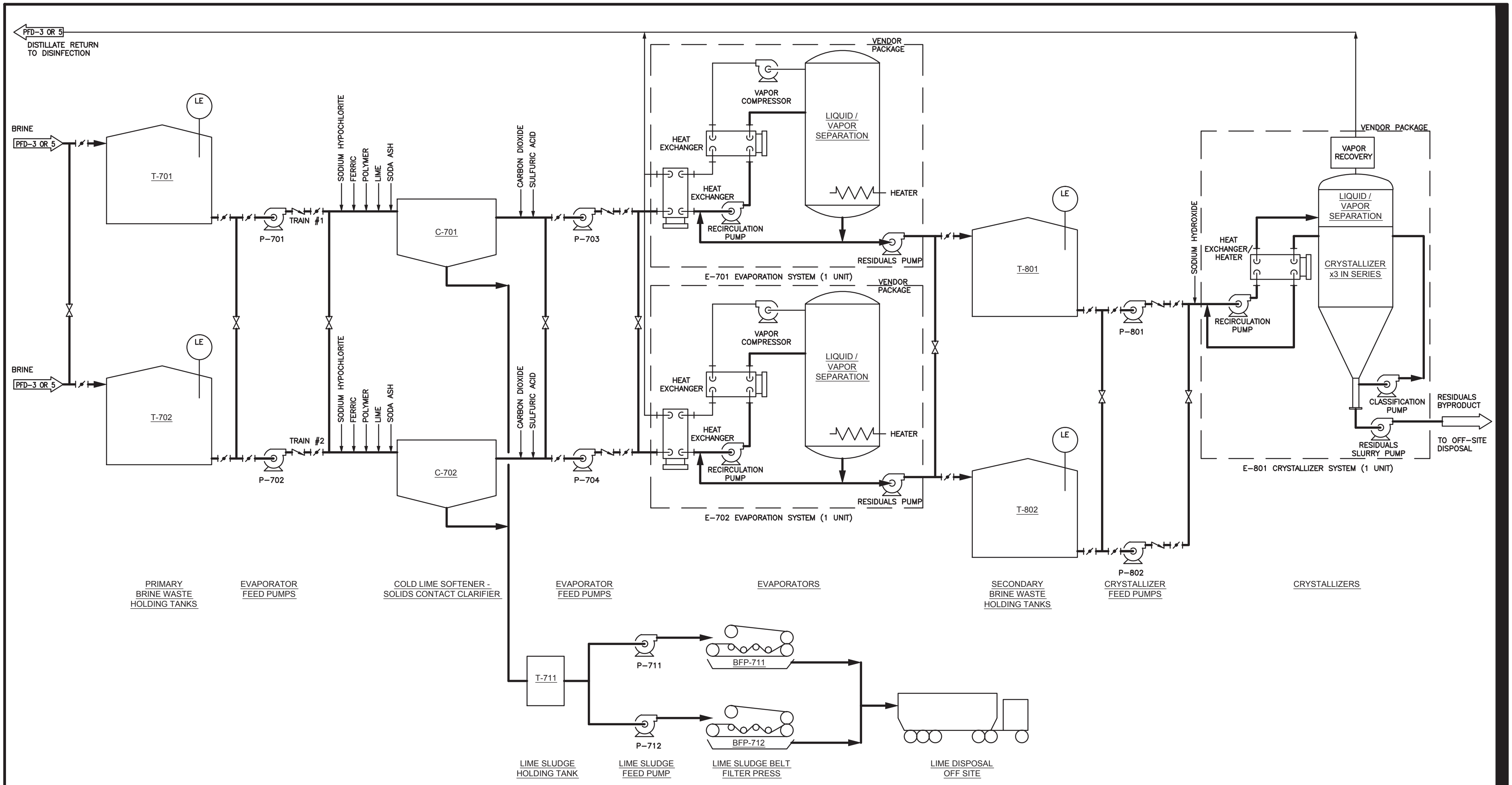
ANSI B 11" x 17"

Approved:

Checked:

Designer:

Project Management Initials:



MASS BALANCE -UF/RO					
	EVAPORATOR FEED	EVAPORATOR DISTILLATE	EVAPORATOR RESIDUALS	CRYSTALLIZER DISTILLATE	CRYSTALLIZER RESIDUALS
FLOW	1.5 MGD	1.3 MGD	0.15 MGD	0.13 MGD	0.015 MGD
CHLORIDE	4,330 mg/L	43.3 mg/L	42,913 mg/L	429 mg/L	425,272 mg/L
	52,850 lbs/day	476 lbs/day	52,374 lbs/day	471 lbs/day	51,903 lbs/day
TOTAL PHOSPHORUS	1.7 mg/L	0.02 mg/L	17 mg/L	0.17 mg/L	0,171 mg/L
	21 lbs/day	0.2 lbs/day	21 lbs/day	0.2 lbs/day	21 lbs/day
ORTHO PHOSPHORUS	1.7 mg/L	0.02 mg/L	17 mg/L	0.17 mg/L	0,171 mg/L
	21 lbs/day	0.2 lbs/day	21 lbs/day	0.2 lbs/day	21 lbs/day
AMMONIA	2.5 mg/L	1.3 mg/L	13.8 mg/L	6.9 mg/L	75.9 mg/L
	31 lbs/day	14 lbs/day	17 lbs/day	8 lbs/day	9 lbs/day
NITRATE	156 mg/l	2 mg/l	1,550 mg/L	16 mg/l	15,363 mg/L
	1,909 lbs/day	17 lbs/day	1,892 lbs/day	17 lbs/day	1,875 lbs/day

MASS BALANCE - EDR					
	EVAPORATOR FEED	EVAPORATOR DISTILLATE	EVAPORATOR RESIDUALS	CRYSTALLIZER DISTILLATE	CRYSTALLIZER RESIDUALS
FLOW	1.5 MGD	1.4 MGD	0.15 MGD	0.14 MGD	0.015 MGD
CHLORIDE	4,165 mg/L	41.6 mg/L	41,274 mg/L	413 mg/L	419,511 mg/L
	52,134 lbs/day	460 lbs/day	51,664 lbs/day	465 lbs/day	51,200 lbs/day
TOTAL PHOSPHORUS	2.6 mg/L	0.03 mg/L	26 mg/L	0.26 mg/L	0,264 mg/L
	33 lbs/day	0.3 lbs/day	33 lbs/day	0.3 lbs/day	32 lbs/day
ORTHO PHOSPHORUS	1.5 mg/L	0.02 mg/L	15 mg/L	0.15 mg/L	0.153 mg/L
	19 lbs/day	0.2 lbs/day	19 lbs/day	0.2 lbs/day	19 lbs/day
AMMONIA	2.8 mg/L	1.4 mg/L	15.2 mg/L	7.6 mg/L	85.5 mg/L
	35 lbs/day	16 lbs/day	19 lbs/day	9 lbs/day	10 lbs/day
NITRATE	172 mg/L	2 mg/L	1,703 mg/L	17 mg/L	17,310 mg/L
	2,151 lbs/day	19 lbs/day	2,132 lbs/day	19 lbs/day	2,113 lbs/day

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AECOM

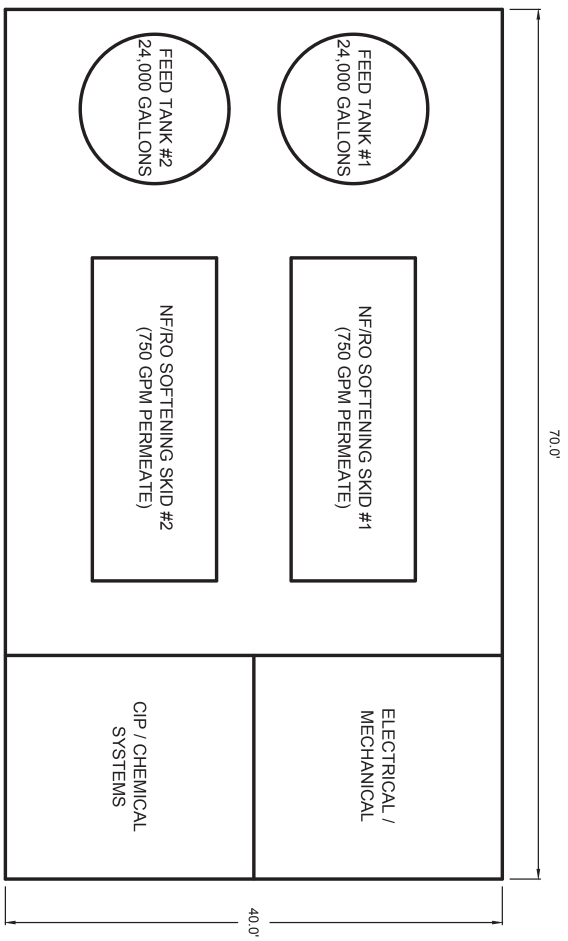
Figure: PFD-6

BRINE CONCENTRATE,
EVAPORATION / CRYSTALLIZATON -
CHLORIDE REMOVAL SYSTEM

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

Appendix C

Site Plans



CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

SITE PLAN
SOURCE WATER SOFTENING ALTERNATIVE 1A
WELLHEAD TREATMENT

AECOM

Figure: C-1A

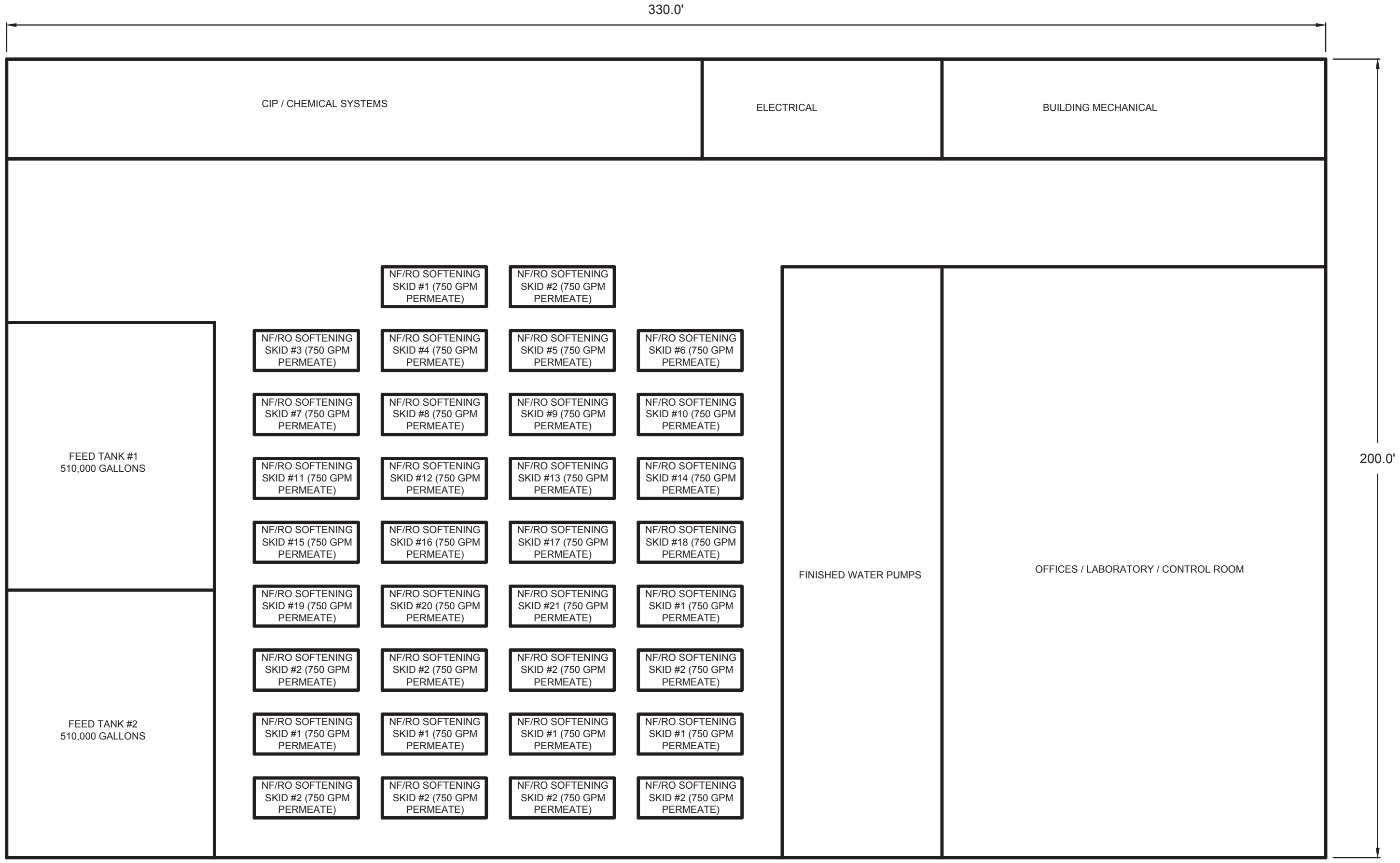
ANSI B 11" x 17"

Approved:

Checked:

Designer:

Project Management Initials:



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SCALE: 1" = 30'

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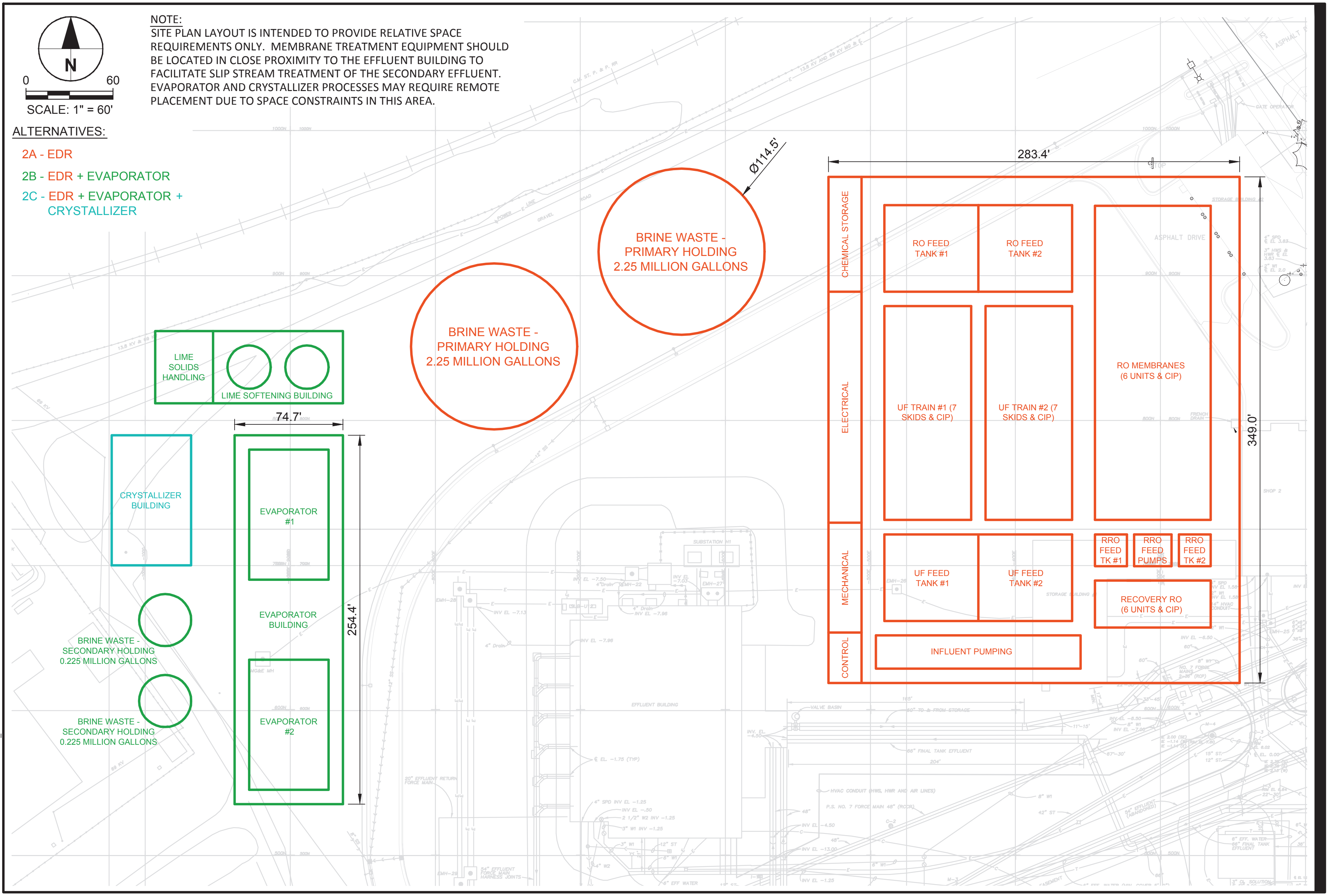
Figure: C-1B

SITE PLAN
SOURCE WATER SOFTENING ALTERNATIVE 1B
CENTRALIZED TREATMENT

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015



NOTE:
SITE PLAN LAYOUT IS INTENDED TO PROVIDE RELATIVE SPACE REQUIREMENTS ONLY. MEMBRANE TREATMENT EQUIPMENT SHOULD BE LOCATED IN CLOSE PROXIMITY TO THE EFFLUENT BUILDING TO FACILITATE SLIP STREAM TREATMENT OF THE SECONDARY EFFLUENT. EVAPORATOR AND CRYSTALLIZER PROCESSES MAY REQUIRE REMOTE PLACEMENT DUE TO SPACE CONSTRAINTS IN THIS AREA.

ALTERNATIVES:
- 2A - EDR
- 2B - EDR + EVAPORATOR
- 2C - EDR + EVAPORATOR + CRYSTALLIZER

AECOM

Figure: C-2

SITE PLAN - UF / RO ALTERNATIVE 2

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

ANSI B 11" x 17"
Approved:
Checked:
Designer:
Project Management Initials:
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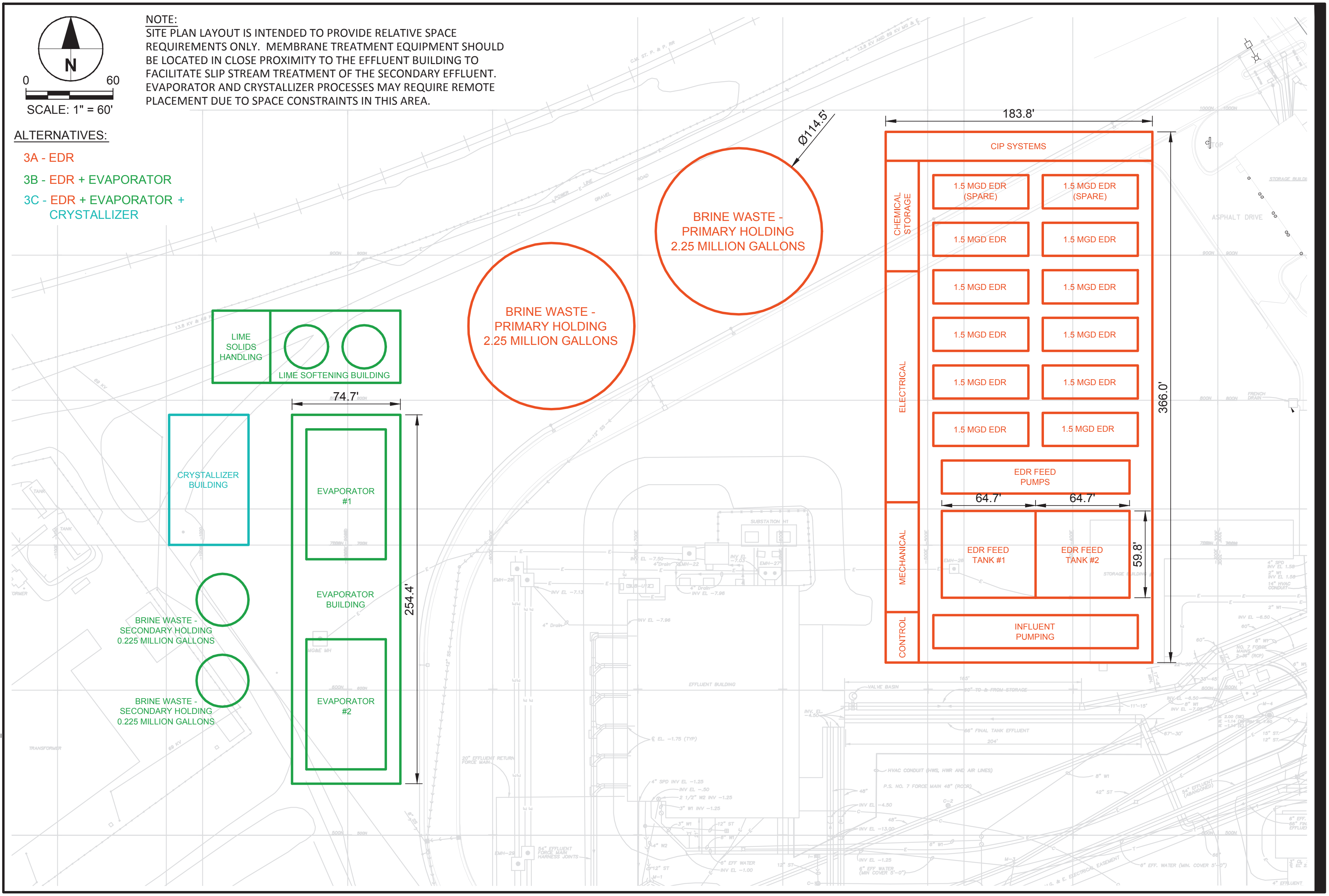


NOTE:
SITE PLAN LAYOUT IS INTENDED TO PROVIDE RELATIVE SPACE REQUIREMENTS ONLY. MEMBRANE TREATMENT EQUIPMENT SHOULD BE LOCATED IN CLOSE PROXIMITY TO THE EFFLUENT BUILDING TO FACILITATE SLIP STREAM TREATMENT OF THE SECONDARY EFFLUENT. EVAPORATOR AND CRYSTALLIZER PROCESSES MAY REQUIRE REMOTE PLACEMENT DUE TO SPACE CONSTRAINTS IN THIS AREA.

ALTERNATIVES:
- 3A - EDR
- 3B - EDR + EVAPORATOR
- 3C - EDR + EVAPORATOR + CRYSTALLIZER

ANSI B 11" x 17"
Approved:
Checked:
Designer:
Project Management Initials:

Last saved by: EGGERDINGD(2015-02-13) Last Plotted: 2015-02-13
Filename: P:\60329238\900-CAD-GIS\60329238_C1.DWG

AECOM
Figure: C-3

SITE PLAN - EDR ALTERNATIVE 3

CHLORIDE EFFLUENT LIMIT COMPLIANCE OPTIONS
MADISON METROPOLITAN SEWAGE DISTRICT
NINE SPRINGS WASTEWATER TREATMENT PLANT
Project No.: 60329238 Date: FEB. 13, 2015

Appendix D

Cost Projections

AECOM

Source Water Well Head Softening Treatment - 2.5 MGD Capacity

Rough Construction Cost Estimate		Estimate/Rev Date:	1/23/2015
Client:	Madison Metropolitan Sewerage District	Project No.:	60329238
Project:	**Chloride Treatment Feasibility Study**	Sales Tax:	
Location:	Madison , Wisconsin	Building S.F.:	
		Site S.F.:	Default Rate:

	Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
		General Conditions & Mobilization						
		All trades (10% of construction cost)	1	LS	$286,872.43	$286,872	$286,872	Estimate based on past construction experience
		Civil/Site Work Trades						
		Erosion control	400	LF	$7.50	$3,000	$3,000	Estimate based on experience and preliminary takeoff
		Fencing / security allowance	400	LF	$30.00	$12,000	$12,000	Estimate based on experience and preliminary takeoff
		Softening building excavation	741	CYD	$25.00	$18,519	$18,519	Estimate based on experience and preliminary takeoff
		Softening building foundation	181	CYD	$750.00	$135,833	$135,833	Estimate based on experience and preliminary takeoff
		Yard piping - potable water modifications and sanitary sewer connection	1	LS	$50,000.00	$50,000	$50,000	Allowance based on past experience
		Site electrical upgrade allowance	1	LS	$50,000.00	$50,000	$50,000	Allowance based on past experience
		General site grading allowance	10,000	SF	$1.00	$10,000	$10,000	Estimate based on experience and preliminary takeoff
		Gravel drive allowance	75	LF	$60.00	$4,500	$4,500	Estimate based on experience and preliminary takeoff
		Buildings						
		Softening building	2,800	SF	$100.00	$280,000	$280,000	Estimate based on experience and preliminary takeoff
		Equipment						
	T-201, T-202	Feed tank (24,000 gallon each)	2	EA	$45,000.00	$90,000	$90,000	Estimate based on past construction experience
	P-301, P-302	Feed pumps (800 gpm each)	2	EA	$40,000.00	$80,000	$80,000	Estimate based on past construction experience
	NF/RO-301, NF/RO-302	NF or RO softening systems (includes pump & pre-filter) (640 gpm permeate capacity)	2	EA	$400,000.00	$800,000	$800,000	Budget quote - Newterra
		CIP system (included in NF or RO treatment system)	1	LS	$0.00	$0	$0	Budget quote - Newterra
		Acid chemical feed system	1	LS	$10,000.00	$10,000	$10,000	Estimate based on past construction experience
		Antiscalant chemical feed system	1	LS	$10,000.00	$10,000	$10,000	Estimate based on past construction experience
		Misc. chemical feed systems	1	LS	$20,000.00	$20,000	$20,000	Estimate based on past construction experience
		Process piping and valves allowance	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
		Freight allowance (5% of equipment cost)	1	LS	$53,000.00	$53,000	$53,000	Estimate based on past construction experience
		Construction Trades						
		Mechanical allowance (50% of equipment costs)	1	LS	$530,000.00	$530,000	$530,000	Estimate based on past construction experience
		Electrical allowance	1	LS	$250,000.00	$250,000	$250,000	Estimate based on past construction experience
		Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$125,000.00	$125,000	$125,000	Estimate based on past construction experience

Estimated Construction Cost			$2,868,724
Engineering Services	20%		$573,745
Contingency	25%		$717,181
Total			**$4,159,650**

Note:

Taxes are excluded.

Costs estimated based on past construction experience and conceptual level budget quotes

Does not include any land procurement.

AECOM

Source Water Centralized Softening Treatment - 50 MGD Capacity

Rough Construction Cost Estimate

Client:	Madison Metropolitan Sewerage District	**Estimate/Rev Date:**	1/23/2015
Project:	**Chloride Treatment Feasibility Study**	**Project No.:**	60329238
Location:	Madison , Wisconsin	**Sales Tax:**	
		Building S.F.:	
		Site S.F.:	**Default Rate:**

Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
	General Conditions & Mobilization						
	All trades (10% of construction cost)	1	LS	$5,193,074.38	$5,193,074	$5,193,074	Estimate based on past construction experience
	Civil/Site Work Trades						
	Erosion control	1,860	LF	$7.50	$13,950	$13,950	Estimate based on experience and preliminary takeoff
	Fencing / security allowance	1,860	LF	$30.00	$55,800	$55,800	Estimate based on experience and preliminary takeoff
	Softening building excavation	13,222	CYD	$25.00	$330,556	$330,556	Estimate based on experience and preliminary takeoff
	Softening building foundation	4,197	CYD	$750.00	$3,147,500	$3,147,500	Estimate based on experience and preliminary takeoff
	Clearwell excavation	22,122	CYD	$25.00	$553,056	$553,056	Estimate based on experience and preliminary takeoff
	Yard piping	1	LS	$300,000.00	$300,000	$300,000	Allowance based on past experience
	Site electrical upgrade allowance	1	LS	$500,000.00	$500,000	$500,000	Allowance based on past experience
	General site grading allowance	212,000	SF	$1.00	$212,000	$212,000	Estimate based on experience and preliminary takeoff
	Paved drive allowance	26,500	SF	$7.50	$198,750	$198,750	Estimate based on experience and preliminary takeoff
	Buildings						
	Softening building	66,000	SF	$100.00	$6,600,000	$6,600,000	Estimate based on experience and preliminary takeoff
	Equipment						
T-201, T-202	Feed tanks - concrete (2 @ 510,000 gallons each)	1,169	CYD	$750.00	$877,000	$877,000	Estimate based on experience and preliminary takeoff
P-301 to P-334	Feed pumps (900 gpm each)	34	EA	$40,000.00	$1,360,000	$1,360,000	Estimate based on past construction experience
NF/RO-301 to NF/RO-334	NF or RO softening systems (includes pump & pre-filter) (750 gpm permeate capacity)	34	EA	$368,000.00	$12,512,000	$12,512,000	Budget quote - Newterra
	CIP system (included in NF or RO treatment system)	1	LS	$0.00	$0	$0	Budget quote - Newterra
	Acid chemical feed system	1	LS	$150,000.00	$150,000	$150,000	Estimate based on past construction experience
	Antiscalant chemical feed system	1	LS	$120,000.00	$120,000	$120,000	Estimate based on past construction experience
	Chlorination system - Sodium hypochlorite	1	LS	$225,000.00	$225,000	$225,000	Estimate based on past construction experience
T-401, T-402	Clearwell - concrete (2 @ 0.8 MG)	2,820	CYD	$750.00	$2,115,208	$2,115,208	Estimate based on experience and preliminary takeoff
P-401 to P-407	Finished water pumps (5,800 gpm each)	7	EA	$200,000.00	$1,400,000	$1,400,000	Estimate based on past construction experience
	Process piping and valves allowance	1	LS	$900,000.00	$900,000	$900,000	Estimate based on past construction experience
	Freight allowance (5% of equipment cost; excludes concrete tanks)	1	LS	$833,350.00	$833,350	$833,350	Estimate based on past construction experience
	Construction Trades						
	Mechanical allowance (50% of equipment costs; excluding tanks)	1	LS	$8,333,500.00	$8,333,500	$8,333,500	Estimate Based on Past Construction Experience
	Electrical allowance	1	LS	$4,000,000.00	$4,000,000	$4,000,000	Estimate Based on Means Data and Preliminary Takeoff
	Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$2,000,000.00	$2,000,000	$2,000,000	Estimate Based on Past Construction Experience

Note:

Piping to and from centralized treatment location is excluded.

Taxes are excluded.

Costs estimated based on past construction experience and conceptual level budget quotes

Does not include any land procurement.

Estimated Construction Cost		$51,930,744
Engineering Services	20%	$10,386,149
Contingency	25%	$12,982,686
Total		**$75,299,579**

AECOM

NSWTP UF/RO Chloride Reduction - 15 MGD

Estimate/Rev Date: 1/23/2015

Rough Construction Cost Estimate

Project No.: 60329238
Client: Madison Metropolitan Sewerage District
Sales Tax:
Project: **Chloride Treatment Feasibility Study**
Building S.F.:
Location: Madison , Wisconsin
Site S.F.:
Default Rate:

Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
	General Conditions & Mobilization						
	All trades (10% of construction cost)	1	LS	$5,988,477.10	$5,988,477	$5,988,477	Estimate based on past construction experience
	Civil/Site Work Trades						
	Erosion control	2,300	LF	$7.50	$17,250	$17,250	Estimate based on experience and preliminary takeoff
	Membrane building excavation	20,000	CYD	$25.00	$500,000	$500,000	Estimate based on experience and preliminary takeoff
	Membrane building foundation	5,994	CYD	$750.00	$4,495,833	$4,495,833	Estimate based on experience and preliminary takeoff
	Brine waste holding tank excavation - Primary	7,000	CYD	$25.00	$175,000	$175,000	Estimate based on experience and preliminary takeoff
	Brine waste holding tank foundation - Primary	2,895	CYD	$750.00	$2,171,250	$2,171,250	Estimate based on experience and preliminary takeoff
	Diversion structure excavation	1,037	CYD	$25.00	$25,926	$25,926	Estimate based on experience and preliminary takeoff
	Diversion structure concrete	133	CYD	$750.00	$100,000	$100,000	Estimate based on experience and preliminary takeoff
	Yard piping	1	LS	$200,000.00	$200,000	$200,000	Allowance based on past experience
	Site electrical upgrade allowance	1	LS		$0	$0	
	General site grading allowance	228,000	SF	$1.00	$228,000	$228,000	Estimate based on experience and preliminary takeoff
	Paved drive allowance	33,000	SF	$7.50	$247,500	$247,500	Estimate based on experience and preliminary takeoff
	Buildings						
	Membrane building	101,500	SF	$100.00	$10,150,000	$10,150,000	Estimate based on experience and preliminary takeoff
	Equipment						
P-001 to P-006	Secondary effluent pumps (3.0 MGD each)	6	EA	$75,000.00	$450,000	$450,000	Estimate based on past construction experience
T-401, T-402	UF feed tanks - concrete (2 @ 320,000 gallons each)	427	CYD	$750.00	$320,000	$320,000	Estimate based on experience and preliminary takeoff
P-401 to P-414	UF feed pumps (1.3 MGD each)	14	EA	$40,000.00	$560,000	$560,000	Estimate based on past construction experience
UF-401 to UF-414	UF pretreatment system (includes recirc. pump & pre-filter) (1.3 MGD capacity each)	14	EA	$458,333.33	$6,416,667	$6,416,667	Budget quote - Evoqua
	UF CIP system (included in UF pretreatment system)	2	EA	$0.00	$0	$0	Budget quote - Evoqua
T-501, T-502	RO feed tanks - concrete (320,000 gallons each)	427	CYD	$750.00	$320,000	$320,000	Estimate based on experience and preliminary takeoff
RO-501 to RO-506	RO treatment system (includes pump and pre-filter) (3.0 MGD capacity each)	6	EA	$1,979,500.00	$11,877,000	$11,877,000	Budget quote - Evoqua
	RO CIP system (included in RO treatment system)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
T-601, T-602	Recovery RO feed tanks - Concrete (47,000 gallons each)	110	CYD	$750.00	$82,500	$82,500	Estimate based on experience and preliminary takeoff
RO-601 to RO-606	Recovery RO treatment system (includes pump & pre-filter) (0.45 MGD capacity each)	6	EA	$256,000.00	$1,536,000	$1,536,000	Budget quote - Evoqua
	Recovery RO CIP system (included in RO treatment system)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
	Acid chemical feed systems (included in UF and RO packages)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
	Antiscalant chemical feed system (included in UF and RO packages)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
	Ammonium hydroxide chemical feed system (included in UF and RO packages)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
	Sodium hypochlorite chemical feed system (included in UF and RO packages)	1	LS	$0.00	$0	$0	Budget quote - Evoqua
	Acid bulk storage systems	1	LS	$75,000.00	$75,000	$75,000	Estimate based on past construction experience
	Antiscalant bulk storage systems	1	LS	$40,000.00	$40,000	$40,000	Estimate based on past construction experience
	Ammonium hydroxide bulk storage systems	1	LS	$75,000.00	$75,000	$75,000	Estimate based on past construction experience
	Sodium hypochlorite bulk storage system	1	LS	$75,000.00	$75,000	$75,000	Estimate based on past construction experience
	Final pH adjustment allowance	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
T-701, T-702	Brine waste holding tanks (coated steel) - Primary 2.25 MG each	2	EA	$424,384.50	$848,769	$848,769	Budget quote - Tank Connection
	Tank roof adder	2	EA	$224,537.00	$449,074	$449,074	Budget quote - Tank Connection
	Process piping and valves allowance	1	LS	$1,200,000.00	$1,200,000	$1,200,000	Estimate based on past construction experience
	Freight allowance (5% of equipment cost; excludes tanks)	1	LS	$1,121,858.33	$1,121,858	$1,121,858	Estimate based on past construction experience

		Construction Trades						
		Mechanical allowance (25% of equipment costs; excluding tanks)	1	LS	$5,588,666.67	$5,588,667	$5,588,667	Estimate based on past construction experience
		Electrical allowance	1	LS	$3,000,000.00	$3,000,000	$3,000,000	Estimate based on past construction experience
		Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$1,500,000.00	$1,500,000	$1,500,000	Estimate based on past construction experience
		Note:						
			Estimated Construction Cost				$59,884,771	
		Taxes are excluded.	**Engineering Services**		20%		$11,976,954	
		Costs estimated based on past construction experience and conceptual level budget quotes	**Contingency**		25%		$14,971,193	
		Does not include any land procurement.						
			Total				**$86,832,918**	

AECOM

NSWTP EDR Chloride Reduction - 15 MGD

Rough Construction Cost Estimate		**Estimate/Rev Date:**	1/23/2015
Client:	Madison Metropolitan Sewerage District	**Project No.:**	60329238
Project:	**Chloride Treatment Feasibility Study**	**Sales Tax:**	
Location:	Madison , Wisconsin	**Building S.F.:**	
		Site S.F.:	**Default Rate:**

Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
	General Conditions & Mobilization						
	All trades (10% of construction cost)	1	LS	$5,574,042.12	$5,574,042	$5,574,042	Estimate based on past construction experience
	Civil/Site Work Trades						
	Erosion control	2,050	CYD	$7.50	$15,375	$15,375	Estimate based on experience and preliminary takeoff
	Membrane building excavation	14,074	CYD	$25.00	$351,852	$351,852	Estimate based on experience and preliminary takeoff
	Membrane building foundation	4,341	CYD	$750.00	$3,255,833	$3,255,833	Estimate based on experience and preliminary takeoff
	Brine waste holding tank excavation - Primary	7,000	CYD	$25.00	$175,000	$175,000	Estimate based on experience and preliminary takeoff
	Brine waste holding tank foundation - Primary	2,895	CYD	$750.00	$2,171,250	$2,171,250	Estimate based on experience and preliminary takeoff
	Diversion structure excavation	1,037	CYD	$25.00	$25,926	$25,926	Estimate based on experience and preliminary takeoff
	Diversion structure concrete	133	CYD	$750.00	$100,000	$100,000	Estimate based on experience and preliminary takeoff
	Yard piping	1	LS	$200,000.00	$200,000	$200,000	Allowance based on past experience
	Site electrical upgrade allowance	1	LS		$0	$0	
	General site grading allowance	188,800	SF	$1.00	$188,800	$188,800	Estimate based on experience and preliminary takeoff
	Paved drive allowance	30,000	SF	$7.50	$225,000	$225,000	Estimate based on experience and preliminary takeoff
	Buildings						
	Membrane building	70,300	SF	$100.00	$7,030,000	$7,030,000	Estimate based on experience and preliminary takeoff
	Equipment						
P-001 to P-006	Secondary effluent pumps (3.0 MGD each)	6	EA	$75,000.00	$450,000	$450,000	Estimate based on past construction experience
T-401, T-402	EDR feed tanks - concrete (2 @ 320,000 gallons)	427	CYD	$750.00	$320,000	$320,000	Estimate based on experience and preliminary takeoff
P-401 to P-412	EDR feed pumps (1.5 MGD each)	12	EA	$40,000.00	$480,000	$480,000	Estimate based on past construction experience
EDR-401 to EDR-412	EDR treatment system (includes recirc. pump & pre-filter) (1.5 MGD capacity each)	12	EA	$1,750,000.00	$21,000,000	$21,000,000	Budget quote - GE
	EDR CIP system	2	EA	$50,000.00	$100,000	$100,000	Estimate based on past construction experience
	Acid chemical feed system w/ storage	1	LS	$90,000.00	$90,000	$90,000	Estimate based on past construction experience
	Antiscalant chemical feed system w/ storage	1	LS	$65,000.00	$65,000	$65,000	Estimate based on past construction experience
	Ammonium hydroxide chemical feed system w/ storage	1	LS	$90,000.00	$90,000	$90,000	Estimate based on past construction experience
	Sodium hypochlorite chemical feed system w/ storage	1	LS	$90,000.00	$90,000	$90,000	Estimate based on past construction experience
	Final pH adjustment allowance	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
T-701, T-702	Brine waste holding tanks (coated steel) - Primary 2.25 MG each	2	EA	$424,384.50	$848,769	$848,769	Budget quote - Tank Connection
	-Tank Roof Adder	2	EA	$224,537.00	$449,074	$449,074	Budget quote - Tank Connection
	Process piping and valves allowance	1	LS	$900,000.00	$900,000	$900,000	Estimate based on past construction experience
	Freight allowance (5% of equipment cost; excludes tanks)	1	LS	$1,165,750.00	$1,165,750	$1,165,750	Estimate based on past construction experience
	Construction Trades						
	Mechanical allowance (25% of equipment costs; excluding tanks)	1	LS	$5,828,750.00	$5,828,750	$5,828,750	Estimate based on past construction experience
	Electrical allowance	1	LS	$3,000,000.00	$3,000,000	$3,000,000	Estimate based on past construction experience
	Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$1,500,000.00	$1,500,000	$1,500,000	Estimate based on past construction experience

Note:

Taxes are excluded.

Costs estimated based on past construction experience and conceptual level budget quotes

Does not include any land procurement.

Estimated Construction Cost		$55,740,421
Engineering Services	20%	$11,148,084
Contingency	25%	$13,935,105
Total		**$80,823,611**

AECOM **Brine Waste Evaporator - 1.5 MGD**

Rough Construction Cost Estimate

Estimate/Rev Date:	2/9/2015		
Client:	Madison Metropolitan Sewerage District	**Project No.:**	60329238
Project:	**Chloride Treatment Feasibility Study**	**Sales Tax:**	
		Building S.F.:	
Location:	Madison , Wisconsin	**Site S.F.:**	**Default Rate:**

Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
	General Conditions & Mobilization						
	All trades (10% of construction cost)	1	LS	$5,786,101.99	$5,786,102	$5,786,102	Estimate based on past construction experience
	Civil/Site Work Trades						
	Erosion control	1,800	LF	$7.50	$13,500	$13,500	Estimate based on experience and preliminary takeoff
	Lime softening building excavation	1,556	CYD	$25.00	$38,889	$38,889	Estimate based on experience and preliminary takeoff
	Lime softening building foundation	661	CYD	$750.00	$496,111	$496,111	Estimate based on experience and preliminary takeoff
	Lime softening concrete tanks (2 @ 30' dia x 16' SWD)	241	CYD	$750.00	$180,642	$180,642	Estimate based on experience and preliminary takeoff
	Evaporator building excavation	4,500	CYD	$25.00	$112,500	$112,500	Estimate based on experience and preliminary takeoff
	Evaporator building foundation	1,937	CYD	$750.00	$1,453,056	$1,453,056	Estimate based on experience and preliminary takeoff
	Cooling tower excavation	239	CYD	$25.00	$5,963	$5,963	Estimate based on experience and preliminary takeoff
	Cooling tower foundation	102	CYD	$750.00	$76,500	$76,500	Estimate based on experience and preliminary takeoff
	Brine waste holding tank excavation - Secondary	1,111	CYD	$25.00	$27,778	$27,778	Estimate based on experience and preliminary takeoff
	Brine waste holding tank foundation - Secondary	473	CYD	$750.00	$355,000	$355,000	Estimate based on experience and preliminary takeoff
	Yard piping	1	LS	$150,000.00	$150,000	$150,000	Allowance based on past experience
	Site electrical upgrade allowance	1	LS		$0	$0	
	General site grading allowance	72,500	SF	$1.00	$72,500	$72,500	Estimate based on experience and preliminary takeoff
	Paved drive allowance	20,000	SF	$7.50	$150,000	$150,000	Estimate based on experience and preliminary takeoff
	Buildings						
	Lime softening building	6,500	SF	$125.00	$812,500	$812,500	Estimate based on experience and preliminary takeoff
	Evaporator building	20,800	SF	$125.00	$2,600,000	$2,600,000	Estimate based on experience and preliminary takeoff
	Equipment						
P-701, P-702	Cold lime softening feed pumps (520 gpm each)	2	EA	$45,000.00	$90,000	$90,000	Estimate based on past construction experience
C-701, C-702	Lime softening clarifier mechanism	2	EA	$400,000.00	$800,000	$800,000	Budget quote - WesTech
	Lime sludge chemical feed system allowance	1	LS	$1,500,000.00	$1,500,000	$1,500,000	Estimate based on past construction experience
T-711	Lime sludge holding tank	1	EA	$100,000.00	$100,000	$100,000	Estimate based on past construction experience
P-711, P-712	Lime sludge dewatering feed pumps (XXX gpm each)	2	EA	$40,000.00	$80,000	$80,000	Estimate based on past construction experience
BFP-711, BFP-712	Lime sludge belt fitler press	2	EA	$200,000.00	$400,000	$400,000	Estimate based on past construction experience
P-721, P-722	Evaporator feed pumps (520 gpm each)	2	EA	$45,000.00	$90,000	$90,000	Estimate based on past construction experience
E-721, E-722	Evaporator system (0.75 MGD each)	2	EA	$11,500,000.00	$23,000,000	$23,000,000	Budget quote - GEA
	Acid chemical feed system w/ storage	1	LS	$100,000.00	$100,000	$100,000	Estimate based on past construction experience
	Sodium hydroxide chemical feed system w/ storage	1	LS	$200,000.00	$200,000	$200,000	Estimate based on past construction experience
	Antiscalant feed system w/ storage	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
CT-721, CT-722	Cooling tower system (400 gpm 85F supply/100F return) 250 Ton	2	EA	$20,000.00	$40,000	$40,000	Estimate
T-801, T-802	Brine waste holding tanks (stainless steel) - Secondary 0.225 MG each	2	EA	$191,405.00	$382,810	$382,810	Budget quote - Tank Connection
	-Tank Roof Adder	2	EA	$46,587.00	$93,174	$93,174	Budget quote - Tank Connection
	Process piping and valves allowance	1	LS	$3,500,000.00	$3,500,000	$3,500,000	Estimate based on past construction experience
	Freight allowance (5% of equipment cost; excludes tanks which include shipping)	1	LS	$1,497,500.00	$1,497,500	$1,497,500	Estimate based on past construction experience
	Construction Trades						
	Mechanical allowance (25% of equipment costs; excluding tanks)	1	LS	$7,606,496.00	$7,606,496	$7,606,496	Estimate based on past construction experience
	Electrical allowance	1	LS	$4,000,000.00	$4,000,000	$4,000,000	Estimate based on past construction experience
	Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$2,000,000.00	$2,000,000	$2,000,000	Estimate based on past construction experience

Note:

Taxes are excluded.
Costs estimated based on past construction experience and conceptual level budget quotes
Does not include any land procurement.

Estimated Construction Cost		$57,861,020
Engineering Services	20%	$11,572,204
Contingency	25%	$14,465,255
Total		**$83,898,479**

AECOM

Brine Waste Crystallizer - 0.15 MGD

Rough Construction Cost Estimate		**Estimate/Rev Date:**	2/9/2015
Client:	Madison Metropolitan Sewerage District	**Project No.:**	60329238
Project:	**Chloride Treatment Feasibility Study**	**Sales Tax:**	
Location:	Madison , Wisconsin	**Building S.F.:**	
		Site S.F.:	**Default Rate:**

Equipment or Pipe ID	DESCRIPTION	QTY	UNIT	MAT/UNIT SUB	TOTAL MAT./SUB.	TOTAL L&M/SUB	SOURCE
	General Conditions & Mobilization						
	All trades (10% of construction cost)	1	LS	$1,569,088.31	$1,569,088	$1,569,088	Estimate based on past construction experience
	Civil/Site Work Trades						
	Erosion control	700	LF	$7.50	$5,250	$5,250	Estimate based on experience and preliminary takeoff
	Crystallizer building excavation	1,204	CYD	$25.00	$30,093	$30,093	Estimate based on experience and preliminary takeoff
	Crystallizer building foundation	536	CYD	$750.00	$401,875	$401,875	Estimate based on experience and preliminary takeoff
	Cooling tower excavation	179	CYD	$25.00	$4,472	$4,472	Estimate based on experience and preliminary takeoff
	Cooling tower foundation	77	CYD	$750.00	$57,375	$57,375	Estimate based on experience and preliminary takeoff
	Yard piping	1	LS	$75,000.00	$75,000	$75,000	Allowance based on past experience
	Site electrical upgrade allowance	1	LS		$0	$0	
	General site grading allowance	30,000	SF	$1.00	$30,000	$30,000	Estimate based on experience and preliminary takeoff
	Paved drive allowance	9,264	SF	$7.50	$69,480	$69,480	Estimate based on experience and preliminary takeoff
	Buildings						
	Crystallizer building	4,950	SF	$125.00	$618,750	$618,750	Estimate based on experience and preliminary takeoff
	Equipment						
P-801, P-802	Crystallizer feed pumps (0.075 MGD each)	2	EA	$30,000.00	$60,000	$60,000	Estimate based on past construction experience
E-801	Crystallizer system (0.075 MGD)	1	EA	$8,000,000.00	$8,000,000	$8,000,000	Budget quote - GEA
	Acid chemical feed system	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
	Sodium hydroxide chemical feed system	1	LS	$50,000.00	$50,000	$50,000	Estimate based on past construction experience
	Antiscalant feed system	1	LS	$25,000.00	$25,000	$25,000	Estimate based on past construction experience
CT-801	Cooling tower system (600 gpm 85F supply/100F return) 375 Ton	1	EA	$30,000.00	$30,000	$30,000	Estimate
	Process piping and valves allowance	1	LS	$500,000.00	$500,000	$500,000	Estimate based on past construction experience
	Freight allowance (5% of equipment cost; excludes tanks which include shipping)	1	LS	$435,750.00	$435,750	$435,750	Estimate based on past construction experience
	Construction Trades						
	Mechanical allowance (25% of equipment costs; excluding tanks)	1	LS	$2,178,750.00	$2,178,750	$2,178,750	Estimate based on past construction experience
	Electrical allowance	1	LS	$1,000,000.00	$1,000,000	$1,000,000	Estimate based on past construction experience
	Instrumentation & controls allowance (50% of electrical allowance cost)	1	LS	$500,000.00	$500,000	$500,000	Estimate based on past construction experience

Note:

Taxes are excluded.

Costs estimated based on past construction experience and conceptual level budget quotes

Does not include any land procurement.

Estimated Construction Cost		$15,690,883
Engineering Services	20%	$3,138,177
Contingency	25%	$3,922,721
Total		**$22,751,781**

Madison Metropolitan Sewerage District
Source Water NF or RO Softening at Wellhead (per well site - 2.5 MGD capacity operating at 1.5 MGD)
Annual O&M Cost Projection

Electrical Cost

		Current Conditions				
	Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR	
P-001	NF or RO feed pump	20.0 HP	12.0	14.91	178.97	
P-002	NF or RO feed pump	20.0 HP	12.0	14.91	178.97	
P-003	NF or RO system skid (2 Total Units)	366.6 HP	12.0	273.37	3,280.48	
	Misc. power requirements		24.0	10.00	240.00	
					3,878.42	
		$0.09	per KW*HR		$349.06	
		365	days		**$ 127,406**	**Annual Subtotal**

Sewer Disposal

	MGD	MGY	$/MG		
Reject and CIP waste to sanitary sewer	0.272	99.28	$625	**$ 62,050**	**Annual Subtotal**

Chemical Allowance

Antiscalants	$ 74,016	
Sodium bisulfite	$ 12,336	
CIP	$ 14,400	
	$ 100,752	**Annual Subtotal**

Labor Allowance

Assume 20 hours per week at $47.38/hour	**$ 49,275**	**Annual Subtotal**
	$ 339,483	**Annual Operations Total**

Maintenance Allowance

Mechanical and electrical capital costs	$ 1,435,000	
Assume 5% of mechanical and electrical capital cost	**$ 71,750**	**Annual Replacement Total**
Membrane / Filter replacement (see separate calculation)		
Filter bag changeout	$ 3,744	
NF or RO membranes	$ 78,400	
	$ 82,144	**Annual Membrane Total**
	$ 153,894	**Annual Maintenance Total**
	$ 493,377	**Annual Total O&M**

Madison Metropolitan Sewerage District
Source Water NF or RO Centralized Softening (50 MGD capacity)
Annual O&M Cost Projection

Electrical Cost

	Current Conditions				
Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR	
NF/RO feed pump (34 units)	680.0 HP	13.5	507.08	6,863.78	
NF/RO system Skid (34 Total Units)	6232.2 HP	13.5	4647.35	62,906.55	
Finished water pumps	3400.0 HP	13.5	2535.38	34,318.90	
Misc. power requirements		24.0	200.00	4,800.00	
				108,889.23	
	$0.09	per KW*HR		$9,800.03	
	365	days		**$ 3,577,011**	**Annual Subtotal**

Sewer Disposal

	MGD	MGY	$/MG		
Reject and CIP waste to sanitary sewer	5.10702	1864	$625	**$ 1,165,039**	**Annual Subtotal**

Chemical Allowance

Antiscalants	$ 1,391,500	
Sodium Hypochlorite	$ 212,606	
Sodium bisulfite	$ 231,917	
CIP	$ 244,800	
	$ 2,080,823	**Annual Subtotal**

Labor Allowance

Assume 240 hours per week at $47.38/hour	**$ 591,302**	**Annual Subtotal**
	$ 7,414,176	**Annual Operations Total**

Maintenance Allowance

Mechanical and electrical capital costs	$ 25,659,208	
Assume 5% of mechanical and electrical capital cost	**$ 1,282,960**	**Annual Replacement Total**
Membrane / Filter replacement (see separate calculation)		
Filter bag changeout	$ 63,648	
NF or RO membranes	$ 1,332,800	
	$ 1,396,448	**Annual Membrane Total**
	$ 2,679,408	**Annual Maintenance Total**
	$ 10,093,584	**Annual Total O&M**

Madison Metropolitan Sewerage District
NSWTP UF/RO Chloride Reduction
Annual O&M Cost Projection

Electrical Cost

			Current Conditions (average 2.6 MGD)				Assumed 2030 Conditions (Average 7.3 MGD)				Full capacity (15 MGD)			
	Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR	
P-001	Secondary effluent transfer pump #1	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-002	Secondary effluent transfer pump #2	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-003	Secondary effluent transfer pump #3	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-004	Secondary effluent transfer pump #4	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-005	Secondary effluent transfer pump #5	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-006	Secondary effluent transfer pump #6 (standby)	75.0 HP	0.0	55.93	0.00		0.0	55.93	0.00		0.0	55.93	0.00	
	UF feed pumps		4.2	247.85	1,040.97		11.7	247.85	2,894.90		24.0	247.85	5,948.42	
	UF backflush pumps		4.2	13.98	58.74		11.7	13.98	163.34		24.0	13.98	335.63	
	UF CIP pumps		4.2	5.01	21.05		11.7	5.01	58.54		24.0	5.01	120.29	
	UF membrane air scour blowers		4.2	20.81	87.42		11.7	20.81	243.10		24.0	20.81	499.52	
	UF CIP tank heater		4.2	5.13	21.56		11.7	5.13	59.97		24.0	5.13	123.22	
	RO System		4.2	775.00	3,255.00		11.7	775.00	9,052.00		24.0	775.00	18,600.00	
	RO Recovery System		4.2	649.69	2,728.69		11.7	649.69	7,588.35		24.0	649.69	15,592.50	
					8,376.72				23,326.36				47,930.88	
		$0.09	per KW*HR		$753.90				$2,099.37				$4,313.78	
		365	days		**$ 275,175**	**Annual Subtotal**			**$ 766,271**	**Annual Subtotal**			**$ 1,574,529**	**Annual Subtotal**

		Current Conditions		Assumed 2030 Conditions		Full capacity	
Chemical Allowance							
UF - Sodium Hypochlorite		$ 2,338		$ 6,563		$ 13,486	
UF -Citric Acid		$ 5,129		$ 14,400		$ 29,588	
RO - Sodium Hypochlorite		$ 5,500		$ 15,441		$ 31,729	
RO - Ammonium Hydroxide		$ 2,282		$ 6,407		$ 13,166	
RO - Antiscalants		$ 46,501		$ 130,561		$ 268,275	
RO - Sulfuric Acid		$ 70,138		$ 196,926		$ 404,642	
RO - CIP Chemicals		$ 23,725		$ 66,613		$ 136,875	
Recovery RO - Antiscalants		$ 16,940		$ 47,561		$ 97,729	
Recovery RO - Sulfuric Acid		$ 288,471		$ 809,937		$ 1,664,255	
Recovery RO - CIP Chemicals		$ 7,402		$ 20,783		$ 42,705	
pH Adjustment Allowance		$ 17,333		$ 48,667		$ 100,000	
		$ 485,758	**Annual Subtotal**	**$ 1,363,859**	**Annual Subtotal**	**$ 2,802,449**	**Annual Subtotal**
Labor Allowance							
Assume 320 hours per week at $47.38/hour		**$ 788,403**	**Annual Subtotal**	**$ 788,403**	**Annual Subtotal**	**$ 788,403**	**Annual Subtotal**
		$ 1,549,336	**Annual Operations Total**	**$ 2,918,533**	**Annual Operations Total**	**$ 5,165,382**	**Annual Operations Total**
Maintenance Allowance							
Mechanical and electrical capital costs		$ 28,102,510		$ 28,102,510		$ 28,102,510	
Assume 5% of mechanical and electrical capital cost		**$ 1,405,125**	**Annual Replacement Total**	**$ 1,405,125**	**Annual Replacement Total**	**$ 1,405,125**	**Annual Replacement Total**
Membrane replacement (see separate calculation)							
UF membrane		$ 518,571		$ 518,571		$ 518,571	
RO membrane		$ 688,800		$ 688,800		$ 688,800	
Recovery RO membrane		$ 64,800		$ 64,800		$ 64,800	
		$ 1,272,171	**Annual Membrane Total**	**$ 1,272,171**	**Annual Membrane Total**	**$ 1,272,171**	**Annual Membrane Total**
		$ 2,677,297	**Annual Maintenance Total**	**$ 2,677,297**	**Annual Maintenance Total**	**$ 2,677,297**	**Annual Maintenance Total**
		$ 4,226,633	**Annual Total O&M**	**$ 5,595,830**	**Annual Total O&M**	**$ 7,842,679**	**Annual Total O&M**
Waste Disposal							
Assume 10% reject (0.26 MGD, 0.73 MGD and 1.5 MGD)							
Disposal	@ $ .16 per gallon	**$ 15,302,625**	**Annual Subtotal**	**$ 42,965,063**	**Annual Subtotal**	**$ 88,284,375**	**Annual Subtotal**
Transportation	@ $ .33 per gallon	**$ 31,416,314**	**Annual Subtotal**	**$ 88,207,343**	**Annual Subtotal**	**$ 181,247,965**	**Annual Subtotal**
		$ 46,718,939	**Annual Total Disposal**	**$ 131,172,406**	**Annual Total Disposal**	**$ 269,532,340**	**Annual Total Disposal**
		$ 4.5	/1000 gallons	$ 2.1		$ 1.4	
		$ 50,945,572	Annual Total O&M and Disposal	$ 136,768,235	Annual Total O&M and Disposal	$ 277,375,019	Annual Total O&M and Disposal

Madison Metropolitan Sewerage District
NSWTP EDR Chloride Reduction
Annual O&M Cost Projection

Electrical Cost			Current Conditions (average 2.6 MGD)				Assumed 2030 Conditions (Average 7.3 MGD)				Full capacity (15 MGD)			
	Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR	
P-001	Secondary effluent transfer pump #1	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-002	Secondary effluent transfer pump #2	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-003	Secondary effluent transfer pump #3	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-004	Secondary effluent transfer pump #4	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-005	Secondary effluent transfer pump #5	75.0 HP	4.2	55.93	232.66		11.7	55.93	653.23		24.0	55.93	1,342.26	
P-006	Secondary effluent transfer pump #6 (standby)	75.0 HP	0.0	55.93	0.00		0.0	55.93	0.00		0.0	55.93	0.00	
	EDR pumping systems		4.2	906.25	3,806.25		11.7	906.25	10,585.00		24.0	906.25	21,750.00	
	EDR direct current		4.2	244.69	1,027.69		11.7	244.69	2,857.95		24.0	244.69	5,872.50	
					5,997.23				16,709.12				34,333.80	
		$0.09	per KW*HR		$539.75				$1,503.82				$3,090.04	
		365	days		**$ 197,009**	**Annual Subtotal**			**$ 548,894**	**Annual Subtotal**			**$ 1,127,865**	**Annual Subtotal**

		Current Conditions		Assumed 2030 Conditions		Full capacity	
Chemical Allowance							
Sodium Hypochlorite		$ 5,500		$ 15,441		$ 31,729	
Ammonium Hydroxide		$ 2,282		$ 6,407		$ 13,166	
Antiscalants		$ 46,501		$ 130,561		$ 268,275	
Sulfuric Acid		$ 22,662		$ 63,628		$ 130,743	
CIP Chemicals		$ 23,725		$ 66,613		$ 136,875	
pH Adjustment Allowance		$ 17,333		$ 48,667		$ 100,000	
		$ 118,003	**Annual Subtotal**	**$ 331,316**	**Annual Subtotal**	**$ 680,787**	**Annual Subtotal**
Labor Allowance							
Assume 320 hours per week at $47.38/hour		**$ 788,403**	**Annual Subtotal**	**$ 788,403**	**Annual Subtotal**	**$ 788,403**	**Annual Subtotal**
		$ 1,103,415	**Annual Operations Total**	**$ 1,668,614**	**Annual Operations Total**	**$ 2,597,056**	**Annual Operations Total**
Maintenance Allowance							
Mechanical and electrical capital costs		$ 29,062,843		$ 29,062,843		$ 29,062,843	
Assume 5% of mechanical and electrical capital cost		**$ 1,453,142**	**Annual Replacement Total**	**$ 1,453,142**	**Annual Replacement Total**	**$ 1,453,142**	**Annual Replacement Total**
Membrane replacement (see separate calculation)							
Anion/cation membranes		$ 1,036,800		$ 1,036,800		$ 1,036,800	
		$ 1,036,800	**Annual Membrane Total**	**$ 1,036,800**	**Annual Membrane Total**	**$ 1,036,800**	**Annual Membrane Total**
		$ 2,489,942	**Annual Maintenance Total**	**$ 2,489,942**	**Annual Maintenance Total**	**$ 2,489,942**	**Annual Maintenance Total**
		$ 3,593,357	**Annual Total O&M**	**$ 4,158,556**	**Annual Total O&M**	**$ 5,086,998**	**Annual Total O&M**
Waste Disposal							
Assume 10% reject (0.26 MGD, 0.73 MGD and 1.5 MGD)							
Disposal	@ $ .16 per gallon	**$ 15,302,625**	**Annual Subtotal**	**$ 42,965,063**	**Annual Subtotal**	**$ 88,284,375**	**Annual Subtotal**
Transportation	@ $ .33 per gallon	**$ 31,416,314**	**Annual Subtotal**	**$ 88,207,343**	**Annual Subtotal**	**$ 181,247,965**	**Annual Subtotal**
		$ 46,718,939	**Annual Total Disposal**	**$ 131,172,406**	**Annual Total Disposal**	**$ 269,532,340**	**Annual Total Disposal**
		$ 3.8	/1000 gallons	$ 1.6		$ 0.9	
		$ 50,312,296	Annual Total O&M and Disposal	$ 135,330,962	Annual Total O&M and Disposal	$ 274,619,338	Annual Total O&M and Disposal

Madison Metropolitan Sewerage District
Brine Waste Evaporator
Annual O&M Cost Projection

			Current Conditions (average 2.6 MGD)				Assumed 2030 Conditions (Average 7.3 MGD)				Full capacity (15 MGD)			
Electrical Cost														
	Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR	
P-701	Evaporator feed pump #1	25.0 HP	4.2	18.64	77.55		11.7	18.64	217.74		24.0	18.64	447.42	
P-702	Evaporator feed pump #2	25.0 HP	4.2	18.64	77.55		11.7	18.64	217.74		24.0	18.64	447.42	
P-703	Evaporator feed pump #3	25.0 HP	0.0	18.64	0.00		0.0	18.64	0.00		0.0	18.64	0.00	
E-701	Evaporator #1		4.2	4,750.00	19,760.00		11.7	4,750.00	55,480.00		24.0	4,750.00	114,000.00	
E-702	Evaporator #2		4.2	4,750.00	19,760.00		11.7	4,750.00	55,480.00		24.0	4,750.00	114,000.00	
	Misc power requirements transfer and cooling	500.0 HP	4.2	372.85	1,551.06		11.7	372.85	4,354.89		24.0	372.85	8,948.40	
					41,226.16				115,750.38				237,843.24	
		$0.09	per KW*HR		$3,710.35				$10,417.53				$21,405.89	
		365	days		**$ 1,354,279**	**Annual Subtotal**			**$ 3,802,400**	**Annual Subtotal**			**$ 7,813,150**	**Annual Subtotal**
Steam Cost														
	5,500 pounds per hour per unit at design capacity	@ $ 0.005 per pound			**$ 83,512**	**Annual Subtotal**			**$ 234,476**	**Annual Subtotal**			**$ 481,800**	**Annual Subtotal**
Chemical Allowance														
	Chemical Allowance				$ 17,333				$ 48,667				$ 100,000	
	Lime softening operating allowance (2 $/kgal)				$ 520,000				$ 1,460,000				$ 3,000,000	
					$ 537,333	**Annual Subtotal**			**$ 1,508,667**	**Annual Subtotal**			**$ 3,100,000**	**Annual Subtotal**
Labor Allowance														
	Assume 80 hours per week at $47.38/hour				**$ 197,101**	**Annual Subtotal**			**$ 197,101**	**Annual Subtotal**			**$ 197,101**	**Annual Subtotal**
					$ 2,172,226	**Annual Operations Total**			**$ 5,742,643**	**Annual Operations Total**			**$ 11,592,051**	**Annual Operations Total**
Maintenance Allowance														
	Mechanical and electrical capital costs				$ 36,335,984				$ 36,335,984				$ 36,335,984	
	Assume 5% of mechanical and electrical capital cost				**$ 1,816,799**	**Annual Replacement Total**			**$ 1,816,799**	**Annual Replacement Total**			**$ 1,816,799**	**Annual Replacement Total**
					$ 1,816,799	**Annual Maintenance Total**			**$ 1,816,799**	**Annual Maintenance Total**			**$ 1,816,799**	**Annual Maintenance Total**
					$ 3,989,025	**Annual Total O&M**			**$ 7,559,443**	**Annual Total O&M**			**$ 13,408,850**	**Annual Total O&M**
Waste Disposal														
	Assume 10% reject (0.026 MGD, 0.073 MGD and 0.15 MGD)													
	Disposal	@ $ .16 per gallon			**$ 1,530,263**	**Annual Subtotal**			**$ 4,296,506**	**Annual Subtotal**			**$ 8,828,438**	**Annual Subtotal**
	Transportation	@ $ .33 per gallon			**$ 3,141,631**	**Annual Subtotal**			**$ 8,820,734**	**Annual Subtotal**			**$ 18,124,797**	**Annual Subtotal**
					$ 4,671,894	**Annual Total Disposal**			**$ 13,117,241**	**Annual Total Disposal**			**$ 26,953,234**	**Annual Total Disposal**
	Annual disposal savings over base 90% recovery				$ 42,047,045				$ 118,055,165				$ 242,579,106	
	Net annual savings with evaporation				$ 38,058,020				$ 110,495,722				$ 229,170,256	

Madison Metropolitan Sewerage District
Brine Waste Crystallizer
Annual O&M Cost Projection

			Current Conditions (average 2.6 MGD)				Assumed 2030 Conditions (Average 7.3 MGD)				Full capacity (15 MGD)			
Electrical Cost														
	Equipment	Assumed Size	Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR		Duration (hrs.)	KW	KW* HR	
P-801	Crystallizer feed pump #1	5.0 HP	4.2	3.73	15.51		11.7	3.73	43.55		24.0	3.73	89.48	
P-802	Crystallizer feed pump #1	5.0 HP	0.0	3.73	0.00		0.0	3.73	0.00		0.0	3.73	0.00	
E-801	Crystallizer #1													
	Turbofans		4.2	1,250.00	5,200.00		11.7	1,250.00	14,600.00		24.0	1,250.00	30,000.00	
	Axial flow crystallizer pump		4.2	175.00	728.00		11.7	175.00	2,044.00		24.0	175.00	4,200.00	
	Misc power requirements transfer and cooling	500.0 HP	4.2	372.85	1,551.06		11.7	372.85	4,354.89		24.0	372.85	8,948.40	
					7,494.57				21,042.44				43,237.88	
		$0.09	per KW*HR		$674.51				$1,893.82				$3,891.41	
		365	days		**$ 246,197**	**Annual Subtotal**			**$ 691,244**	**Annual Subtotal**			**$ 1,420,364**	**Annual Subtotal**
Steam Cost														
	4,000 pounds per hour per unit at design capacity	@ $ 0.005 per pound			**$ 30,368**	**Annual Subtotal**			**$ 85,264**	**Annual Subtotal**			**$ 175,200**	**Annual Subtotal**
Chemical Allowance														
	Chemical Allowance				$ 17,333				$ 48,667				$ 100,000	
					$ 17,333	**Annual Subtotal**			**$ 48,667**	**Annual Subtotal**			**$ 100,000**	**Annual Subtotal**
Labor Allowance														
	Assume 40 hours per week at $47.38/hour				**$ 98,550**	**Annual Subtotal**			**$ 98,550**	**Annual Subtotal**			**$ 98,550**	**Annual Subtotal**
					$ 392,448	**Annual Operations Total**			**$ 923,725**	**Annual Operations Total**			**$ 1,794,115**	**Annual Operations Total**
Maintenance Allowance														
	Mechanical and electrical capital costs				$ 10,215,000				$ 10,215,000				$ 10,215,000	
	Assume 5% of mechanical and electrical capital cost				**$ 510,750**	**Annual Replacement Total**			**$ 510,750**	**Annual Replacement Total**			**$ 510,750**	**Annual Replacement Total**
					$ 510,750	**Annual Maintenance Total**			**$ 510,750**	**Annual Maintenance Total**			**$ 510,750**	**Annual Maintenance Total**
					$ 903,198	**Annual Total O&M**			**$ 1,434,475**	**Annual Total O&M**			**$ 2,304,865**	**Annual Total O&M**
Waste Disposal														
	Assume solids w/ 15% moisture (18, 50 & 102 tons per day)													
	Disposal	@ $ 38.00 per ton			**$ 249,660**	**Annual Subtotal**			**$ 693,500**	**Annual Subtotal**			**$ 1,414,740**	**Annual Subtotal**
	Transportation	@ $ 11.40 per ton			**$ 74,917**	**Annual Subtotal**			**$ 208,103**	**Annual Subtotal**			**$ 424,531**	**Annual Subtotal**
					$ 324,577	**Annual Total Disposal**			**$ 901,603**	**Annual Total Disposal**			**$ 1,839,271**	**Annual Total Disposal**
	Annual disposal savings over evaporation				$ 4,347,317				$ 12,215,637				$ 25,113,963	
	Net annual savings with crystallization				$ 3,444,118				$ 10,781,162				$ 22,809,098	

Madison Metropolitan Sewerage District
UF/RO and EDR Chloride Reduction System Alternatives
Chemical Cost Projections

RO Well Softening - Source is Newterra

Chemical

	Dose (ppm)	Design Feed Flow Rate (gpm)	lbs/day	gpd	Cost ($/lbs)	Cost ($/day)	Cost ($/year)	Average Feed Flow Rate (MGD) to produce 1.5 MGD blended permeate	Cost ($/year)
Antiscalants	3	2,000	72.10	7.21	6	$ 432.60	$ 157,900.75	1.35	$ 74,015.98
Sodium Bisulfite	3	2,000	72.10	5.84	1	$ 72.10	$ 26,316.79	1.35	$ 12,336.00
CIP	2 *		600 **		6		2 ***		$ 14,400.00

RO Centralized Softening - Source is Newterra

Chemical

	Dose (ppm)	Design Feed Flow Rate (gpm)	lbs/day	gpd	Cost ($/lbs)	Cost ($/day)	Cost ($/year)	Average Feed Flow Rate (MGD) to produce 28.2 MGD blended permeate	Cost ($/year)
Antiscalants	3	34,000	1,225.71	122.57	6	$ 7,354.28	$ 2,684,312.78	25.4	$ 1,391,500.38
Sodium Hypochlorite	3	34,000	10,215.03	1103.13	0.11	$ 1,123.65	$ 410,133.41	25.4	$ 212,605.92
Sodium Bisulfite	3	34,000	1,225.71	99.25	1	$ 1,225.71	$ 447,385.46	25.4	$ 231,916.73
CIP	34 *		600 **		6		2 ***		$ 244,800.00

*# of trains

**chemical lbs./cleaning

***cleanings per year (assumes cleaning frequency of 6 months)

UF System - Source is Koch November 6 Internal Memo

	Flow Assumption (MGD)	gal/year	$/gal	$/year	$/year @ 15 MGD
Sodium Hypochlorite	26.4	23,735	$ 1.00	$ 23,735	$ 13,486
Citric Acid	26.4	10,415	$ 5.00	$ 52,075	$ 29,588

RO System - Source is Evoqua Proposal

	Flow Assumption (MGD)	gal/year	$/gal	lbs/1,000 gallons treated	lbs/year @ 15 MGD	Chemical Density lbs/gal	$/1,000 gallons treated	$/year	$/year @ 15 MGD	
Chlorine	15	31,729	$ 1.00	0.059	323,025	10.18		$ 31,729	$ 31,729	
Ammonium Hydroxide	15	8,777	$ 1.50	0.012	65,700	7.49		$ 13,166	$ 13,166	
Anti-scalant	15						$ 0.049		$ 268,275	
Sulfuric Acid	15	224,801	$ 1.80	0.62	3,394,500	15.1		$ 404,642	$ 404,642	
CIP Chemicals	15						$ 0.025		$ 136,875	Based on 6 month cleaning

Recovery RO System - Source is Evoqua Proposal

	Flow Assumption (MGD)	gal/year	$/gal	lbs/1,000 gallons treated	lbs/year @ 2.25 MGD	Chemical Density lbs/gal	$/1,000 gallons treated	$/year	$/year @ 2.25 MGD	
Chlorine	2.25	-	$ 1.00	0	0	10.18		$ -	$ -	
Ammonium Hydroxide	2.25	-	$ 1.50	0	0	7.49		$ -	$ -	
Anti-scalant	2.25						$ 0.119		$ 97,729	
Sulfuric Acid	2.25	924,586	$ 1.80	17	13,961,250	15.1		$ 1,664,255	$ 1,664,255	
CIP Chemicals	2.25						$ 0.052		$ 42,705	Based on 6 month cleaning

EDR

	Flow Assumption (MGD)	gal/year	$/gal	lbs/1,000 gallons treated	lbs/year @ 15 MGD	Chemical Density lbs/gal	$/1,000 gallons treated	$/year	$/year @ 15 MGD	
Chlorine	1.5	3,173	$ 1.00			10.18		$ 3,173	$ 31,729	Copied from RO
Ammonium Hydroxide	1.5	878	$ 1.50			7.49		$ 1,317	$ 13,166	Copied from RO
Anti-scalant	1.5						$ 0.049		$ 268,275	Copied from RO
Sulfuric Acid	1.5	7,264	$ 1.80			15.1		$ 13,074	$ 130,743	
CIP Chemicals	15						$ 0.025		$ 136,875	Copied from RO

Evaporator - GEA

	Flow Assumption (MGD)	gal/year	$/gal	lbs/1,000 gallons treated	lbs/year @ 1.5 MGD	Chemical Density lbs/gal	$/1,000 gallons treated	$/year	$/year @ 1.5 MGD
Sodium Hypochlorite	1.50	-	$ 1.00		0	10.18		$ -	$ -
	1.50	-	$ 1.50		0	7.49		$ -	$ -
Anti-scalant	1.50								$ -
Sulfuric Acid	1.50	-	$ 1.80		0	15.1		$ -	$ -

NaOH upstream to shift bi-carbonate to carbonate and drop out calcium carbonate

Madison Metropolitan Sewerage District
UF/RO and EDR Chloride Reduction System Alternatives
Membrane Cost Projections

Softening RO Membranes - Well Head

	Units	Membranes / Unit	Total Membranes	Cost per Membrane	Total Membrane Cost	Average Life (years)	Annual Replacement Cost
Bag filters	2	52	104	$ 3	$ 312	0.083333	$ 3,744
RO membranes	2	168	336	$ 700	$ 235,200	3	$ 78,400
							$ 82,144

Softening RO Membranes - Centralized

	Units	Membranes / Unit	Total Membranes	Cost per Membrane	Total Membrane Cost	Average Life (years)	Annual Replacement Cost
Bag filters	34	52	1,768	$ 3	$ 5,304	0.083333	$ 63,648
RO membranes	34	168	5,712	$ 700	$ 3,998,400	3	$ 1,332,800
							$ 1,396,448

RO Membranes

	Units	Membranes / Unit	Total Membranes	Cost per Membrane	Total Membrane Cost	Average Life (years)	Annual Replacement Cost
Primary Treatment							
[1] UF			1,210	$ 3,000	$ 3,630,000	7	$ 518,571
[2] RO	6	574	3,444	$ 600	$ 2,066,400	3	$ 688,800
Recovery System							
[2] RO	6	54	324	$ 600	$ 194,400	3	$ 64,800
							$ 1,272,171

EDR System

	Units	Stacks / Unit	Total Stacks	Cost per Membrane Stack	Total Membrane Cost	Average Life (years)	Annual Replacement Cost
Primary Treatment							
[3] Anion/Cation	12	24	288	$ 36,000	$ 10,368,000	10	$ 1,036,800
							$ 1,036,800

Notes

[1] Based on Koch Membrane System Puron proposal

[2] Based on Evoqua proposal

[3] Based on GE Information

Madison Metropolitan Sewerage District
UF/RO and EDR Chloride Reduction System Alternatives
Membrane Cost Projections

DISPOSAL - LIQUID

Disposal	$	0.15	/gallon		
Environmental fee	$	0.01125	/gallon	7.5%	of disposal
	$	**0.16**	**/gallon**		

TRANSPORTATION

Transportation	$	2,190	per Trip		based on Vickery, Ohio Disposal Site (430 Miles)
Tanker Volume		5,000	gallons = Tanker Volume		
Transportation	$	0.44	/gallon		
Fuel surcharge	$	0.1314	/gallon	30.0%	of disposal @ $3.50 to $3.579 /gallon
	$	0.57	/gallon		
		250	miles		Assumed transportation (one way)
		58%	Transportation Factor		
		$0.33			

DISPOSAL - SOLID (Madison Prairie)

Disposal	$	25.00	/ton
WI generator tax	$	13.00	/ton
	$	**38.00**	**/ton**

TRANSPORTATION

Transportation - delivery	$	75.00	/trip		20 to 30 CYD container (Assume 20 cyds @ 1.35 tons/cyd = 27 tons)
Transportation - haul	$	185.00	/trip		
Environmental Surcharge	$	27.99	/trip		10% of transporation
Fuel surcharge	$	19.89	/trip	7.65%	@ $3.50 /gallon
	$	307.88	/trip		
		27	tons/trip		
	$	11.40	/ton		

Appendix E

TBL Analysis Data Sheets and Output

MMSD Chloride Treatment Technology Options

Triple Bottom Line Assessment

☑ Assign Criteria Weighting Manually (From 0 to 5) ☐ Remove N/A Show / Hide Scores

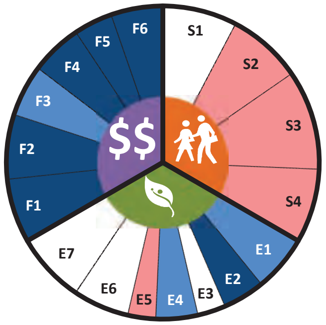
Social & Community		Weighting
S1	Leadership/Community Image	3
S2	Public Acceptance	3
S3	Worker Safety	4
S4	Public Health Impact	3

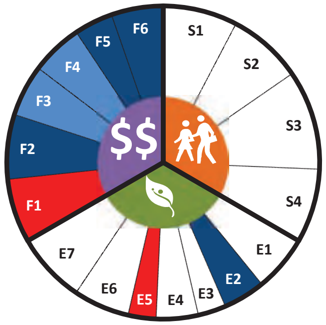
Environmental		
E1	Energy Use	4
E2	Air Quality Impact	3
E3	Noise Impact	2
E4	Plant Carbon Footprint	3
E5	Land Use Impact	2
E6	Byproduct Reuse Potential	4
E7	Impact on Effluent Quality	3

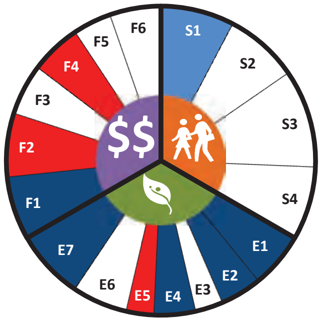
Financial & Operational		
F1	Capital Cost	5
F2	O&M Cost	5
F3	Avoided Cost & New Revenue	4
F4	Chloride Removal Efficiency	4
F5	Process Complexity	3
F6	Operational Risk	4

++	Very High Score	-	Low Score
+	High Score	--	Very Low Score
O	Medium Score	TBD	Unknown / TBD / NA

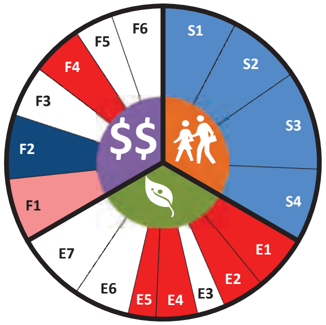
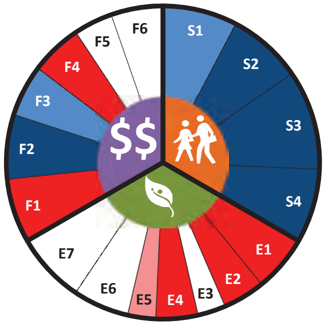
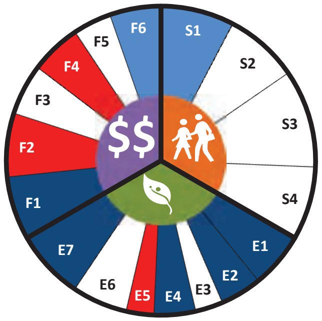
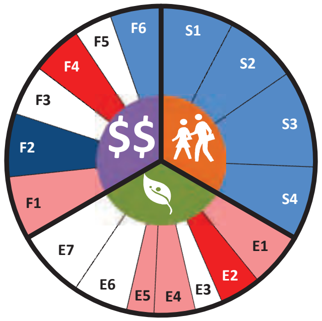
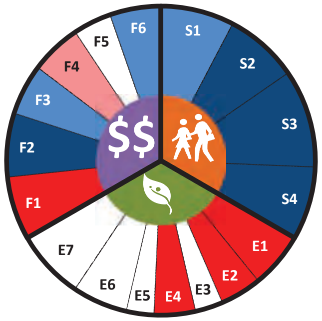
Alternative 1A	Alternative 1B	Alternative 2A
Source water softening - Wellhead treatment for hardness (50 well sites)	Source water softening - Centralized treatment for hardness (50 MGD)	Treatment at NSWTP using RO
Technology Options: SR-3	*Technology Options:* SR-5	*Technology Options:* TP-2, BM-1, D-3
Treatment for removal of hardness at water supply source (and associated elimination of residential, commercial and industrial zeolite water softeners). Treatment consists of membrane softening located at individual wells. It was assumed that 22 individual treatment systems each capable of softening a 3.0 MGD raw water supply would be required.	Treatment for removal of hardness from water supply at a centralized location (and associated elimination of residential, commercial, and industrial zeolite water softeners). Treatment consists of membrane softening located at a single centralized treatment site. It was assumed that the centralized system would be capable of producing 50 MGD of softened water. Infrastructure improvements to direct water from supply wells to the treatment facility and from the treatment facility to the distribution system are required, and are assumed to include 135 miles of watermain at $1M per mile.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.







		Alternative 1A	Alternative 1B	Alternative 2A
M1	Total Life-cycle Costs Net Present Value($M) :	$287.8 M	$386.0 M	$2,348.8 M
M2	Total Capital Cost ($M) :	$91.5 M	$210 M	$87 M
M3	Annual O&M Cost ($M/yr) :	$10.9 M/yr	$10.1 M/yr	$136.8 M/yr
M4	Chloride Removal Efficiency (lb/$1000) :	953	710	48
M5	Total Energy Use (MWh/yr) :	31,100	39,000	8,500
M6	Carbon Footprint (MT CO2e/yr) :	22,700	28,400	16,500
M7	By-product Quantity :	None	None	730,000 gpd
M8	Truck Hauling Distance (miles/yr) :	71,250	30,000	21,900,000

Alternative 2B	Alternative 2C	Alternative 3A	Alternative 3B	Alternative 3C
Treatment at NSWTP using RO and brine minimization using evaporation	Treatment at NSWTP using RO and brine minimization using evaporation/crystallization	Treatment at NSWTP using EDR	Treatment at NSWTP using EDR and brine minimization using evaporation	Treatment at NSWTP using EDR and brine minimization using evaporation/crystallization
Technology Options: TP-2, BM-1, BM-3, D-3	***Technology Options:*** TP-2, BM-1, BM-3, BM-4, D-4	***Technology Options:*** TP-3, D-3	***Technology Options:*** TP-3, BM-3, D-3	***Technology Options:*** TP-3, BM-3, BM-4, D-4
				
Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using reverse osmosis technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal. Treatment includes handling and disposal of up to 1.5 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation for the reduction of brine waste volume. Treatment includes handling and disposal of up to 0.15 MGD of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.	Treatment of up to 15 MGD of the NSWTP effluent using electrodialysis reversal technology for chloride removal followed by evaporation and crystallization for the reduction of brine waste quantity. Treatment includes handling and disposal of up to 102 tons per day of concentrated brine waste. This analysis assumes an average treatment rate of 7.3 MGD.
$619.0 M	$464.4 M	$2,319.1 M	$589.3 M	$434.8 M
$171 M	$193 M	$81 M	$165 M	$187 M
$26.3 M/yr	$15.4 M/yr	$135.3 M/yr	$24.8 M/yr	$14.0 M/yr
183	244	49	192	261
66,600	80,000	6,100	64,100	77,600
41,000	46,500	14,800	39,200	44,700
73,000 gpd	36.8 CYDS/day	730,000 gpd	73,000 gpd	36.8 CYDS/day
2,550,000	135,000	21,900,000	2,550,000	135,000

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

🟩 =Required Field

🟦 =Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	1A
1.2	Alternative Name	Source water softening - Wellhead treatment for hardness (22 well sites)
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	SR-3
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	30.0%	(%)	
2.2	Chloride reduction quantity	22000000	lb/yr	*Based on removal of approx 60,000 lbs. of chloride on expected max chloride load day to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	No	(Y/N)	
2.4	Other wastewater constituents	No	(Y/N)	
2.5	Effluent temperature impact	Low	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 91,512,305	
3.1.2	Annual O&M Cost	$ 10,854,300	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	11	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items	Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost			No saving	
3.2.2	Avoided treatment cost			High	*Avoids chloride treatment at NSWTP*
3.2.3	Sale of by-product			No saving	
3.2.4	Energy savings through co-gen, etc.			No saving	
3.2.5	Avoided raw material cost			No saving	
3.2.6	(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	3						
3.3.2	Number of other processes impacted (#)	2						*Membrane reject requires additional raw water pumping & increase in hydraulic load at NSWTP.*
3.3.3	Process reliability/proven effectiveness (H/M/L)	High						
3.3.4	Pretreatment requirements (y/n)	No						*Assumes no sand, iron to be addressed with chemical addition*

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)

*Consider the sub-process with the highest risk

Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Low	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Low	
3.4.3	Temperature sensitivity (H/M/L)	Low	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	No	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	31,143,708			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	31,143,708	(kWh/yr)	
4.2.2	Total natural gas		(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	4.75	(trips/day)	*More, smaller deliveries due to multiple locations*
4.2.4	Average hauling distance	50	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	No	
4.3.2	NOx (Nitrogen Oxides)	No	
4.3.3	CO (Carbon Monoxide)	No	
4.3.4	SOx (Sulphur Dioxides)	No	
4.3.5	PM (Particulate Matter)	No	
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	No	

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Low	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	Medium	Low	*Assume 35% of well sites have land available and 65% have adjacent land available for purchase.*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Low	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Medium	*Based on amount of equipment*
5.1.2	Excessive Noise	Medium	*Based on amount of equipment*
5.1.3	Heat Stress	Medium	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Medium	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Medium	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Larger volumes associated with higher treatment capacity*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	High	*Larger volumes associated with higher treatment capacity*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Low	
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	Yes	*Buildings*
5.3.2	Please rate the potential Public Nuisance caused by the process.	Medium	*Based on truck traffic to multiple locations*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	Yes	*Removal of zeolite softeners*

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	No	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	No	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	Yes	*Removal of zeolite softeners*

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	1B
1.2	Alternative Name	Source water softening - Centralize treatment for hardness (50 MGD design capacity with 28.2 MGD average)
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	SR-5
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	30.0%	(%)	
2.2	Chloride reduction quantity	22000000	lb/yr	*Based on removal of approx 60,000 lbs. of chloride on expected max chloride load day to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	No	(Y/N)	
2.4	Other wastewater constituents	No	(Y/N)	
2.5	Effluent temperature impact	Low	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 210,299,579	*Includes an allowance of $135M to cover an estimated 135 miles of distribution piping requirements.*
3.1.2	Annual O&M Cost	$ 10,093,584	*Softening plant O&M only*

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	6	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				High	*Avoids chloride treatment at NSWTP*
3.2.3	Sale of by-product				No saving	
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	3						
3.3.2	Number of other processes impacted (#)	2						*Membrane reject requires additional raw water pumping & increase in hydraulic load at NSWTP.*
3.3.3	Process reliability/proven effectiveness (H/M/L)	High						
3.3.4	Pretreatment requirements (y/n)	No						*Assumes no sand, iron to be addressed with chemical addition*

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Low	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Low	
3.4.3	Temperature sensitivity (H/M/L)	Low	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	No	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	39,744,571			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	39,744,571	(kWh/yr)	
4.2.2	Total natural gas		(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	1	(trips/day)	
4.2.4	Average hauling distance	100	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	No	
4.3.2	NOx (Nitrogen Oxides)	No	
4.3.3	CO (Carbon Monoxide)	No	
4.3.4	SOx (Sulphur Dioxides)	No	
4.3.5	PM (Particulate Matter)	No	
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	No	

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Low	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	High	Low	*Assumes land will need to be acquired for the site. Cost of land procurement is not included in project cost.*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Low	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Medium	*Based on amount of equipment*
5.1.2	Excessive Noise	Medium	*Based on amount of equipment*
5.1.3	Heat Stress	Medium	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Medium	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Medium	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Larger volumes associated with higher treatment capacity*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	High	*Larger volumes associated with higher treatment capacity*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Low	
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	Yes	*Buildings*
5.3.2	Please rate the potential Public Nuisance caused by the process.	Low	*Based on truck traffic to single location*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	Yes	*Removal of zeolite softeners*

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	No	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	No	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	Yes	*Removal of zeolite softeners*

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

🟩 =Required Field 🟦 =Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	2A
1.2	Alternative Name	Treatment at NSWTP using RO
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-2, BM-1, D-3
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	Low	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 86,832,918	
3.1.2	Annual O&M Cost	$ 136,768,235	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	8	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Low	*Quality and volume of brine not conducive to reuse*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	3						
3.3.2	Number of other processes impacted (#)	1						*5% UF pretreatment reject stream back to NSWTP*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	Yes						*UF System*

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	Notes:

*Consider the sub-process with the highest risk

3.4.1	Highly variable wastewater volume (H/M/L)	Medium	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	No	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	8,514,122			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	8,514,122	(kWh/yr)	
4.2.2	Total natural gas		(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	146	(trips/day)	*Primarily brine disposal*
4.2.4	Average hauling distance	500	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	No	
4.3.2	NOx (Nitrogen Oxides)	No	
4.3.3	CO (Carbon Monoxide)	No	
4.3.4	SOx (Sulphur Dioxides)	No	
4.3.5	PM (Particulate Matter)	No	
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	No	

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		High	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	Medium	High	*Onsite requirements higher than EDR (3A)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		High	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Low	*Based on amount of equipment*
5.1.2	Excessive Noise	Low	*Based on amount of equipment*
5.1.3	Heat Stress	Low	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Low	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Low	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	Medium	*Due to chemicals used*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	Low	*Due to lower volumes assoc. with lower treatment capacity*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	High	*Due to volume of brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	High	*Due to volume of brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	High	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	2B
1.2	Alternative Name	Treatment at NSWTP using RO
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-2, BM-1, BM-3, D-3
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	High	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 170,731,397	
3.1.2	Annual O&M Cost	$ 26,272,513	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	10	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Low	*Quality and volume of brine not conducive to reuse*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	2						
3.3.2	Number of other processes impacted (#)	1						*5% UF pretreatment reject stream back to NSWTP*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	Yes						*UF system*

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Medium	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	No	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	66,564,205			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	50,763,010	(kWh/yr)	
4.2.2	Total natural gas	539,295	(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	17	(trips/day)	*Primarily brine and lime sludge disposal*
4.2.4	Average hauling distance	500	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	Yes	*Due to gas-fired boiler operation*
4.3.2	NOx (Nitrogen Oxides)	Yes	*Due to gas-fired boiler operation*
4.3.3	CO (Carbon Monoxide)	Yes	*Due to gas-fired boiler operation*
4.3.4	SOx (Sulphur Dioxides)	Yes	*Due to gas-fired boiler operation*
4.3.5	PM (Particulate Matter)	Yes	*Due to gas-fired boiler operation*
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	Yes	*Due to gas-fired boiler operation*

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Medium	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	High	Medium	*Onsite requirements higher than EDR (3B)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Medium	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		*Reuse may be possible; none assumed for cost analysis*
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Medium	*Based on amount of equipment*
5.1.2	Excessive Noise	Medium	*Based on amount of equipment*
5.1.3	Heat Stress	Medium	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Medium	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Medium	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Due to increase in chemicals used.*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	Medium	*Based on additional chemicals for evaporation process*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Medium	*Due to volume of brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

Notes:

5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	Medium	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

Notes:

5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	2C
1.2	Alternative Name	Treatment at NSWTP using RO
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-2, BM-1, BM-3, BM-4, D-4
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	High	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 193,483,177	
3.1.2	Annual O&M Cost	$ 15,391,351	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	11	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Medium	*Potential for crystallized brine waste reuse based on chemical constituents*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	1						
3.3.2	Number of other processes impacted (#)	1						*5% UF pretreatment reject stream back to NSWTP*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	Yes						*UF system*

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

			Notes
3.4.1	Highly variable wastewater volume (H/M/L)	Medium	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	No	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	79,990,584			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	58,443,499	(kWh/yr)	
4.2.2	Total natural gas	735,402	(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	4.5	(trips/day)	*Primarily crystallized brine and lime sludge disposal*
4.2.4	Average hauling distance	100	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	Yes	*Due to gas-fired boiler operation*
4.3.2	NOx (Nitrogen Oxides)	Yes	*Due to gas-fired boiler operation*
4.3.3	CO (Carbon Monoxide)	Yes	*Due to gas-fired boiler operation*
4.3.4	SOx (Sulphur Dioxides)	Yes	*Due to gas-fired boiler operation*
4.3.5	PM (Particulate Matter)	Yes	*Due to gas-fired boiler operation*
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	Yes	*Due to gas-fired boiler operation*

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Low	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	High	Medium	*Onsite requirements higher than EDR (3C)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Medium	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		*Reuse may be possible; none assumed for cost analysis*
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	High	*Based on amount of equipment*
5.1.2	Excessive Noise	High	*Based on amount of equipment*
5.1.3	Heat Stress	High	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	High	*Based on amount of equipment*
5.1.5	Vibrating Machinery	High	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Due to increase in chemicals used.*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	High	*Based on additional chemicals for crystallization process*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Medium	*Due to volume of crystallized brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of crystallized brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	Low	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	3A
1.2	Alternative Name	Treatment at NSWTP using EDR
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-3, D-3
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	Low	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 80,823,611	
3.1.2	Annual O&M Cost	$ 135,330,962	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	8	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Low	*Quality and volume of brine not conducive to reuse*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	3						
3.3.2	Number of other processes impacted (#)							*Side stream no significant impact on other processes.*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	No						

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Low	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	Yes	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	6,098,827			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	6,098,827	(kWh/yr)	
4.2.2	Total natural gas		(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	146	(trips/day)	*Primarily brine disposal*
4.2.4	Average hauling distance	500	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	No	
4.3.2	NOx (Nitrogen Oxides)	No	
4.3.3	CO (Carbon Monoxide)	No	
4.3.4	SOx (Sulphur Dioxides)	No	
4.3.5	PM (Particulate Matter)	No	
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	No	

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		High	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	Low	High	*Onsite requirements lower than UF/RO (2A)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		High	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Low	*Based on amount of equipment*
5.1.2	Excessive Noise	Low	*Based on amount of equipment*
5.1.3	Heat Stress	Low	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Low	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Low	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	Medium	*Due to chemicals used*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	Low	*Due to lower volumes assoc. with lower treatment capacity*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	High	*Due to volume of brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	High	*Due to volume of brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	High	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	3B
1.2	Alternative Name	Treatment at NSWTP using EDR
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-3, BM-3, D-3
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	High	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 164,722,090	
3.1.2	Annual O&M Cost	$ 24,835,239	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	10	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Low	*Quality and volume of brine not conducive to reuse*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	2						
3.3.2	Number of other processes impacted (#)							*Side stream - no significant impact on other processes*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	No						

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Low	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	Yes	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	64,148,910			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	48,347,718	(kWh/yr)	
4.2.2	Total natural gas	539,295	(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	17	(trips/day)	*Primarily brine and lime sludge disposal*
4.2.4	Average hauling distance	500	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	Yes	*Due to gas-fired boiler operation*
4.3.2	NOx (Nitrogen Oxides)	Yes	*Due to gas-fired boiler operation*
4.3.3	CO (Carbon Monoxide)	Yes	*Due to gas-fired boiler operation*
4.3.4	SOx (Sulphur Dioxides)	Yes	*Due to gas-fired boiler operation*
4.3.5	PM (Particulate Matter)	Yes	*Due to gas-fired boiler operation*
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	Yes	*Due to gas-fired boiler operation*

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Medium	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	Medium	Medium	*Onsite requirements lower than UF/RO (2B)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Medium	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		*Reuse may be possible; none assumed for cost analysis*
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	Medium	*Based on amount of equipment*
5.1.2	Excessive Noise	Medium	*Based on amount of equipment*
5.1.3	Heat Stress	Medium	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	Medium	*Based on amount of equipment*
5.1.5	Vibrating Machinery	Medium	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Due to increase in chemicals used.*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	Medium	*Based on additional chemicals for evaporation process*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Medium	*Due to volume of brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	Medium	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

MMSD CHLORIDE TREATMENT PLANT ALTERNATIVE OPTIONS DATASHEET

Instructions: Please fill-out this datasheet for each Alternative in consideration. Each alternative should include the complete process for the plant.

=Required Field

=Optional Input

1 Basic Information

Provide basic information about technology option.

1.1	Alternative ID	3C
1.2	Alternative Name	Treatment at NSWTP using EDR
1.3	Technologies Applied (i.e. SR-1, BR-1,TP-1,D-1, etc.)	TP-3, BM-3, BM-4, D-4
1.4	Description	

2 Nutrient Removal Performance

Provide nutrient removal performance information.

Ref #	Category	Answers		Notes:
2.1	Chloride reduction %	17.0%	(%)	
2.2	Chloride reduction quantity	9100000	lb/yr	*Based on the need to remove approx. 25,000 lbs./day of chloride on average to maintain 395 mg/L limit.*
2.3	Phosphorous / Nitrogen Removal	Yes	(Y/N)	
2.4	Other wastewater constituents	Yes	(Y/N)	
2.5	Effluent temperature impact	High	(H/M/L)	

3 Financial & Operational

3.1 Life-cycle Cost Information

Provide an estimate of overall alternative costs, including all technology costs, labor related costs, life span, and funding.

Overall Alternative Costs (* can use component cost worksheet to calculate totals)

Ref #	Category	Est. Costs($)	Notes:
3.1.1	Total Capital Cost	$ 187,473,870	
3.1.2	Annual O&M Cost	$ 13,954,077	

Labor Related Costs

				Notes:
3.1.3	Total FTE (Full Time Employees)	11	employees	
3.1.4	Average Annual Salary/FTE	$98,550	$/Yr/FTE	

Life Span

				Notes:
3.1.5	What is the life span of this technology?	20	yrs	

Funding

				Notes:
3.1.6	Are there components in the alternative eligible for funding?	No	y/n	

3.2 Avoided Costs/ New Revenues

Please provide avoided costs and new revenue information in the table below. Provide $ per year if possible.

Ref #	Items		Amount of cost savings and/or new revenue ($/Yr)	OR	Level of cost savings and/or new revenue (H/M/L)	Notes:
3.2.1	Avoided disposal cost				No saving	
3.2.2	Avoided treatment cost				Low	*Removes some phosphorus and ammonia*
3.2.3	Sale of by-product				Medium	*Potential for crystallized brine waste reuse based on chemical constituents*
3.2.4	Energy savings through co-gen, etc.				No saving	
3.2.5	Avoided raw material cost				No saving	
3.2.6		(other)				

3.3 Please rate the complexity of the processes involved in this alternative

If possible, provide sub process complexity below.

Ref #	Processes	Overall process complexity	Sub-process 1	Sub-process 2	Sub-process 3	Sub-process 4	Sub-process 5	Notes:
3.3.1	Ease of operation (scale 1-5) (5 is the easiest)	1						
3.3.2	Number of other processes impacted (#)							*Side stream - no significant impact on other processes*
3.3.3	Process reliability/proven effectiveness (H/M/L)	Medium						
3.3.4	Pretreatment requirements (y/n)	No						

3.4 Please rate the operational risk (ability to work in variable conditions) for this alternative

Ref #	Condition	Overall Risk Level* (H/M/L)	*Consider the sub-process with the highest risk	Notes:

3.4.1	Highly variable wastewater volume (H/M/L)	Low	
3.4.2	Variable dilution / concentration of chemicals (H/M/L)	Medium	
3.4.3	Temperature sensitivity (H/M/L)	Medium	

3.5 Please provide information about sole-source equipment/technology

			Notes:
3.5.1	Does Implementing this alternative process require any sole-source equipment/technology? (Y/N)	Yes	

4 Environmental

4.1 Please provide an estimate of total energy use for this alternative.

Ref #	Item	Amount of Energy Use (kWh/yr)	OR	Level of Energy Use (H/M/L)	Notes:
4.1.1	Total energy use	77,575,289			

4.2 Please provide information about carbon footprint for this alternative

Plant GHG

				Notes:
4.2.1	Total electrical energy	56,028,204	(kWh/yr)	
4.2.2	Total natural gas	735,402	(therm/yr)	

Transportation related GHG

				Notes:
4.2.3	Number of truck hauls per day	4.5	(trips/day)	*Primarily crystallized brine and lime sludge disposal*
4.2.4	Average hauling distance	100	(miles/day)	

4.3 Please answer the following question about air quality (Non GHG)

Do the alternative processes (significantly) affect the following air pollutants concentration over standard limits?

			Notes:
4.3.1	ROG (Ozone)	Yes	*Due to gas-fired boiler operation*
4.3.2	NOx (Nitrogen Oxides)	Yes	*Due to gas-fired boiler operation*
4.3.3	CO (Carbon Monoxide)	Yes	*Due to gas-fired boiler operation*
4.3.4	SOx (Sulphur Dioxides)	Yes	*Due to gas-fired boiler operation*
4.3.5	PM (Particulate Matter)	Yes	*Due to gas-fired boiler operation*
4.3.6	Lead	No	
4.3.7	Other Air Pollutants	Yes	*Due to gas-fired boiler operation*

4.4 Please answer the following question about noise (operational).

			Notes:
4.4.1	Do the alternative processes have a noise impact greater than 80 db? (in plant, outside plant)?	No	

4.5 Please answer the following question about Land Use Impacts.

		onsite	offsite	Notes:
4.5.1	(To what extent) Does implementing any of the alternative processes require changes in Transportation Infrastructure? (Road Widening etc.)		Low	
4.5.2	(To what extent) Does implementing any of the alternative processes require additional land assets for storage, construction, disposal of material onsite or off-site?	Medium	Medium	*Onsite requirements lower than UF/RO (2C)*
4.5.3	(To what extent) Does implementing any of the alternative processes require dependency on land-fills or other disposal sites?		Medium	

4.6 Please provide information about By-Product Reuse Potential

				Notes:
4.6.1	Does implementing any of the alternative processes generate a reusable by-product?	No		*Reuse may be possible; none assumed for cost analysis*
4.6.2	If yes, what percent of total by-product is reusable		%	

5 Social & Community

5.1 Please provide information about Worker Safety Conditions:

Provide risk of the following Physical and Mechanical Safety Hazards

			Notes:
5.1.1	Confined or Elevated Spaces for workers	High	*Based on amount of equipment*
5.1.2	Excessive Noise	High	*Based on amount of equipment*
5.1.3	Heat Stress	High	*Based on amount of equipment*
5.1.4	Electrocution Risk / Wet Areas	High	*Based on amount of equipment*
5.1.5	Vibrating Machinery	High	*Based on amount of equipment*

Provide risk of the following Chemical Hazards while working with or transporting materials

			Notes:
5.2.1	Heavy Metals	Low	
5.2.2	Solvents	Low	
5.2.3	Petroleum	Low	
5.2.4	Fumes	Low	
5.2.5	Highly Reactive Chemicals	High	*Due to increase in chemicals used.*
5.2.6	Poisonous Chemicals	Low	

5.2 Please answer these questions on Public Health Impact:

			Notes:
5.2.1	Please rate the risk to the General Public from storage and transportation of raw materials involved specifically for this process.	High	*Based on additional chemicals for crystallization process*

5.2.2	Please rate the risk to the General Public from the disposal of by-products and wastes from the process (groundwater pollution, soil contamination etc.).	Medium	*Due to volume of crystallized brine waste*
5.2.3	Please rate the risk to the General Public in the event of catastrophic accident (leakage/explosion/flooding etc.) directly attributable to this process.	Medium	*Due to volume of crystallized brine waste and chemicals*

5.3 Please evaluate the Public Acceptance Factors for this process?

			Notes:
5.3.1	Do any of alternative processes have a local (neighborhood) impact on Odors, or Visual Aesthetics?	No	
5.3.2	Please rate the potential Public Nuisance caused by the process.	Low	*Due to waste hauling truck traffic*
5.3.3	Do any of alternative processes involve any kind of behavior change on the part of the resident community?	No	

5.4 Please Assess the Impact to Community Image and Leadership of MMSD:

			Notes:
5.4.1	Are any of the alternative processes State-of-the-Art and first of it's kind in the region?	Yes	
5.4.2	Are any of the alternative processes innovative as to serve as a model for other technology implementations?	Yes	
5.4.3	Does the alternative involve the by-large community in terms of progressive actions/behavior changes?	No	

Appendix F

Manufacturer Literature

UF/RO VENDOR INFO - SOFTENING

Newterra

Vanorman, Eric

From: Harry Cummings <hcummings@newterra.com>
Sent: Tuesday, December 30, 2014 9:49 AM
To: Vanorman, Eric; Jordan, James <jtjordan@kochmembrane.com> (jtjordan@kochmembrane.com)
Cc: Pugh, Lucy B.
Subject: RE: Wisconsin Chloride Removal/Softening
Attachments: Wisconsin Well 27C.pdf; Wisconsin Well 9C.pdf; AECOM Well Treatment PFD.pdf; AE Wisonsin RO Skid Layout.pdf; AECOM Wisconsin Well Water RO Operating Costs.xlsx

Eric,

Attached is the information for softening the source water.

The flow diagram is for the WELL OPTION. That has two RO skids with a blend stream to produce water with a 100 ppm as CaCO3 hardness. The skid layout is from a similar size RO skid we did on a previous project, although some of the details (like the number of pumps) may change. Note the RO skid requires 4' maintenance clearance at either end to remove membranes (as well as the usual clearance in front of the control panels). The estimated capital cost per well head (ie, two RO skids) is $800,000.

For the CENTRALIZED OPTION, I assumed we would have 34 of these RO skids in place. Each skid size and projection would remain the same. The estimated capital cost is $12.5 million.

Attached is also the estimated operating costs for each skid.

I am still working on some of the information for the Wastewater Treatment Option and hope to have that to you shortly.

Harry Cummings
Senior Application Engineer
T: 610.631.7700 | **F:** 610.630.6656 | **Direct Dial:** 484.690.2461
Cell: 484.238.7973
2650 Eisenhower Dr.
Bldg. 100-A
Trooper, PA. 19403
hcummings@newterra.com | industrial.newterra.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 19, 2014 2:59 PM
To: Jordan, James <jtjordan@kochmembrane.com> (jtjordan@kochmembrane.com); Harry Cummings
Cc: Pugh, Lucy B.
Subject: Wisconsin Chloride Removal/Softening

Tim/Harry:

We are in the process of finalizing the chloride reduction preliminary engineering report for our Wisconsin client. Thank you for providing the information to date related to this project. For the final document we are looking to cleanup a few things and fill in a few remaining holes. To that end can you:

For the Wastewater UF system:

- Adjust the Puron offering to provide a permeate of 15MGD to feed to the RO. Please incorporate 1 standby unit in the capital cost so that we have a 15MGD firm permeate capacity from the system with one unit out of service.
- Provide the UF systems efficiency.
- Provide general arrangement drawing including overall dimensions.
- Include system sizing including layout, flux rate……
- Describe how the system would operate if only one unit would be required to be in service. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide estimated labor costs associated with O&M of the RO system.

For the Wastewater RO system:

- Adjust the RO offering to accommodate a 15MGD feed. Please incorporate 1 standby unit in the capital cost so that we have a 15MGD raw flow capacity from the system with one unit out of service.
- Describe how the system would operate if only one unit would be required to be in service. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide a general arrangement drawing including dimensions.
- Provide O&M costs including:
    - Utility consumption
    - Chemical usage
    - Labor
    - Replacement costs (Total # pre-filters and membranes, cost per pre-filter/membrane and life expectancy)

For the Wastewater recovery RO system:

- Adjust the recovery RO offering based on the 15MGD feed to the main RO. At this point we are assuming a total of 6 skids (5 duty and 1 standby)
- Describe how the system would operate if only a 3 MGD flow through the main RO system would be required. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide a general arrangement drawing including dimensions.
- Provide O&M costs including:
    - Utility consumption
    - Chemical usage
    - Labor

  - Replacement costs (Total # pre-filters and membranes, cost per pre-filter/membrane and life expectancy)

For Softening of Source Water

- WELL OPTION - Adjust the well softening offering (if needed) to provide softened blended water from a 3.0 MGD raw water supply. Assume two units combined (or suggest alternate) would be required to accomplish this.
- CENTRALIZED OPTION - Provide a membrane softening option which can provide 50 MGD of softened blended water (quality data previously sent). Further assume that the reject from this system could be discharged to the sanitary, minimizing the overall foot print. Information on the processing rate and an estimate on the % reject would be required as well.
- Provide information on proposed softening equipment options including capital cost, equipment sizes (capacity and foot prints), materials of construction and O&M costs including labor.
- Provide O&M costs including:
  - Utility consumption
  - Chemical usage
  - Labor
  - Replacement costs (Total # pre-filters (if needed) and membranes, cost per pre-filter/membrane and life expectancy)

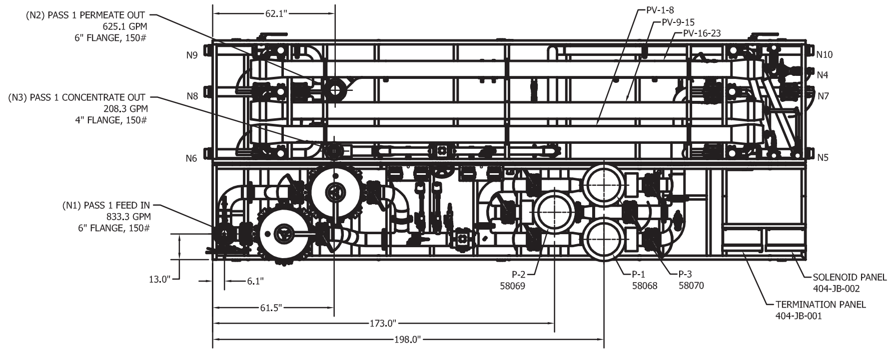
We are hoping this is something which can be updated by the end of the year. If this is not feasible please let us now when the information could be provided. If you have any questions please don't hesitate to contact either myself or Lucy.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

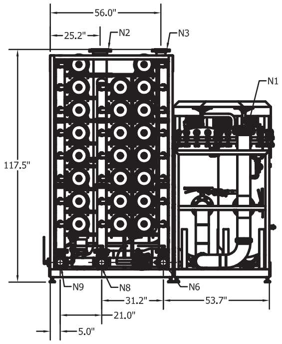
AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600   F 1.616.940.4396   Cisco 2084446
www.aecom.com

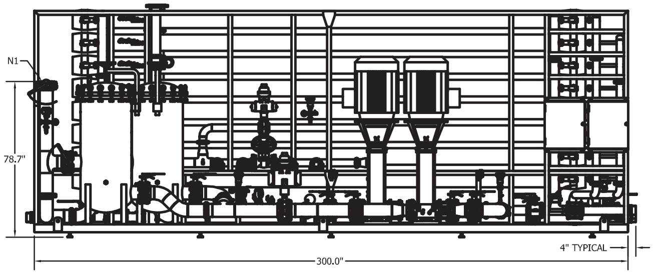
CONNECTION TABLE		
ID	DESCRIPTION	SIZE
N1	SYSTEM INLET	6" FLANGE
N2	PERMEATE OUTLET	6" FLANGE
N3	CONCENTRATE OUTLET	4" FLANGE
N4	CLEANING RETURN	2" QUICK CONN.
N5	CLEANING FEED	4" QUICK CONN.
N6	CLEANING RETURN	4" QUICK CONN.
N7	CLEANING FEED	4" QUICK CONN.
N8	CLEANING RETURN	4" QUICK CONN.
N9	CLEANING FEED	4" QUICK CONN.
N10	CLEANING RETURN	4" QUICK CONN.

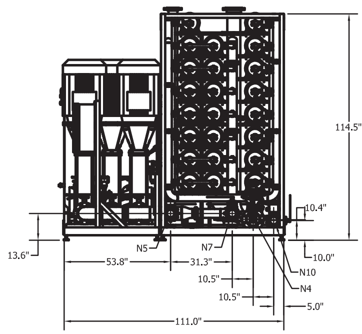


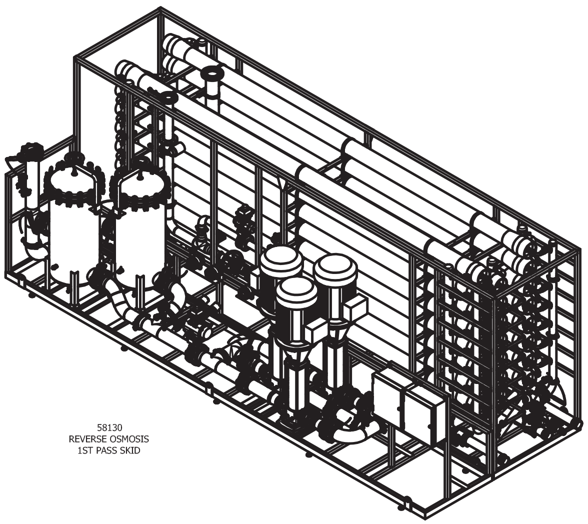
NOTES:
1.) WELDED CARBON STEEL FRAME
2.) PAINT: JESUP DOVER WHITE
4.) MAINTENANCE CLEARANCE: 4' EACH END

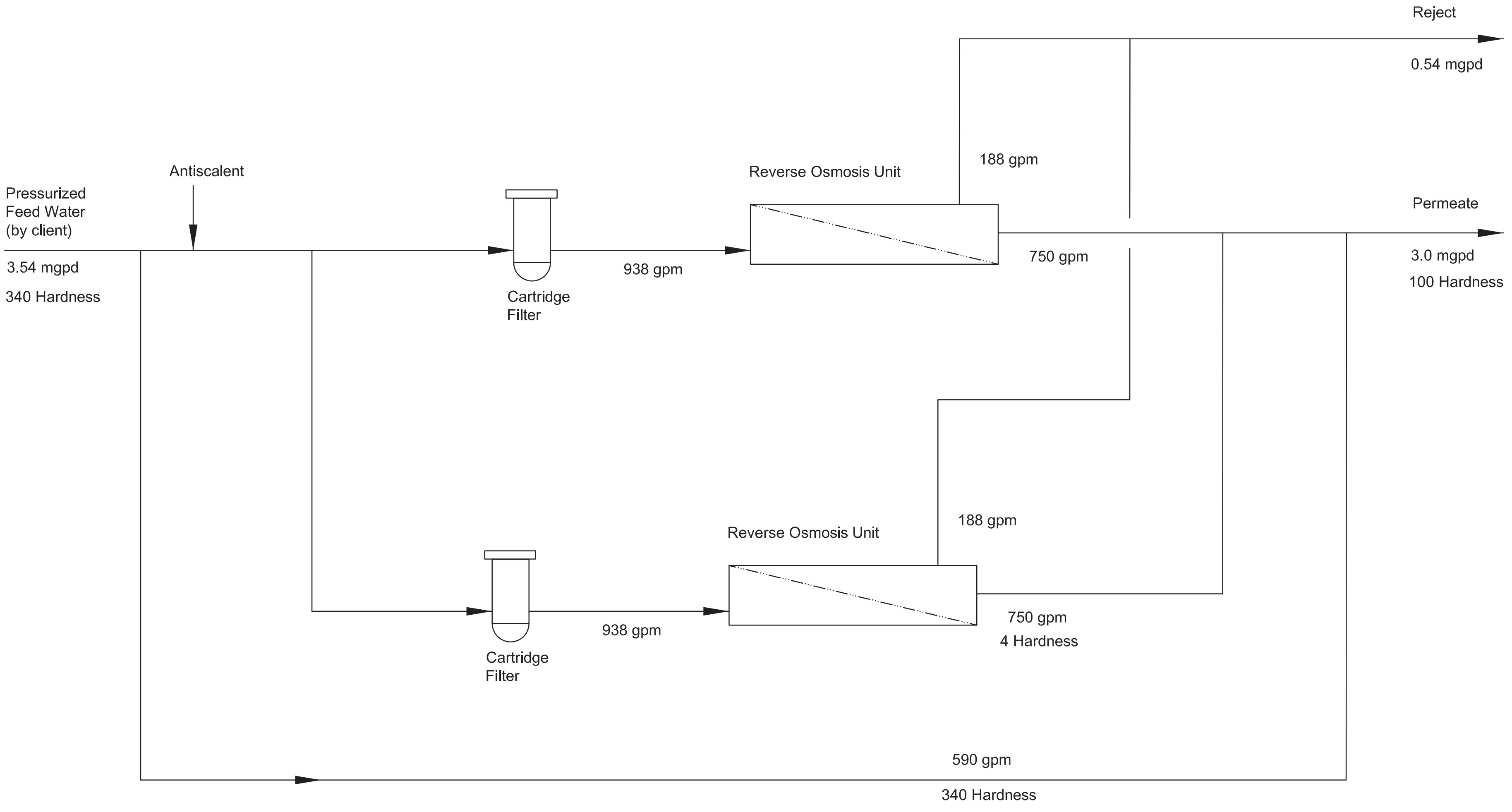
ESTIMATED SYSTEM WEIGHTS:
EMPTY: 16,500 POUNDS (PUMP SKID = 7500lb, VESSEL RACK = 9000lb)
OPERATING: 30,000 POUNDS








58130
REVERSE OSMOSIS
1ST PASS SKID



NOTES

DRAWING IS NOT TO SCALE
NOT ALL PROCESS LINES AND EQUIPMENT HAVE BEEN SHOWN FOR CLARITY

newterra

PHONE:
(800) 420-4056
www.newterra.com

LEVEL	REVISION	DATE (mm/dd/yy)	BY

PROJECT NUMBER xxx

TITLE AND LOCATION
PROCESS FLOW DIAGRAM
SINGLE WELL TREATMENT

CUSTOMER
AECOM

DRAWN BY HGC
DATE 12/28/14
SHEET
SHEETS

Reverse Osmosis System Analysis for FILMTEC™ Membranes ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - raw water Case: 1
HGC, newterra 11/20/2014

Project Information:

Case-specific:

System Details

Feed Flow to Stage 1	937.50 gpm	Pass 1 Permeate Flow	749.95 gpm	Osmotic Pressure:	
Raw Water Flow to System	937.50 gpm	Pass 1 Recovery	80.00 %	Feed	3.75 psig
Feed Pressure	190.21 psig	Feed Temperature	9.0 C	Concentrate	17.48 psig
Flow Factor	0.85	Feed TDS	577.39 mg/l	Average	10.61 psig
Chem. Dose	None	Number of Elements	161	Average NDP	146.12 psig
Total Active Area	70840.00 ft²	Average Pass 1 Flux	15.24 gfd	Power	96.98 kW
Water Classification: Well Water SDI < 3				Specific Energy	2.16 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	LE-440i	16	7	937.50	185.21	0.00	368.98	148.75	568.52	16.61	0.00	0.00	2.82
2	LE-440i	7	7	368.98	143.75	0.00	187.55	109.19	181.44	12.12	0.00	0.00	8.01

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	14.00	14.00	35.28	68.86	0.19	0.58	0.28
Na	12.00	12.00	30.38	59.54	0.07	0.23	0.11
Mg	39.00	39.00	98.88	194.12	0.14	0.43	0.21
Ca	72.00	72.00	182.56	358.41	0.25	0.78	0.37
Sr	0.07	0.07	0.18	0.35	0.00	0.00	0.00
Ba	0.03	0.03	0.08	0.15	0.00	0.00	0.00
CO3	0.65	0.65	4.55	16.82	0.00	0.00	0.00
HCO3	368.47	368.47	928.11	1805.62	1.75	4.66	2.42
NO3	2.00	2.00	4.74	8.71	0.22	0.65	0.32
Cl	34.00	40.91	103.74	203.69	0.13	0.42	0.20
F	0.75	0.75	1.90	3.72	0.01	0.02	0.01
SO4	19.00	19.00	48.21	94.74	0.04	0.12	0.06
SiO2	8.50	8.50	21.54	42.27	0.04	0.11	0.06
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	19.78	19.77	21.39	25.93	19.89	22.56	20.56
TDS	570.48	577.39	1460.15	2857.01	2.82	8.01	4.04
pH	7.50	7.50	7.82	7.98	5.29	5.65	5.41

*Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area. DISCLAIMER: NO WARRANTY, EXPRESSED OR IMPLIED, AND NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, IS GIVEN. Neither FilmTec Corporation nor The Dow Chemical Company assume any obligation or liability for results obtained or damages incurred from the application of this information. Because use conditions and applicable laws may differ from one location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. FilmTec Corporation and The Dow Chemical Company assume no liability, if, as a result of customer's use of the ROSA membrane design software, the customer should be sued for alleged infringement of any patent not owned or controlled by the FilmTec Corporation nor The Dow Chemical Company.

Reverse Osmosis System Analysis for FILMTEC™ Membranes ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - raw water Case: 1
HGC, newterra 11/20/2014

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.10	5.62	1.79	58.59	577.39	185.21
2	0.10	5.39	2.02	52.97	638.45	177.07
3	0.11	5.20	2.30	47.58	710.54	170.05
4	0.12	5.03	2.66	42.38	797.26	164.06
5	0.13	4.88	3.12	37.35	903.99	159.00
6	0.15	4.76	3.75	32.47	1039.15	154.81
7	0.17	4.65	4.61	27.71	1216.50	151.42

Stage 2 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.08	4.37	5.18	52.71	1460.15	143.75
2	0.09	4.13	5.94	48.34	1591.15	136.67
3	0.09	3.90	6.84	44.22	1738.58	130.43
4	0.09	3.69	7.89	40.32	1905.49	124.93
5	0.09	3.48	9.13	36.63	2095.62	120.12
6	0.10	3.28	10.63	33.15	2313.58	115.93
7	0.10	3.08	12.44	29.87	2565.04	112.31

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.50	7.50	7.98
Langelier Saturation Index	-0.03	-0.03	1.77
Stiff & Davis Stability Index	0.61	0.61	1.82
Ionic Strength (Molal)	0.01	0.01	0.06
TDS (mg/l)	570.48	577.39	2857.01
HCO3	368.47	368.47	1805.62
CO2	19.78	19.78	25.92
CO3	0.65	0.65	16.82
CaSO4 (% Saturation)	0.35	0.35	4.34
BaSO4 (% Saturation)	18.93	18.93	204.17
SrSO4 (% Saturation)	0.04	0.04	0.22
CaF2 (% Saturation)	5.38	5.38	658.07
SiO2 (% Saturation)	9.14	9.14	42.19
Mg(OH)2 (% Saturation)	0.00	0.00	0.06

To balance: 6.91 mg/l Cl added to feed.

Reverse Osmosis System Analysis for FILMTEC™ Membranes | ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - raw water | Case: 1
HGC, newterra | 11/20/2014

Project Information:

Case-specific:

System Details

Feed Flow to Stage 1	937.50 gpm	Pass 1 Permeate Flow	750.01 gpm	Osmotic Pressure:	
Raw Water Flow to System	937.50 gpm	Pass 1 Recovery	80.00 %	Feed	3.99 psig
Feed Pressure	106.11 psig	Feed Temperature	27.0 C	Concentrate	18.36 psig
Flow Factor	0.85	Feed TDS	577.32 mg/l	Average	11.17 psig
Chem. Dose	None	Number of Elements	161	Average NDP	69.40 psig
Total Active Area	70840.00 ft²	Average Pass 1 Flux	15.25 gfd	Power	54.10 kW
Water Classification: Well Water SDI < 3				Specific Energy	1.20 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	LE-440i	16	7	937.50	101.11	0.00	335.10	74.71	602.40	17.60	0.00	0.00	7.75
2	LE-440i	7	7	335.10	69.71	0.00	187.49	46.20	147.61	9.86	0.00	0.00	30.17

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	14.00	14.00	38.22	66.81	0.53	1.90	0.80
Na	12.00	12.00	33.17	58.55	0.22	0.93	0.36
Mg	39.00	39.00	108.34	192.29	0.43	1.71	0.68
Ca	72.00	72.00	200.06	355.11	0.77	3.11	1.23
Sr	0.07	0.07	0.19	0.35	0.00	0.00	0.00
Ba	0.03	0.03	0.08	0.15	0.00	0.00	0.00
CO3	1.01	1.01	7.89	22.27	0.00	0.00	0.00
HCO3	368.47	368.47	1012.60	1779.08	4.56	18.00	7.18
NO3	2.00	2.00	4.55	6.71	0.58	1.81	0.82
Cl	34.00	40.48	112.53	199.78	0.41	1.70	0.66
F	0.75	0.75	2.07	3.64	0.02	0.07	0.03
SO4	19.00	19.00	52.93	94.22	0.12	0.50	0.20
SiO2	8.50	8.50	23.57	41.78	0.12	0.44	0.18
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	14.55	14.53	17.26	22.12	15.01	18.65	15.74
TDS	570.84	577.32	1596.23	2820.76	7.75	30.17	12.14
pH	7.50	7.50	7.81	7.90	5.68	6.17	5.86

*Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area.

Reverse Osmosis System Analysis for FILMTEC™ Membranes ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - raw water Case: 1
HGC, newterra 11/20/2014

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.11	6.35	3.96	58.59	577.32	101.11
2	0.11	5.93	4.80	52.25	646.84	94.97
3	0.12	5.58	5.87	46.32	728.89	89.76
4	0.13	5.29	7.23	40.73	827.69	85.40
5	0.14	5.04	8.99	35.45	949.66	81.78
6	0.16	4.83	11.35	30.41	1105.04	78.84
7	0.18	4.63	14.67	25.58	1310.76	76.50

Stage 2 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.09	4.11	17.66	47.87	1596.23	69.71
2	0.08	3.70	21.18	43.77	1743.60	65.01
3	0.08	3.33	25.43	40.06	1902.10	60.87
4	0.08	2.97	30.57	36.73	2071.32	57.21
5	0.08	2.64	36.86	33.76	2250.16	53.97
6	0.07	2.32	44.57	31.12	2436.71	51.09
7	0.07	2.02	54.16	28.80	2628.19	48.52

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Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.50	7.50	7.90
Langelier Saturation Index	0.39	0.39	2.10
Stiff & Davis Stability Index	0.95	0.95	2.09
Ionic Strength (Molal)	0.01	0.01	0.06
TDS (mg/l)	570.84	577.32	2820.76
HCO3	368.47	368.47	1779.08
CO2	14.54	14.54	22.11
CO3	1.01	1.01	22.27
CaSO4 (% Saturation)	0.35	0.35	4.30
BaSO4 (% Saturation)	18.93	18.93	203.02
SrSO4 (% Saturation)	0.04	0.04	0.22
CaF2 (% Saturation)	5.38	5.38	626.60
SiO2 (% Saturation)	6.59	9.14	31.38
Mg(OH)2 (% Saturation)	0.00	0.00	0.04

To balance: 6.48 mg/l Cl added to feed.

AECOM Well Water RO Operating Cost

Note: Costs below are for one skid which produces 750 gpm of RO permeate

1. Electricity Cost

RO High pressure Pump -	Flow rate	1000	gpm
	Pump head	220.0	psi
	Pump Eff.	70.0%	
	bHP	183.3	
	KW	136.8	
Control Panel	KW	1.0	
Net KW		137.8	
		2.30	KWHr/kgal
RO Permeate Flow Rate		1000	gpm
Average daily usage		2000000	gpd
Power Cost		$0.10	per KWHr
Power Cost per day		$459.22	
Power Cost per year		$167,616	

2. Chemical Costs

Antiscalant Dosage	3	ppm
Feed Flow Rate	1000	gpm
Chemical Use	49.98	lbs. per day
	5.00	gallons per day
Chemical Cost	$6.00	per lbs
Antiscal Cost per day	$299.88	
Antiscal Cost per year	$109,456	
SBS Dosage	3	ppm
Feed Flow Rate	1000	gpm
Chemical Use	49.98	lbs. per day
	5.00	gallons per day

Chemical Cost		$1.00	per lbs
SBS Cost per day		$49.98	
SBS Cost per year		$18,243	

3. Filter Bag Changeout

Number of Cartridge Filter Elements		52	
Changeout frequency	once per	1	month
Filter Cost		$3.00	per element
Filter Cost per year		$1,872	

4. RO Membrane Replacement

Number of RO Membranes Installed		168	
Changeout frequency		3	years
Membrane Cost		$700.00	per membrane
Membrane Cost per year		$39,200	

5. RO Cleaning Chemicals

Chemicals wieght per cleaning		600	lbs.
Cleaning frequency	once every	6	months
Chemical Cost		$6.00	per lbs
Cleaning Chemical Cost per year		$7,200	

Total Operating Cost per year	**$343,587**

UF/RO VENDOR INFO – CHLORIDE REMOVAL

Evoqua

Newterra

RO Model Output

Evoqua (Memcor) – UF

Vanorman, Eric

From: Cohoon, Kevin L <kevin.cohoon@evoqua.com>
Sent: Tuesday, December 09, 2014 4:00 PM
To: Vanorman, Eric; Pugh, Lucy B.
Cc: Gerald Alexander; Cohoon, Kevin L; Davis, Calvin R
Subject: RE: Chloride Removal - UF Info (2)

Hi Eric,

Please see responses below in red. Thanks!

Kevin Cohoon
Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Tuesday, December 09, 2014 9:02 AM
To: Cohoon, Kevin L; Pugh, Lucy B.
Cc: Gerald Alexander
Subject: RE: Chloride Removal - UF Info

Hi Kevin:

Thanks for the UF system info. I assume the 12 units are for a firm capacity of 15MGD. So 1.25 MGD per skid.
Yes, although this is designed based on membrane flux and not flow.

If we wanted to add some redundancy we could have two trains of 7 units each for a firm capacity of 7.5 MGD per train and total capacity per train of 8.75 MGD. Is this correct? This design has redundancy built in

Would the recommendation be for one CIP system per train as shown in the Grand Forks drawings? So a total of 2 CIP for our system? Correct

Any specific requirements for equalization tanks upstream and downstream of the UF system? Yes, you need supply an equalized flow. You would have a tank after the UF with about 15 minutes residence time.

It is assumed that no additional pretreatment of the secondary effluent upstream of the UF system is required. Is this correct? Also, there was reference to self-cleaning wedgewire screen filters in the RO offering ahead of the UF. Do the strainers shown on the Grand Forks drawing cover this? Yes the strainers are included.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446 M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
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Grand Rapids, Michigan 49512
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www.aecom.com

From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Monday, December 08, 2014 7:27 PM
To: Vanorman, Eric; Pugh, Lucy B.
Cc: Gerald Alexander
Subject: Chloride Removal - UF Info

Hi Eric and Lucy,

For a 15 MGD supply we would tentatively size the UF system as a 12 x 112L40N. Budget price = $5.5M

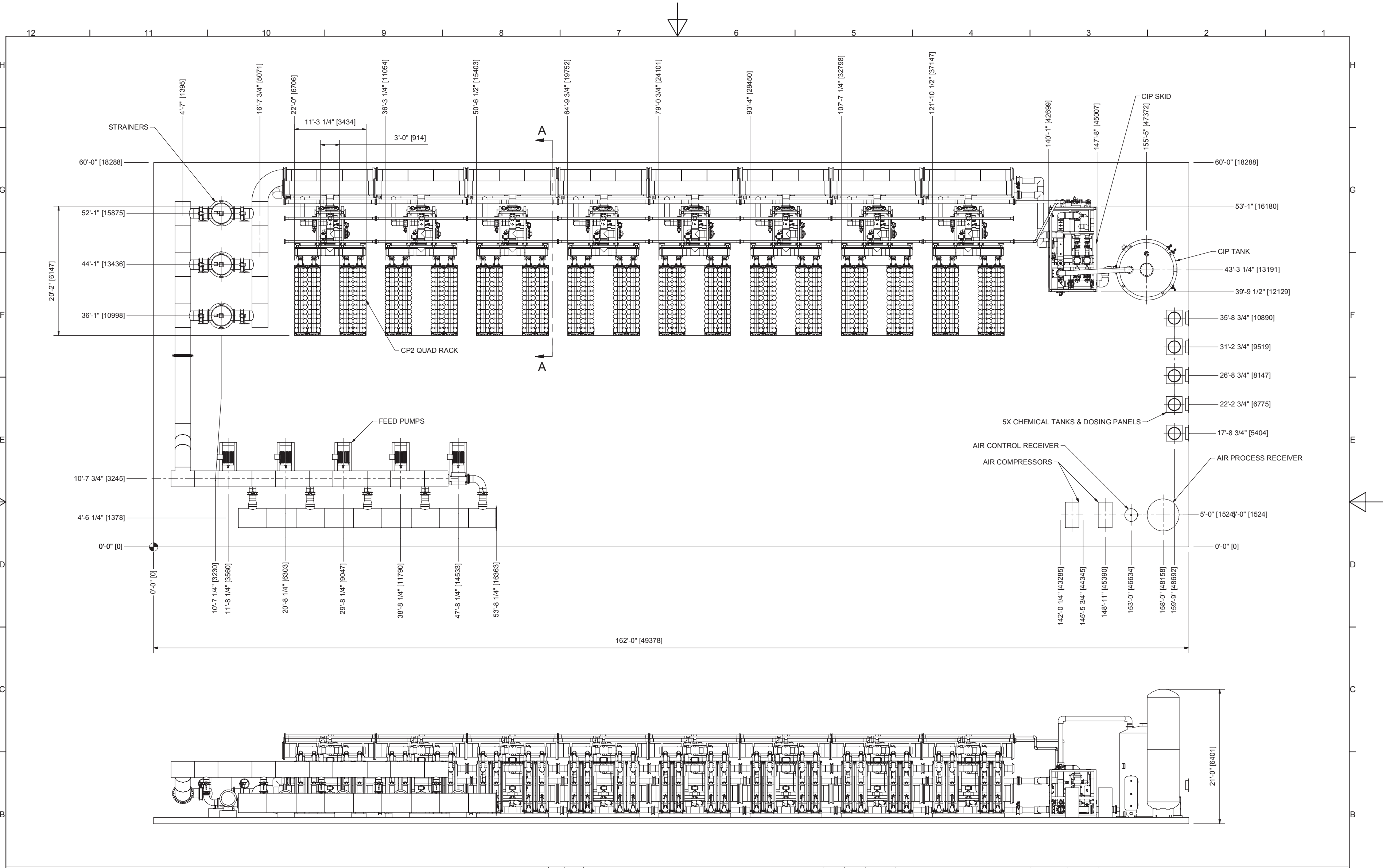
Attached is an 8 skid system for a project we are working on in North Dakota. A twelve skid system would look like this except there would be two identical rows, but with 6 skids per row not 8.

Finally, attached are some articles/brochures pertaining to Memcor's experience in Reuse. We call membrane filtration of secondary treated wastewater "Reuse" because this is usually the reason for adding the extra treatment—they want to treat it to a reuse standard not a discharge standard.

Hope this helps. Thanks!

Kevin Cohoon
Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

Electronic Filing: Received, Clerk's Office 05/30/2019 P.C. #6



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SMKB	
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KK	
APPROVED	DATE
AZ	

TITLE MEMCOR CPII 8 UNIT QUAD RACK SYSTEM
GENERAL ARRANGEMENT

CLIENT GRAND FORKS, ND

SIEMENS

U.S.A.
55 TECHNOLOGY DRIVE, SUITE 201
LOWELL,
MA 01851-5203
1-800-636-2674 (1-800-MEMCOR4)

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1 MEMTEC PARKWAY,
SOUTH WINDSOR.
NSW 2756
TEL +61 (0) 2 4577 6800

U.K.
OUTRAMS WHARF.
LITTLE EATON,
DERBY. ENGLAND, DE21 5EL
TEL +44 (0) 1332 387300

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SCALE:	PROJECT	DRAWING	SHEET	STATUS
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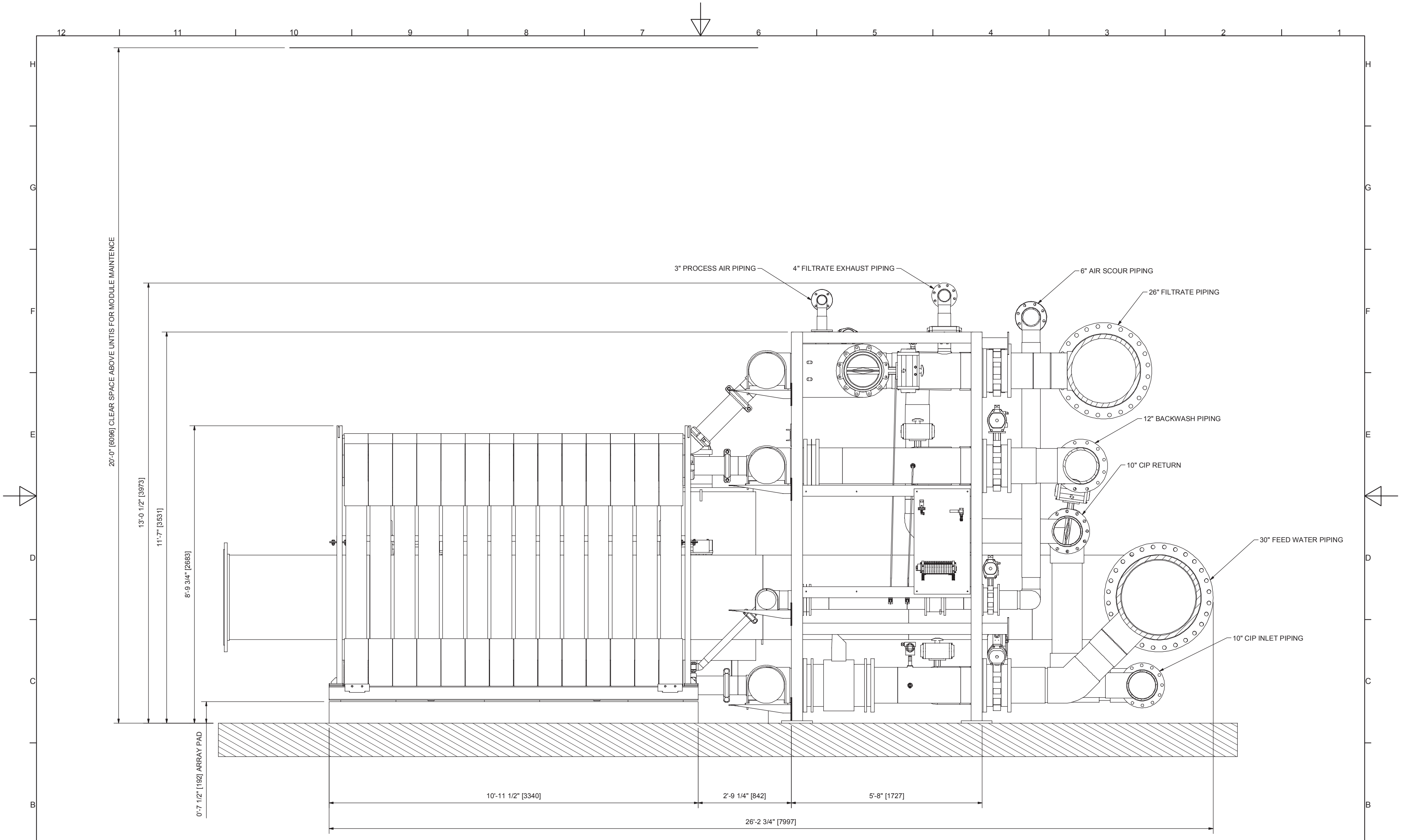

SECTION A-A

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DRAWN SMKB	DATE	TITLE MEMCOR CPII 8 UNIT QUAD RACK SYSTEM GENERAL ARRANGEMENT
CHECKED KK	DATE	CLIENT GRAND FORKS, ND
APPROVED AZ	DATE	

SIEMENS

U.S.A.
55 TECHNOLOGY DRIVE, SUITE 201
LOWELL,
MA 01851-5203
1-800-636-2674 (1-800-MEMCOR4)

AUSTRALIA
1 MEMTEC PARKWAY,
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U.K.
OUTRAMS WHARF.
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TEL +44 (0) 1332 387300

DO NOT SCALE ALL DIMENSIONS IMPERIAL	SCALE:	PROJECT	DRAWING	SHEET	STATUS
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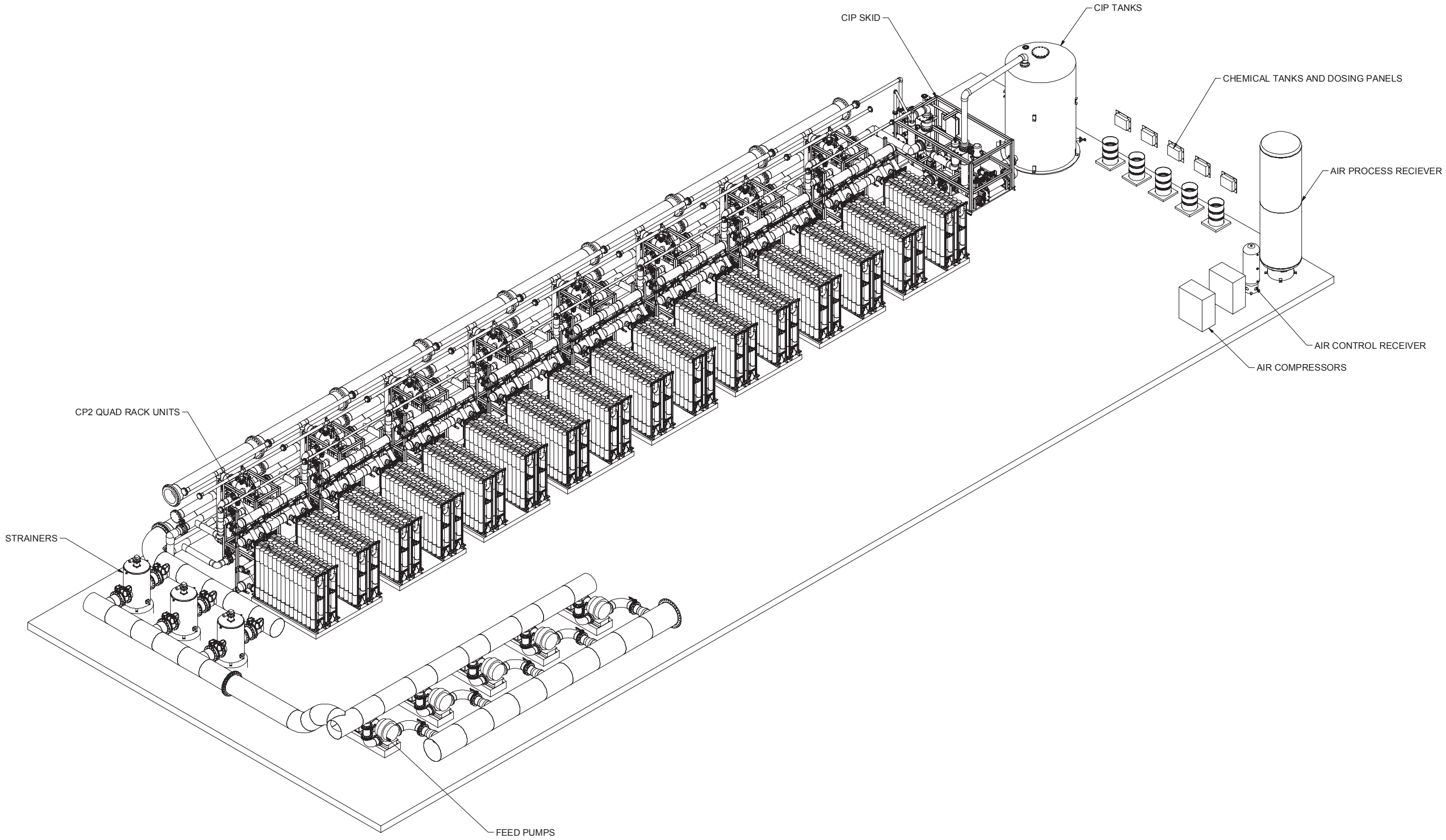

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DRAWN
SMKB
DATE
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KK
DATE
APPROVED
AZ
DATE

TITLE MEMCOR CPII 8 UNIT QUAD RACK SYSTEM
GENERAL ARRANGEMENT

CLIENT GRAND FORKS, ND

SIEMENS

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DO NOT SCALE
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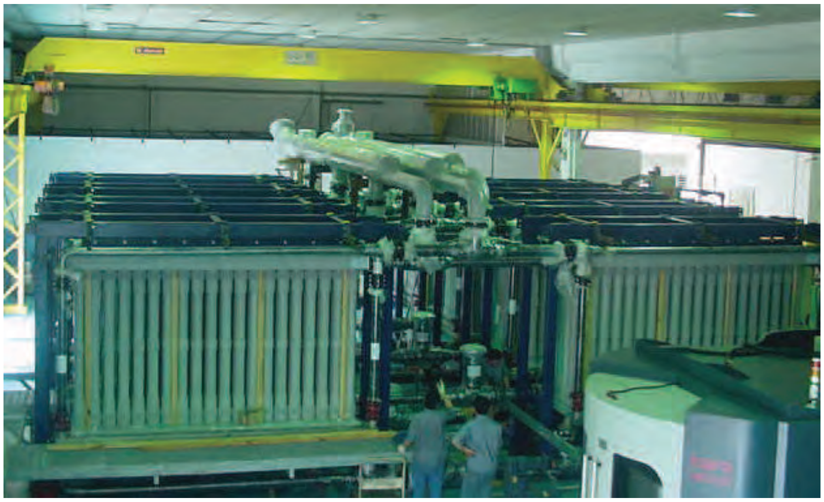
SCALE:	PROJECT	DRAWING	SHEET	STATUS
NONE		14P1408CPD4102-GA	3 OF 3	0

SIEMENS

Water Technologies

MEMCOR® WASTEWATER REUSE EXPERIENCE



Changi- 288ML/d (7 x MEMCOR® CP960)

Water Factory 21- 326 ML/d (26 x Memcor® CS608)

1.0 MEMCOR®'s Long History in Wastewater

From the time Memcor installed the world's first membrane filtration plant to polish secondary effluent at Blackheath, NSW in 1990[1] it became clear that membrane filtration, with the added protection of chlorination, could produce microbiologically safe recycled water that exceeds guidelines for unrestricted non potable urban reuse.

MEMCOR® membranes are used in the following notable Australian reuse projects:

- Sydney Olympic Park (WRAMS)
- Rouse Hill Urban Reuse Scheme
- Illawarra Water Reclamation Plant
- Kwinana Water Reclamation Plant
- Gerringong Gerroa Reclaimed Water Facility
- Port Macquarie Wastewater Reuse Project
- Sydney Water North Head STP Recycled Water Project
- Bundamba Advanced WRP (Western Corridor)
- Wynnum Water Recycling Plant

In the last decade MEMCOR® Membrane Filtration has become accepted as the "enabling technology" for indirect potable reuse in United States (in particular California), Singapore, China and elsewhere. Until recently there was little economic, environmental or regulatory pressure to exploit membrane treatment's potential for urban reuse. This has changed. In particular Australia has embarked on a number of commendable reuse schemes as a result of climate change, and an increasing population to sure up the water supply.

More recently, MEMCOR® Membranes have been successfully chosen as the preferred technology for the following high profile projects in Australia:

- South East Queensland Western Corridor's "GIBSON ISLAND" and "BUNDAMBA Stage 1A and Stage 1B" Indirect Potable Reuse projects
- Gold Coast Water's "PIMPAMA" Water Reclamation Project
- Brisbane Water's "WYNNUM" Water Reclamation Project
- Gippsland Water Factory

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[1] "Demonstration of Memtec microfiltration for disinfection of secondary treated sewage", Water Board, Memtec Limited & Department of Industry, Technology and Commerce, May 1992

The following Memcor installations in Australia, Singapore and China demonstrate the diversity of reclaimed water applications using MEMCOR® Pressurised or Submerged membrane filtration technology.

2.0 Memcor Reuse Plants in Australia

Eraring Power Station (NSW)

The first application to combine Microfiltration and RO to produce boiler feed quality water from a secondary municipal wastewater. There are now over 30 MEMCOR® Membrane/RO applications treating municipal wastewater with many more industrial installations worldwide. The largest is the 328 ML/d Orange County, CA project currently being commissioned.

- The Eraring plant was commissioned in 1995 and upgraded to 3.7 ML/d of RO water in late 2000.
- The feed is secondary effluent. The process train is MEMCOR® Pressure membranes, Chlorination and Reverse Osmosis incorporating Cellulose Acetate membranes.
- The original MF and RO membranes were installed in late 1995. In November 2001 they continued to provide good service. The RO membranes were achieving 97% rejection (98% when new) and had not been cleaned for over two years.
- The water reclamation plant has operated efficiently and effectively with the original set of membranes for more than 9 years. This represents the longest operation of membranes on a secondary wastewater application globally.

Sydney Olympic Site – Sydney Olympic Park Authority

- The Water Reclamation and Management Scheme (WRAMS) for the Sydney Olympic Games site at Homebush Bay in Sydney recycles treated storm and wastewater to the Olympic site sporting venues and adjacent residential areas for toilet flushing and irrigation via a separate reticulation system.
- The project involved construction of three key components – a site biological sewage treatment plant; a 300 mega-litres storage reservoir (from an old quarry) for storage of secondary treated effluent and storm water run off; and a MEMCOR® Pressure/RO water treatment plant to reclaim blended storm and treated wastewater from the storage reservoir.
- The MEMCOR® Pressure/RO plant is designed to produce 7.5 ML/day of filtered reclaim water, 2 ML/day of RO water, or a blend of the two depending on TDS of the plant's feedwater. TDS control was necessary to protect soil salinity when the product water was used for irrigation.
- The plant comprises two 90M10C MEMCOR® CP units and two RO trains using 8 inch pressure vessels and spiral wound thin film composite membranes.

United Group Infrastructure, were awarded the contract for the design, installation and commissioning of the WRAMS plant. Additionally they have continual involvement with the site having been awarded a 25 year operations contract.

Rouse Hill Urban Reuse Scheme (NSW) – Sydney Water Corporation

- The Rouse Hill Urban Reuse Scheme is the result of a NSW State Government decision to incorporate dual water reticulation to reduce incremental pressure on Sydney's fresh water resources. This new residential area (on the way to Windsor) will house 350,000 people by 2050.
- The treatment plant incorporates two MEMCOR® Pressure trains of 2.6 ML/day for tertiary filtration of a non-potable supply that meets the NSW Guidelines for Urban and Residential Use of Reclaimed Water (May 1993).
- The non-potable supply is used for toilet flushing, non-potable outdoor uses such as garden watering, and for the fire hydrant system.
- Sydney Water Corporation originally installed biological nutrient removal, sedimentation and chemically assisted filtration. After commissioning the authority found it could not meet the quality criteria for human pathogen removal, particularly with to respect to Cryptosporidium. In 1999 they subsequently installed a Memcor CMF membrane system to ensure protozoa removal.

North Lakes, Darwin, Northern Territory Power & Water Authority

- This 2 ML/day municipal reuse scheme was originally supplied by Acumen to polished secondary sewage for golf course irrigation. The Acumen MF plant could not be made to operate reliably in dry weather. USF inherited the plant and the problem. The solution was to install an alum dosed DAF plant followed by MEMCOR® Pressure system (108M10C).
- The STP comprises two parallel trains of three shallow ponds (less than 2 metres depth) that decant into each other. There is no mechanical aeration.
- The effluent quality is seasonal and differs between night and day. In wet weather monsoonal rainfall dilutes the effluent placing little pressure on the tertiary treatment facility. In dry weather algal concentrations of 5,000 counts/mL are experienced during the day. At night the challenge is high suspended solids (200 mg/L).
- Microbiological quality is critical, as the treated water is spray irrigated onto a golf course.

Gerringong & Gerroa Reclaimed Water Facility – Sydney Water Corporation

- Gerrringong and Gerroa are coastal towns south of Sydney and popular holiday destinations. The treatment plant is a 3.8 ML/day advanced tertiary facility installed as a 20 year build, own and operate plant for Sydney Water.
- Treatment involves screening, biological treatment (including nutrient removal), ozonation, biological activated carbon, membrane filtration and UV disinfection.
- Sydney Water describes the additional treatments of ozonation, BAC and MF as those required to convert normal tertiary treated sewage into "Reclaimed Water".
- 80% of the plant's output will be used for irrigating farmland adjacent to the plant.
- The range of treatment processes used and the high level of treatment achieved offer significant opportunities for research and development in areas such as treatment processes, other reuse opportunities and biosolids management.

Illawarra Water Reclamation Plant – Sydney Water Corporation

- The project involved decommissioning the sewage treatment plants at Bellambi and Pt Kembla (surrounding areas of Wollongong) and returning most of the land to the community.
- The Wollongong Sewage Treatment Plant was upgraded extensively including a large, state of the art, biological nutrient removal facility. The resulting high grade secondary effluent is further treated to produce reclaimed water.
- This advanced treatment involved nine MEMCOR® Pressure E112M10C units providing pre-treatment to four 5 ML/d RO trains to produce low TDS process water for the Port Kembla steelworks and other industry. The plant was commissioned in 2003.
- Water quality is shown in the following table.

Parameter	Value
Filtrate flow	23.5 ML/d
Feed quality	SS 80 ppm Turbidity <0.3 NTU TDS 800 uS/cm
Filtrate Quality	SDI <3
RO Recovery	85%
RO Permeate flow	20 ML/day
RO Permeate quality	<50 uS/cm

Mt Barker Effluent Disposal Scheme, South Australia – Mount Barker District Council

- This project is an example of reclaimed water being used to supply an artificially constructed wetland followed by crop irrigation.
- Mt Barker operates the largest STED (septic tank effluent drainage) system in South Australia collecting an average 1.9 MLD from a population of 10,000.
- Treatment involves oxidation ponds (with high levels of algae contamination), alum dosed DAF to remove algae and phosphorus (the latter down to 0.5 mg/L) and microfiltration. Treated effluent is discharged to an artificial wetland for nitrogen and ammonia removal.
- About 25% of annual flow (175 ML) from the wetland is used to irrigate brussel sprouts.
- Water quality must meet the SA Reclaimed Water Guidelines – less than 20 e-coli per 100mL. The levels are zero to one from the MEMCOR® Pressure unit but can rise to over 200 from the wetland in summer due to bird activity. The latter is accepted so long as there are no human e-coli detected. Surplus water flows to a creek.
- The first MEMCOR® CP unit was installed in 1997 (72M10C) and later expanded to 90 modules. An extra 60M10C was added in July 2002 bringing the plant's capacity to 3 MLD.

- Council plans to achieve 100% reuse with irrigation of municipal parks and gardens. Residents adjacent to the non-potable reticulation will be invited to pipe into this supply. Chlorination is not used as salinity is already high. Municipal reticulation will necessitate UV disinfection.

Kwinana Industrial Area – Water Corporation

- The Kwinana Water Reclamation Plant (KRWP) plant produces up to 5 Gigalitres per year of high quality process water to be used by industry in the Kwinana industrial area. Plant capacity is the equivalent of 2% of Perth's consumption or 6 peak summer days. The plant will reduce discharge to Cockburn sound by 6 ML per day.
- The project was announced in May 2002 and a contract signed in July 2003 with Veolia Water Systems and John Holland Water and commissioned in 2004.
- The plants capacity is 16.7 ML/d of RO Permeate and is located in the industrial belt south of Perth, WA.
- The plant uses the dual membrane technology of MEMCOR® Submerged membrane filtration and reverse osmosis to treat secondary effluent from the nearby Woodman Point Wastewater Treatment Plant.
- The KRWTP provides high quality water to large industrial customers such as Rio Tinto, Edison Mission Power and BP, the largest single users of Perth's public water supply.
- The plant is a major step by the WA Government to achieve its goal of 20% reuse of treated wastewater by 2012.

Taronga Zoo Reclamation Plant

- The Zoo uses large quantities of water for human and animal consumption, toilet and urinal flushing, replenishment of animal and ornamental moats, lawn and floral garden watering, and animal cage wash down. Reclaimed water is now used for many of these purposes.
- Prior to installing the MEMCOR® Submerged reuse facility stormwater and animal cage wash down water were discharged into Sydney harbour with minimal treatment.
- The reuse project involved upgrading the site's existing storm and wastewater treatment facilities to improve site discharge and to treat a significant proportion of the partially treated water to a standard suitable for reuse within the site. The latter involved membrane filtration, UV disinfection and pipework for a new non-potable water supply around the site.
- The reclaimed water quality is required to meet the NSW Guidelines for Urban and Residential Use of Reclaimed Water (May 1993).

Western Corridor Recycled Water Projects (South East Queensland Water)

The Western Corridor Recycled Water Project is the largest recycled water scheme to be constructed in Australia and will be the largest project of its kind in the southern hemisphere. The Project will recycle > 220 ML/d of wastewater that will be made available for Industrial/Municipal Reuse the remainder will be used for Indirect Potable

Reuse (also the Western Corridor project is the first large Indirect Potable Reuse in Australia). The recycled water scheme includes the upgrade of 3 WWTPs, namely:

- Bundamba WWTP
- Stage 2 Luggage Point WWTP
- Gibson Island WWTP

The project was “Fast tracked” by the Queensland State Government, and forms an environmentally friendly solution to the water crisis in that state. Not only does it reduce the load on the dwindling freshwater supply, it also aims to improve the water quality in the Moreton Bay watercourse by removing the Nutrients discharged into the system. The process is common to each project and uses Ultrafiltration, Reverse Osmosis and Advanced Oxidation (UV + H2O2).

MEMCOR® Pressure Membranes were selected for the Bundamba 1A, Bundamba 1B and Gibson Island Projects of this scheme. Siemens Water Technologies is proud to have secured 2 of the 3 Western Corridor projects and form an integral part of this monumental project in Australia.

Bundamba AWTP ~ 80 ML/d (2007)

The Bundamba Advanced Water Treatment Plant (AWTP) Stage 1A commenced operation in mid 2007. Bundamba Stage 1B commenced operation in February 2008. This project was executed by Black & Veatch and Thames Alliance. This project was the Winner of the “Global Water Project of the Year Award” from Global Water Intelligence in 2007.

Gibson Island AWTP ~120 ML/d (2008)

Gibson Island AWTP 61 ML/d was commissioned in July 2008. The next 61 ML/d instalment for Gibson Island AWTP will be operational in the first half of 2009. This project was executed with an alliance between United Group Infrastructure, Worley Parsons, MWH and Baulderstone Hornibrook.

Footprint and delivery were the two major issues when selecting the Ultrafiltration pre-treatment technology. As Gibson Island has the largest capacity (122 ML/d) and very limited space, MEMCOR® Pressure membranes was the only technology that met the clients’ requirements.

2.1. Recent MEMCOR® WW Reclamation Project Wins

Wynnum WW Plant Upgrade (Brisbane Water Environment Alliance)

The Wynnum Wastewater Treatment Plant is being upgraded to improve the quality of the treated wastewater produced by the plant, particularly the removal of nitrogen. The capacity of the plant will also be increased by around 6%. This upgrade also forms part of South East Queensland strategy to improve the water quality in the Moreton Bay watercourse with a reuse component.

The upgrade includes:

- a new biological nutrient removal system to treat up to 9 million litres of wastewater a day, removing 80% more nitrogen than the previous treatment system
- environmentally friendly UV disinfection, replacing the previous chlorine dosing method, eliminating chemicals in the discharged treated wastewater
- 7 ML/d Water Reclamation plant. MEMCOR® Pressure membranes were selected for this project

This project is being executed by the Brisbane Water Environment Alliance of which John Holland Water is a key member.

Gold Coast Water's "Pimpama Project"

Gold Coast Water plan is aimed at creating a sustainable community of approximately 15,000 residents that incorporates integrated urban water management. The scheme includes:

- Rain water tanks for every household
- Recycled water through Dual reticulation system (similar to Rouse Hill)
- The introduction of "smart sewers" and water sensitive urban design

It is hoped the plan will reduce demand on drinking water for new houses in the region by 84 per cent. The Recycled water use is expected to reach an ultimate capacity of 60 ML/d. This project is starting from the ground up, and with the release of new housing in the booming South East Queensland region is an innovative project to constrain freshwater requirements. Stage 1 of this project was commissioned in April 2008 and has a capacity of 9 ML/d. MEMCOR® Pressure membranes were selected as the core filtration component for this project.

Beenyup WWTP

The Beenyup Wastewater Treatment Plant is owned by Water Corporation WA, and currently treats domestic sewage, discharging the secondary treated effluent to the ocean via an outfall pipeline.

Water Corporation is trailing the use of dual membrane filtration (Ultrafiltration and Reverse Osmosis) for a Ground Water Replenishment Trial (GWRT). The capacity of the Ultrafiltration plant is 6.7ML/d. MEMCOR® Pressure membranes were selected for this project. The plant is due to be commissioned early 2009.

Glenelg to Adelaide Parklands (GAP), SA Water

As part of the Water Proofing Adelaide initiative, this project will provide, treat and transport high quality recycled water from the Glenelg Wastewater Treatment Plant to irrigate the Adelaide City Park Lands, and provide recycled water for other future users.

The plant will consist of 8 x Memcor CP120 pressurised membrane filtration units, treating 35ML/d of filtrate for further treatment using chlorine and Ultraviolet disinfection. The site is due to be commissioned July 2009.

2.2. Memcor Referees

Please fill free to call the following referees to discuss Memcor's performance in regards to:

- Technical execution of projects
- Delivery of projects
- Hydraulic performance of the project
- Aftermarket support of project

Project cost information can be obtained from publicly available information on the internet.

Name & Position	Project	Contact details
Ralph Wardell (Operations Manager) WRAMS	Sydney Olympic Park (WRAMS) SOPA then OCA won the prestigious ***Banksia Award in 2001*** *with this project*	0419 150 939
Gary Craig (Station Chemist for Eraring Energy)	Eraring Power Station Won a number of national awards during 2002/2003	02 4973 0700 or 02 4973 0521
Murray Thompson (Hastings Water Supply Manager – Hastings Shire Council)	Port Macquarie Reuse Project This Water Reclamation Plant was *a **finalist** in the **Engineer Excellence Awards 2007***	02 6581 8111
Jack De Vries Engineering Manager United Group Infrastructure	Pimpama WRP Gold Coast City Council's Water Future Plan won the **United Nation's (Australian chapter) World Environment Day Awards for 'excellence in water management'.**	03 9239 4144
Stuart Cunningham (Contracts Manager) Black & Veatch	Bundamba AWTP Winner of the *"**Global Water Project of the Year Award**"* from Global Water Intelligence in 2007	07 3121 8581
Troy Walker (Process Manager – Western Corridor Recycled Water projects) **Veolia Water**	Western Corridor Recycled water projects (& Others)	07 3015 9771

2.3. Singapore's Drive to Self Sufficiency in Water

The Singapore projects are major case studies that demonstrate effective integrated water management including the reuse of stormwater and treated wastewater for industrial, non-potable and indirect potable reuse.

Bedok Demonstration Plant – 10 MLD

- In 1998 the Singapore Public Utilities Board (PUB) and Ministry of the Environment (ENV) initiated a joint study to determine the suitability of using NEWater (highly treated reclaimed water) as a source of raw water to supplement Singapore's water supply.
- The Bedok demonstration plant was installed to prove the technical, environmental and economic viability of using NEWater for industry and indirect potable applications. The plant was commissioned in April 2000.
- The plant treats secondary effluent from the Bedok STP using membrane filtration (5 x Memcor 90M10C CMF units), Reverse Osmosis (6 element pressure vessels in a 28:14:8 arrangement) and UV disinfection.
- Based on performance of the demonstration plant Singapore has proceeded to install 200 ML/d of NEWater capacity .
- The following table compares the treated water quality against the USEPA and World Health Organisation Drinking Water standards. It is extracted from the Expert Panel's review of the plant's performance – "The Singapore Water Reclamation Study, Expert Panel Review and Findings", June 2002.

NEWater Quality well within the USEPA & World Health Organization Drinking Water Standards

Water Quality Parameters	**NEWater**	**USEPA**	**WHO**
Physical			
Turbidity (NTU)	<5	5	5
Colour (Hazen units)	<5	15	15
Conductivity (µS/cm)	<200	-	-
pH Value	7.0 - 8.5	6.5 to 8.5	-
Total Dissolved Solids (mg/L)	<100	500	1000
Total Organic Carbon (mg/L)	<0.5	-	-
Total Alkalinity (CaCO3) (mg/L)	<20	-	-
Total Hardness (CaCO3) (mg/L)	<20		NA
Chemical (mg/l)			
Ammoniacal nitrogen (as N)	<0.5	-	1.5
Chloride (Cl)	<20	250	250
Fluoride (F)	<0.5	4	1.5
Nitrate (NO3)	<15	-	-
Silica (SiO2)	<3	-	-
Sulphate (SO4)	<5	250	250
Residual (Cl, Total)	<2	-	5
Total Tri-halo-methane (as mg/l)	<0.08	0.08	-
Metals (mg/l)			
Aluminium	<0.1	0.05 to 0.2	0.2
Barium (Ba)	<0.1	2	0.7
Boron (B)	<0.5	-	0.9
Calcium (Ca)	<20	-	-
Copper (Cu)	<0.05	1.3	2
Iron (Fe)	<0.04	0.3	0.3
Manganese (Mn)	<0.05	0.05	0.5
Sodium (Na)	<20	-	200
Strontium (Sr)	<0.1	-	-
Zinc (Zn)	<0.1	5	3
Bacteriological			
Total Coliform Bacteria (Counts/100 ml)	ND	ND	ND
Entero-virus	ND	ND	ND

Source PUB Website based on the Singapore Water Reclamation Study, Expert Panel Review and Findings, June 2002.

- This demonstration project and its comprehensive review demonstrates the capacity of membrane treatment to remove contaminants and to produce a quality suitable for indirect potable reuse
- The first full scale NEWater production facilities was commissioned in September 2002 – at Kranji WRP

Kranji High Grade Water Reclamation Plant, Singapore (80 ML/d)

- Kranji (Initially 40 ML/d, now expanded to 80 ML/d) is one of two plants constructed at Kranji and Bedok to supply the Wafer Fabrication Parks at Tampines/Pasir Ris and Woodlands. Supply commenced in February 2003 and will replace PUB drinking water for use in wafer fabrication, other manufacturing processes, and for a range of non-potable applications, for example, air conditioning cooling towers. NEWater has a lower TDS than potable water and commands a small price premium. Non potable uses of water in Singapore account about 30% of water consumption.

- The tertiary treatment comprises 12 x 448S10T Memcor CMF-S cells treating secondary effluent for RO pre-treatment. The RO plant consists of 10 x 8 ML/d trains using Hydro-nautics LFC membranes and antiscalant dosing. The Engineers were CH2M-Hill.
- The treatment mirrors that of the Bedok demonstration plant, namely, MF, RO and UV of secondary effluent from the Kranji Water Reclamation Plant.
- It supported NEWater as a safe and sustainable water source for indirect potable use in Singapore, i.e. it would be blended with the water in the island's reservoirs before undergoing conventional treatment for potable use. Current use (early 2003) of NEWater for potable applications account for about 1% of total consumption and will rise progressively to about 2.5% by 2011.

CHANGI NEWater DBOO Project – 288 MLD

Siemens was recently awarded the Changi NEWater DBOO project in Singapore. This is the latest NEWater project that will produce NEWater before the end of 2009. Siemens' **MEMCOR® CP** technology was chosen because of the:

- low footprint
- fast delivery model
- low civil requirements
- no backwash pump and filtered water storage
- lowest cost system

Black & Veatch Singapore are the consultant and Designer to SembCorp Utilities who will Build Own and Operate the plant for 25 years.

2.4. China Initiatives

China's water supply problems are acute. Population growth, urbanisation and rapid industrial development (8~10% pa) have left 400 cities short of adequate drinking water supplies.

Water resources per capita are 25% of world average and less in the northern and coastal areas (10 to 3.3% respectively).

Many reservoirs dried out and rivers ran dry in 2000 while many provinces and cities such as Jiangsu, Guangdong, and Shanghai face serious deterioration of raw water quality.

Consequently, the Chinese government has legislated that major industry, including power stations must reuse secondary effluent for process water.

Tianjin Ji Zhuang Zi STP.

The first of six demonstration plants in the Tianjin region was engineered and installed by US Filter China and was commissioned in late 2002.

- The tertiary treatment of secondary effluent comprises 10 MF units plus ozonation with a capacity 20 MLD
- Reclaimed water is being used in the Mei-jiang. residential district for toilet flushing and garden watering, an agricultural irrigation project in Jing-hai county and for cooling water in Chen-tang-zhuang Heat and Power Plant
- Other uses are for an urban ornamental water body, irrigation at the Cheng-lin nursery and for car washing stations.

Tianjin TEDA STP.

The second demonstration plant for reclaimed water production (also engineered and installed by US Filter China) treats secondary effluent for the Tianjin Economic Development Area (TEDA)

- Treatment involves MF and RO with an initial capacity of 30 MLD. 20 MLD for non-potable municipal use and 10 MLD for industrial use (MF plus RO). The plant is designed for a future capacity of 40 MLD.
- Plant comprises 10 x 108M10C CMF units treating secondary effluent and three x 3.35 ML/d Bekox RO units provide RO permeate, using Dow Filmtec BW30-365FR membranes. Future design up to 40 ML/d.
- Other projects are planned for Qingdao (2003 - 5 MLD in 2002-2003 for industrial cooling applications and 20 MLD for non-potable municipal use), Xi'an (2003 – 50 MLD for non-potable municipal use) and Hefei (2004 – for municipal and industrial use).

Taiyuan No.1 PS Industrial Wastewater Reuse (2006)

Taiyuan is the capital city of Shanxi Province. Taiyuan also has a serious shortage of freshwater. The Power industry requires large amounts of freshwater for various industrial uses. Taiyuan selected MEMCOR® Submerged and is one of the first submerged Membrane installations used in a Chinese Power station. This project was installed and commissioned in the middle 2006.

- The Ultrafiltration capacity treats 15 ML/d of mixed feed of industrial effluent and municipal effluent
- The system has stable operation at the design flux of 40 LMH even though there are high suspended solids spikes in the feed water
- The installation has 3 x MEMCOR® CS 180 (Model S10V)
- The plant acts as pre-treatment to RO
- The plant has been designed to allow future expansion

Liaoning Fuxin PS Submersible System (2006)

Fuxin is located within the Liaoning Province. Similarly, there is a shortage of fresh water, and this reclaimed water plant reduces the demand on the fresh water supply. This installation was commissioned in December 2006.

- The installation will treat approximately 35 ML/d of a combination of industrial waste (such as dirty mine well water, wash water and polluted river water) & municipal secondary effluent within the plant
- The MEMCOR® Submerged system comprises 4 x MEMCOR® CS 396 (Model S10V) Ultrafiltration modules
- The filtered water is used as pre-treatment to Reverse Osmosis for the plant boiler system.

Tianjin Xianyanglu STP (2007)

Tianjin is the third largest city in China and has a serious shortage of fresh water. The Chinese government is implementing a series of reuse schemes to address this issue. Xianyanglu is the third Installation to produce reclaimed water from secondary effluent in the Tianjin region.

- Treatment involves Submerged Ultrafiltration (MEMCOR® CS) with a treatment capacity of 50 ML/day. 40 ML/day is used for non-potable municipal use and 10 ML/day is treated with Reverse Osmosis for industrial use.
- The Ultrafiltration Plant comprises 4 x MEMCOR® CS 432 (Model S10V) units
- The MEMCOR® CS is the first Submerged Ultrafiltration Membrane plant in Tianjin area

Tianjin Dagang Oil Field's Industrial Wastewater & Sewage Reuse (2008)

Tianjin Dagang will be one of the first submerged Ultrafiltration Membrane Plants in the Chinese Oil & Gas Industry. The installation will treat a combination (50/50) of oil industrial waste & local municipal secondary effluent. This plant will be installed by and commissioned by the middle 2008.

- The MEMCOR® Submerged installation will have 3 x MEMCOR® CS 414 (Model S10V) units
- The plant acts as pre-treatment to RO
- The system was designed following a 9 month MEMCOR® XS 4 (Model S10V) trial in 2005 and the design flux of 40 LMH even with high spikes of suspended solids in the feed water.

Tianjin Dongjiao STP (2008)

Tinajin Dongjiao will be the fourth significant installation for reclaimed water production in the Tianjin area. The plant will treat secondary effluent for the Tianjin Yangliuqing Power Station

- Treatment involves MEMCOR® Submerged with a capacity of 50 ML/day. 40 ML/day will be Ultrafiltered water only, with the remaining 10 ML/day treated with Reverse Osmosis for industrial use.
- The plant will install 4 x MEMCOR® CS 432 (Model S10V) Ultrafiltration units.
- The plant will be installed and commissioned by the end of 2008

Tangshan Guofeng Steel Mill Industrial Wastewater & Sewage Reuse (2007)

Guofeng is located in Tangshan city which is in the Hebei Province. This Pressure Membrane Plant for the Chinese steel Industry for treats a combination (50/50) of industrial & local sewage secondary effluent. This plant will be installed and will be commissioned in late 2007.

- The installation provides approximately 32 ML/d of treated water for reuse within the plant
- The Pressure system uses 4 x MEMCOR® CP 162 (Model L20V) Ultrafiltration system
- The Client will also install a 3 x MEMCOR® CP 132 (Model L20V) for their North zone wastewater treating another 20 ML/day treating a combination of effluents
- The effluent from the membranes is used as pre-treatment to RO

3.0 Snapshot of USA Wastewater Reuse Projects

Water Factory 21 (1997 to 2008)

Since 1976, reclaimed wastewater has been treated to potable water quality at OCWD WF21 and injected into coastal aquifers to prevent the intrusion of seawater into the groundwater basins. The treatment process at WF21 consists of flash mixing and flocculation at pH 11.4 using slaked lime, clarification, recarbonation for pH control and granular media filtration.

Although OCWD WF21 has operated successfully for over 20 years with the current treatment process, the treatment process proposed for the GWRS project is based on the use of microfiltration (MF) in place of the conventional RO pretreatment process.

Testing to quantify the benefits of using membrane filtration as pretreatment to RO began at OCWD WF21 in 1992. Extensive piloting over 9 years evaluated all of the major players in the Microfiltration/Ultrafiltration market. In early 2002, MEMCOR® Submerged membranes were chosen for the Worlds Largest Reuse project (326 ML/d) to be implemented over two stages.

The GWR System, which went on-line in 2008, takes treated sewer water from the Orange County Sanitation District and treats it to beyond drinking water standards using advanced membrane purification technologies. At full capacity, the plant will produce up to 130 MGD of treated reclaimed water.

The treated sewer water undergoes an advanced treatment process that includes two membrane filtration systems - microfiltration and reverse osmosis, and treatment by ultraviolet light and hydrogen peroxide.

MEMCOR® Submerged membranes are used in the membrane filtration treatment process. An extensive pilot was performed at Water Factory 21 prior to the construction of the GWR system. Memcor was heavily involved in these trials, initially trialling a 4 module submerged unit, followed by a 32 module demonstration unit. These systems were trialled over a period of 5 years. At full capacity, there are 26 MEMCOR® CS 504 cells with a total of more than 13,000 membrane modules.

Scottsdale, Arizona USA ~45 ML/d in 1998 expanding to ~ 100 ML/d

In 1998, the desert community of Scottsdale, Arizona (population 223,000), found itself with no natural surface water source and a decreasing groundwater supply. Scottsdale had historically treated and disposed of its used water but soon saw the missed opportunity which this water supply presented as an asset for its population and a way of meeting its growing water demand.

The City of Scottsdale decided to build the Water Campus, which contains a 189-ML/d water treatment plant, a 45.4-ML/d water reclamation plant and an advanced water treatment facility, which consists of MEMCOR® Pressure membranes, reverse osmosis and recharge systems. The 45.4-ML/d facility currently produces water principally for golf course irrigation. In the winter when irrigation needs are reduced, the water undergoes advanced purification (microfiltration and reverse osmosis) before discharge into the drinking water aquifer.

The project is currently undergoing an expansion to 100 ML/d of Ultrafiltration pre-treatment capacity.

West Basin, Carson USA ~15 ML/d (2000)

West Basin is an innovative site which takes secondary sewage from Los Angeles and using a combination of MEMCOR® Pressure membranes and Reverse Osmosis (RO) technology, to produce high quality boiler feed water for Mobil Oil Refinery, Carson. The opportunity and pressure for wastewater reuse is most evident in urban environments where water use is concentrated and where large volumes of sewage are seen to be "wasted".

WATER REUSE

An evaluation of the technologies and their benefits

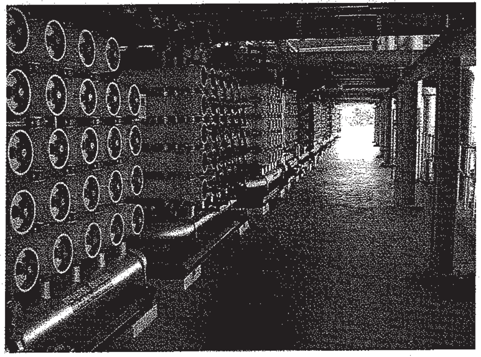
Lisa Sorgini

Reuse is one of the most important issues in the global water industry today, and for good reason. As droughts and water resource issues become more widespread, water reuse is a necessity that has proven to be economically and environmentally beneficial. Water reuse conserves limited potable water supplies by reusing treated wastewater for nonpotable uses, such as irrigation and industrial processes. Recycled water also can be used for direct and indirect potable use, such as aquifer recharge and reservoir augmentation.

Alternate Water Sources Needed

In the United States, roughly 74% of (nonsaline) groundwater withdrawals is used for irrigation, 21% is used for public supply, and 5% is used for self-supplied industrial applications, according to U.S. Geological Survey Circular 1279, *Estimated Withdrawals From Principal Aquifers in the United States, 2000*. Population shifts and industrial and agricultural expansion are overburdening many aquifers. As water use has intensified, groundwater depletion has spread from small, isolated pockets to large areas of the country. The consequences — land subsidence and loss of springs, streams, and wetlands — are already evident. In some coastal communities, seawater has intruded the freshwater aquifers, making the water supply brackish. Droughts aggravate the situation, threatening the economic survival of industries and communities.

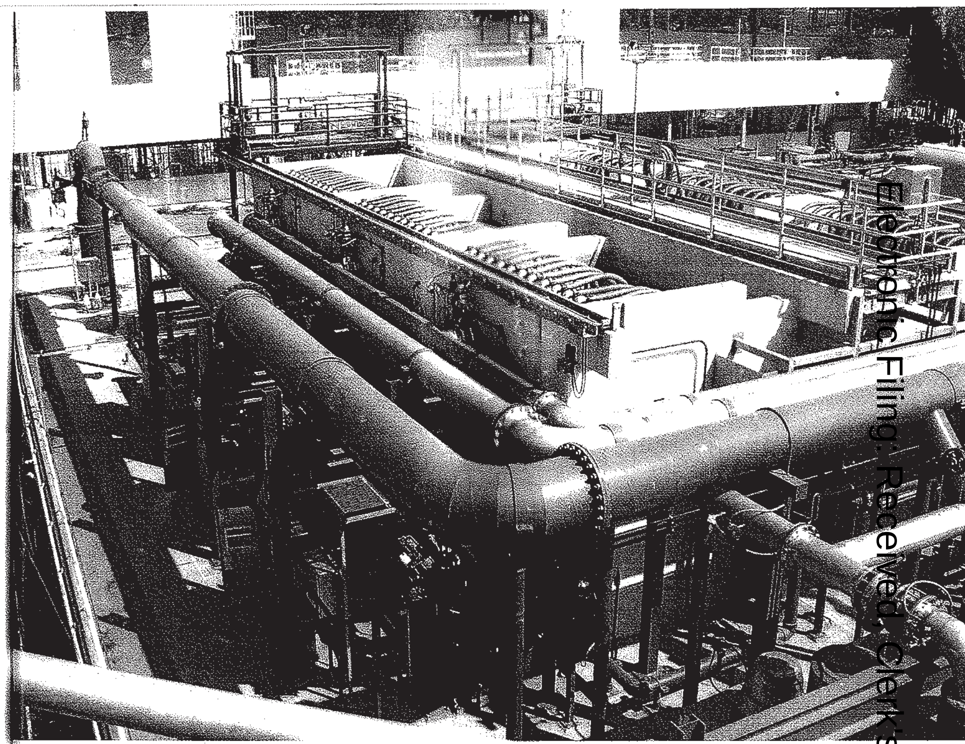
The Kranji Water Reclamation Plant in Singapore combines low-pressure membrane filtration with reverse osmosis and UV disinfection to convert secondary effluent into high-purity water.



Thus, many municipalities are turning to water reuse. Such projects not only can be found in traditionally water-scarce states — Arizona, California, Colorado, Florida, Nevada, New Mexico, and Texas — but also in seemingly water-rich ones, such as the Carolinas, Georgia, Virginia, Washington, and the Northeast. In the 1980s, for example, serious water shortages in California led state agencies to develop large reuse projects to provide irrigation water to farmers. The state then developed a regulation (commonly called "Title 22") that defines water-recycling criteria for surface uses, including irrigation, watering golf courses, and some types of agriculture.

Reuse is becoming law in other parts of the world. In Europe, for example, the European Water Framework Directive is an initiative that will limit groundwater abstractions for industrial uses. Staged implementation will be occurring as policies and enforcement procedures are further defined, with full implementation scheduled for 2015 (see ec.europa.eu/environment/water/water-framework/objectives/implementation_en.htm). About 70% of Europe's groundwater is used for industry; the rest is used for irrigation and drinking, according to the International Seminar on Water Resources Management and the Implementation of the European Water Directive (www.riob.org/medinbo/valencia_resofina.htm).

In China, Chapter 5 of the 2002 Water Law requires all industries to reuse water extensively and increase water recovery, especially during new construction or plant upgrades. For the iron and steel industry, the regulations specify that water intake must be less than 16 m^3 per ton of product, and the water-reuse ratio must be more than 90%. In January 2005, the Chinese government imposed a new water consumption ratio on seven industries: steel, power, textile, papermaking, brewing, alcohol, and petroleum and chemical. These industries now can be charged a fee for using more water than they are allocated, and if the situation is not rectified within a specified timeframe, the offending enterprises will lose access to water supplies. These laws affect both new and existing plants. So, industrial plants are looking for other sources of water, including municipal wastewater, their own wastewater, and seawater.



The West Basin Municipal Water Recycling Facility (El Segundo, Calif.) was one of the first U.S. water agencies to use a low-pressure membrane filtration process to pretreat wastewater for reverse osmosis.

For a sustainable future, then, the objective is to find alternate sources of water that are drought-resistant and adapt to expansion. One possible water source is municipal and industrial wastewater. According to U.S. Geological Survey Circular 1279, as much as 26% of the groundwater withdrawn in the United States becomes wastewater, which currently is treated to meet Clean Water Act standards and then discharged to receiving waters. The treatment process is a considerable capital and operating expense that benefits public health and the environment. If this water were reused, it could benefit the economy as well.

Interest in desalination also has been growing, but desalination plants cost more to build and operate than reuse plants. And disposing of the concentrate, which is roughly equal to the volume of pure water produced, remains a stumbling block for many desalination projects. Reuse plants, on the other hand, actually reduce the amount of waste.

To be economically and ecologically successful, water reuse projects must use technologies that offer long-term reliable operations, have low operating costs, reduce or eliminate the use of chemicals, and are as compact as possible. Many reuse plants are constructed either on the same premises as existing wastewater treatment facilities or in other areas where space is limited.

Effective Technologies Available

Several technologies, including clarification, granular media filtration, carbon adsorption, low-pressure membrane filtration, reverse osmosis, membrane bioreactors (MBRs), and disinfection, have proven to be effective in water reuse applications (see table, p. 56). The choice of technology depends on how the reclaimed water will be used (see figure, p. 57). Industrial facilities, for example, need higher quality water than farms and gardens do.

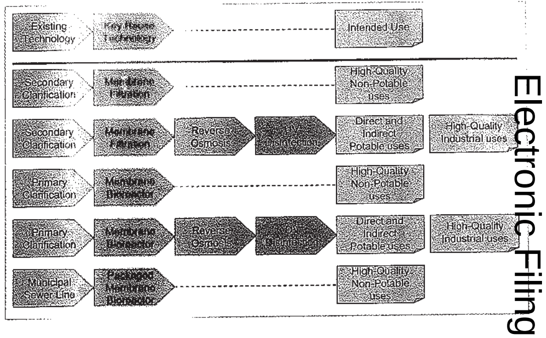
Early reclamation systems used several independent filtration processes, consisting of settling, clarification, and granular media filtration or activated carbon filtration. They had large footprints and were labor-intensive. Today, reclamation systems may pack several processes — such as high-rate tube settling, adsorption clarification, granular media filtration, and ultraviolet (UV) light disinfection — into one package plant. Such systems are smaller, easier to operate, and designed to remove residual biomass, turbidity, and microorganisms.

Treated wastewater typically contains large concentrations of total dissolved solids (TDS), so it is unsuitable for direct or indirect reuse applications, such as aquifer recharge or industrial consumption. Reverse osmosis was the first technology that effectively lowered the wastewater's TDS so it could be used for more than irrigation. Reverse osmosis is a physical separation process in which pressure forces water through a membrane with exceptionally fine pores. Nearly all pollutants are left behind. The technology used to be limited to desalinating seawater and brackish water for potable and industrial uses; now, it has been widely adopted in advanced reuse facilities worldwide.

Comparison of Wastewater Treatment Technologies for Reuse

Technology	Advantages	Limitations
Sedimentation–clarification	· Provides some equalization of wastewater. · Removes vast majority of debris and turbidity. · Well known and understood by engineers and operators. · Relatively low cost.	· Large footprint required. · Slow to respond to changes. · Chemicals required. · Affected by temperature. · Labor-intensive.
Media filtration	· Simple process, well known and understood. · Relatively inexpensive, and low labor required. · Media can last indefinitely.	· Effluent quality varies. · Affected by changing feedwater conditions. · Large volumes of wastewater during backwash.
Packaged multibarrier filtration	· High-rate processes reduce footprint. · Automated operation reduces labor required. · Adapts to changing wastewater conditions.	Chemicals required.
Low-pressure membrane filtration	· Positive physical barrier to pathogens, biosolids and turbidity. · Handles widely changing feedwater conditions and flow rates. · Simple, automated operation with minimal labor required. · Significant reduction in footprint, and low cost per gallon.	· Higher capital cost than granular media filters. · Will require membrane replacement at some point.
Membrane bioreactor	Same advantages as membrane filtration, plus · increased solids retention time for more complete destruction of nutrients; · higher density sludge for easier dewatering or transport; and · further reduction in footprint.	Same limitations as membrane filtration, plus · high energy demand.
Reverse osmosis	· Reduces total dissolved solids and trihalomethane precursors. · Provides water suitable for direct or indirect potable use with disinfection. · Provides high-quality water for industrial uses.	Requires effective pretreatment for · scaling by sparingly soluble salts; · fouling by suspended solids; and · degradation from oxidants and metals.
Chemical disinfection	· Relatively inexpensive. · Well known and understood by engineers and operators.	· Health, safety, and environmental issues with chemical handling. · Labor-intensive.
Ultraviolet (UV) disinfection	· Chemical-free method. · Does not create any disinfection byproducts. · No labor required.	· Requires clear water for optimum transmittance of UV light. · Will require UV lamp replacement on regular basis.

Choosing the Appropriate Reuse Technology

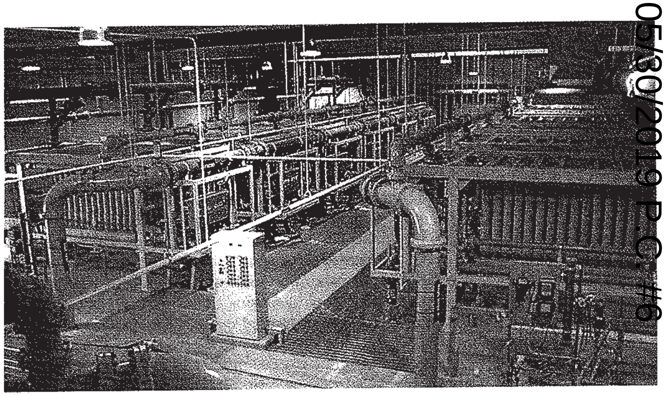


Because reverse osmosis filters have exceptionally fine pores, prefiltration is needed to minimize membrane fouling. Otherwise, their production rates decline, and their operating pressures and chemical cleaning needs increase. Traditional tertiary filters were not designed to provide suitable influent for a reverse osmosis filter. However, other membrane filters are.

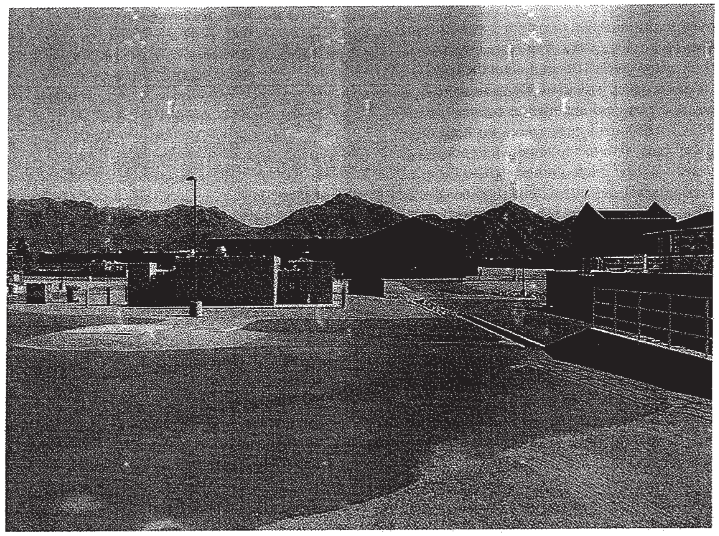
Low-pressure membrane filtration processes, such as microfiltration and ultrafiltration, became economically viable in the 1980s, when communities worldwide began using this technology to filter surface water and groundwater for potable use. They can remove more than 99.99% of pathogens, such as *Cryptosporidium* and *Giardia*, thereby reducing the threat of waterborne disease. They also reduce disinfection chemical requirements and the formation of disinfection byproducts. These membranes physically separate suspended solids from water, rather than relying on gravity and adsorption to granular media.

MBRs are also suitable for water reuse applications. An MBR is a biological reactor with a membrane filtration system immersed in it, so both conventional biological treatment and solids separation occur in one treatment step. It eliminates the need for clarifiers, other peripheral equipment, and the related process controls and maintenance. So, an MBR's footprint is less than half that of a conventional biological treatment process. Also, the membranes allow the biological process to be designed and operated as a high-rate wastewater treatment process. Packaged MBR systems are rapidly gaining acceptance by small communities, municipalities, developers, and industrial facilities. Developers, for example, are using them in communities designed around golf courses and recreational facilities to provide reuse water for irrigation. Also, MBRs are well-received by most state regulators because of their excellent effluent quality, thereby expediting the approval and development process. An MBR can be designed to produce exceptional-quality water for reuse (including nitrogen and phosphorus removal) or to pretreat wastewater for the reverse osmosis process.

Most reuse systems will include disinfection after filtration to ensure that pathogens have been inactivated. Disinfection has evolved from conventional gaseous chlorine to onsite hypochlorite production to UV light, which is



The Scottsdale (Ariz.) Water Campus facility uses a low-pressure membrane filtration process and reverse osmosis to convert reclamation plant effluent into high-quality water suitable for landscape irrigation, groundwater discharge, and aquifer recharge.



The Scottsdale Water Campus "banks" water in an underground aquifer so it can be withdrawn when needed. This reduces the city's demand on water from the Colorado River.

commonly used in reuse applications. UV light effectively inactivates harmful pathogens and bacteria without chemicals, so unlike chlorine and hypochlorite, it does not generate potentially harmful disinfection byproducts.

Proven Results

Following are examples of effective water reuse projects.

Eraring, Australia. The first water reuse project was at Eraring Power Station, which is owned by Eraring Energy (Sydney, New South Wales, Australia). In the early 1990s, Eraring Power purchased its boiler feedwater from Eraring, New South Wales' water utility, and the city was facing an expensive wastewater treatment plant upgrade — including a more than 6-km (3.7-mi) outfall pipe to the ocean — because of urban growth and aging facilities. A visionary power plant chemist proposed an alternative that would suit both organizations better. Eraring Energy built an advanced treatment system, including a low-pressure membrane filtration process and reverse osmosis, that increased the wastewater treatment plant's capacity and produced reusable-quality water. Rather than disposing this water in the ocean, the power plant used it as a source of feedwater. Commissioned in 1995, the advanced plant can reclaim up to 3800 m³/d (1 mgd) for the power plant, irrigation, and supplemental supply during droughts. This project freed up as much as 1900 m³/d (500,000 gal/d) of potable water for the rapidly growing community and saved $2.7 million in construction costs by eliminating the pipeline. It also slashed the power plant's boiler feedwater costs while providing higher-quality water. Even more gains are expected by 2010, when the next treatment plant expansion is expected to free up nearly 3800 m³/d (1.0 mgd) of potable water for the community.

Scottsdale, Ariz. Meanwhile, in the U.S. desert, rising treatment costs and years of persistent drought prompted Scottsdale, Ariz., to implement a long-planned water reuse program. The Scottsdale Water Campus facility now includes a 189,000-m³/d (50-mgd) water treatment plant and a 45,400-m³/d (12-mgd) advanced water reclamation plant. The advanced facility uses a low-pressure membrane filtration process and reverse osmosis to convert reclamation plant effluent into high-quality water suitable for landscape irrigation and groundwater recharge. The campus also recharges aquifers with Colorado River water treated via a low-pressure membrane filtration process. The reclaimed water is injected directly into an underground aquifer via wells.

The Scottsdale Water Campus is now one of the largest municipal facilities in the world to convert wastewater into potable water for aquifer recharge. The city has saved 94.6 million m³ (25 billion gal) of potable water since it began reusing water in October 1998. The campus also has "banked" water — received credits for recharging the aquifer — so it can withdraw an equivalent amount when needed during peak periods. This reduces the city's demand on Colorado River water. Scottsdale currently draws more than 65% of its drinking water from the Colorado River, 30% from city wells, and the rest from other surface waters. According to the city, its goal is to recharge the aquifer with as much as it withdraws.

El Segundo, Calif. Founded in 1947, the West Basin Municipal Water District (El Segundo, Calif.) wholesales imported water to cities, mutual water companies, investor-owned utilities, and private companies in South Bay and the unincorporated areas of Los Angeles County; the district serves more than 900,000 people. In 1995, the district constructed the West Basin Water Recycling Facility to meet the growing demand for a sustainable water supply in Southern California. It was one of the first U.S. water agencies to use a low-pressure membrane filtration process to pretreat wastewater for reverse osmosis. The process it replaced — lime softening, recarbonation, and multimedia filtration — produced lots of sludge and could not efficiently remove suspended solids to low enough levels. The process was also difficult and expensive to operate. The new filtration system consistently produces a silt density index (SDI) of less than 3, compared to the SDI of 5 or more that the previous process produced. The lower SDI fouls the reverse osmosis system less, so more time elapses between cleanings, which translates into lower operating costs and longer membrane life.

West Basin is now the largest recycling facility in the United States, treating more than 114,000 m³/d (30 mgd) of secondary effluent, or about 30.3 million m³ (8 billion gal) of water annually for the South Bay area. The facility produces six "designer" classes of water for various industrial and municipal applications, including irrigation for parks and golf courses, seawater barrier injection, makeup water for oil refineries, water for cooling towers, and high-quality boiler feed. What began as a proactive measure to ease a potable water shortage has saved the region more than 246 million m³ (65 billion gal) of drinking water.

Singapore. Singapore also has taken steps to conserve limited freshwater resources and ensure that its water supply is sustainable. In 2002, the Singapore Public Utilities Board commissioned the 53,000-m³/d (14-mgd) Kranji Water Reclamation Plant, which combines a low-pressure membrane filtration process with reverse osmosis and UV disinfection to convert secondary effluent into high-purity water. The reclaimed water supplements Singapore's water supply for semiconductor manufacturers. Also, the Bedok Water Reclamation site uses a low-pressure membrane filtration process to convert 22,700 m³/d (6 mgd) of secondary municipal effluent into reuse-quality water for domestic use.

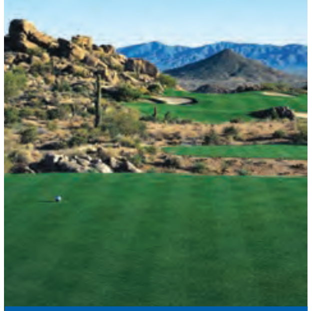
Olympia, Wash. Satellite MBR treatment has worked well for the Hawks Prairie Reclaimed Water Satellite Plant (Olympia, Wash.). Hawks Prairie, which reclaims wastewater from four communities, is the first of three reclaimed water facilities that are part of Olympia's 20-year wastewater resource management plan. The clean water will travel 4.8 km (3 mi) through a pipeline from the plant to wetland ponds and a 3.2-ha (8-ac) groundwater recharge site. Along the way, some of the water will be drawn off for irrigation or other uses.

The municipality chose MBR technology because it can produce high-quality reuse water and functions well at remote sites. The Hawks Prairie MBR currently treats 7600 m³/d (2 mgd) of wastewater and can be expanded to 18,900 m³/d (5 mgd). The reclaimed water meets the state's "Class A" reclaimed water standards, which is the highest water quality defined by the Washington State departments of Health and Ecology. The plant is expected to save 78,000 customers hundreds of millions of gallons of drinking water annually.

Lisa Sorgini is the global marketing manager of the Memcor product line in the Shrewsbury, Mass., office of Siemens Water Technologies (Warrendale, Pa.).

Water Technologies

MEMCOR® membranes for tertiary reuse applications

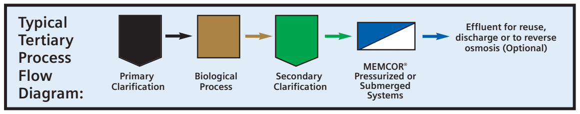


Typical Memcor Membrane Results

Parameter	Result
Silt Density Index	<2.0
Total Suspended Solids	<1 mg/l
Total Coliform	Not Detected

Advantages of Memcor Membranes for Tertiary Applications

- Simplified design reduces process steps, minimizing footprint.
- Physical barrier provides consistent, reliable water quality, day after day, exceeding the most stringent reuse regulations.
- Proven performance in hundreds of installations in operation for over 20 years.
- Simple, automated operation and direct on-line integrity monitoring ensures system membrane integrity is consistently met.



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Water Technologies

MEMCOR® membranes
for tertiary reuse
applications

SIEMENS

Water Technologies

MEMCOR® membranes for tertiary reuse applications

Wastewater reclamation and reuse – an environmentally conscious solution

Water reclamation has become an attractive solution to augment supplies by providing a sustainable water source. Using membrane technology, wastewater can be safely and cost effectively recycled for use in agriculture, irrigation and industrial processes and for groundwater replenishment.

Tertiary treatment using Memcor membranes provides a cost-effective solution when compared to other reclamation alternatives. Membranes provide a verifiable physical barrier, ensuring that consistent, high-quality water standards are met. With a compact footprint and ease of operation, Memcor membranes offer the lowest cost for treated water. Memcor membranes also provide a superior pretreatment to reverse osmosis, prolonging RO membrane life and reducing membrane fouling and operating costs.

MEMCOR membrane advantages:

- **Available in pressurized or submerged configurations to fit multiple needs**
- **Simplified, easy installation**
- **Employs a robust membrane fiber that ensures superior, long-term integrity**
- **Requires minimal operator intervention**
- **Reduces capital costs by providing high capacity in a small plant footprint**
- **Lowers operating costs by reducing chemical requirements**

Memcor Membrane Technologies

Memcor membranes have been proven in multiple reuse applications. Memcor products come in both pressurized and submerged configurations to suit multiple needs and are available as stand-alone, pre-packaged units or as components for large projects.

Pressurized

Memcor pressurized membrane systems operate in a closed environment. Feed water is pressurized through the units at 30 to 40 psi (200 to 275 kPA). Higher pressures can be used if additional residual pressure is needed for applications, such as pretreatment to reverse osmosis.
The system has fully automated processes including backwash, cleaning and membrane integrity testing. All membrane modules are individually isolatable, ensuring consistent operation.

Submerged

Memcor submerged systems operate in an open tank design. Feedwater typically flows by gravity into the membrane cell. A suction pump draws filtrate water through the membranes up to 12 psi (83 kPA). Submerged systems are ideal for retrofitting existing basins, increasing capacity in a small footprint.
The system has fully automated processes including backwash, cleaning and membrane integrity testing. Membrane modules are isolatable in groups of four or clovers.

MEMCOR® membrane systems are currently meeting the needs of communities in more than 1,000 installations around the world— and doing so with impressive reliability, economy and minimal operator intervention.

Featured reuse installations:

Orange County Water District, California
Reclaiming 70 MGD (265,000 m3/day)

Memcor membrane filtration provides consistent, high-quality water significantly enhancing the operation and life expectancy of reverse osmosis and thus reducing overall capital and operating costs.

Homebush Bay, Sydney, Australia Reclaiming 2.5 MGD (9,500 m3/day) in filtered and desalinated water

Recycled water from the 2000 Olympics site is used for public space irrigation and is recycled to residential properties in a separated system for non-potable uses including garden irrigation and car washing.

Kranji NEWater Reclamation Plant, Singapore
Reclaiming 14.7 MGD (56,000 m3/day)

The new water facility provides water to microelectronics manufacturers. The plant also provides water for potable use.

Bedok Water Reclamation Site, Singapore
Reclaiming 3.4 MGD (13,000 m3/day)

The reclaimed water from Bedok is used primarily for demanding industrial applications as the quality has a lower TDS and is more consistent than town water.

Earing Power Station, NSW, Australia
Reclaiming 2 MGD (peak flow) (7,500 m3/day)

The first installation of low-pressure membrane and RO in the world used for boiler feed water, this plant achieved significant operating cost savings while producing high quality water.

Water Technologies

Experience.
Reliability.
Proven performance.

West Basin Solves Potable Water Shortage with Wastewater Reclamation

Snapshot - West Basin	
Location	USA
Source	Municipal wastewater
Application	Reuse
Technology	Memcor® CS
Capacity	14.4 MGD (54.5 MLD)
Commissioned	2006

Challenge

The West Basin Municipal Water District in Carson, Calif., wholesales imported water to cities, mutual water companies, investor-owned utilities and private companies in the South Bay and unincorporated areas of Los Angeles County, serving a population of more than 900,000.

In 1995, West Basin constructed the West Basin Water Recycling Facility to meet the growing demand for a sustainable, reliable water supply in Southern California and to reduce the demand on scarce potable water sources. They became one of the first water agencies in the United States to implement wastewater reclamation using membrane technology. In 1997, the first MEMCOR® low-pressure membrane plant was installed at the facility followed by an additional three between 1998 and 2002.

After using the Memcor® Classic CMF pressurized membrane system for more than eight years, West Basin decided to install its fifth system that offered the same results and incurred less costs.

Solution

West Basin chose the Memcor® CS submerged membrane system for its smaller footprint, lower operating costs, reduced waste production, greater flexibility and the ability to visually inspect the membrane modules. As with all Memcor low-pressure membranes, the CS system consistently produces a silt density index (SDI) of less than three, versus an SDI of five with conventional pretreatment technology. The reduced SDI results in less RO membrane fouling and longer durations between cleaning, which translates into lower operating costs and longer RO membrane life.

Memcor® Membrane Systems

Water Technologies

SIEMENS

Operational Data	West Basin
Number of skids	6
Modules per skid	384
Total capacity	14.4 MGD (54.5 MLD)

Results

West Basin is treating more than 30 MGD of secondary effluent, which equals about eight-billion gallons of water annually for 210 users in the South Bay. The facility produces six customized “designer” classes of water for a variety of industrial and municipal applications, including irrigation for parks and golf courses, seawater barrier injection, make-up water for oil refineries, cooling towers and for high-quality boiler feed.

What began as a proactive measure to ease a potable water shortage has ultimately saved the region more than 65 billion gallons of drinking water. Today, West Basin is recognized as a leader in water conservation and water recycling and was recently named “Large-Size Recycled Water Agency of the Year” by the California section of the WateReuse Association.

Membrane Solutions

Memcor® membranes from Siemens Water Technologies represent the broadest range of low-pressure membrane filtration products -- submerged, pressurized, large capacity or small systems. They continue to be successfully employed in applications as diverse as wastewater reuse, potable water, RO pretreatment, high solids and sand filter retrofits.

Memcor® Products

Product	Pres-surized	Sub-merged	Water Reuse	Potable Water	High Solids	Sand Filter Retrofits	Large Capacity	Small Systems
CP	■		■	■	■		■	
CS		■	■	■	■	■	■	
XP	■		■	■	■			■
XS		■	■	■	■			■

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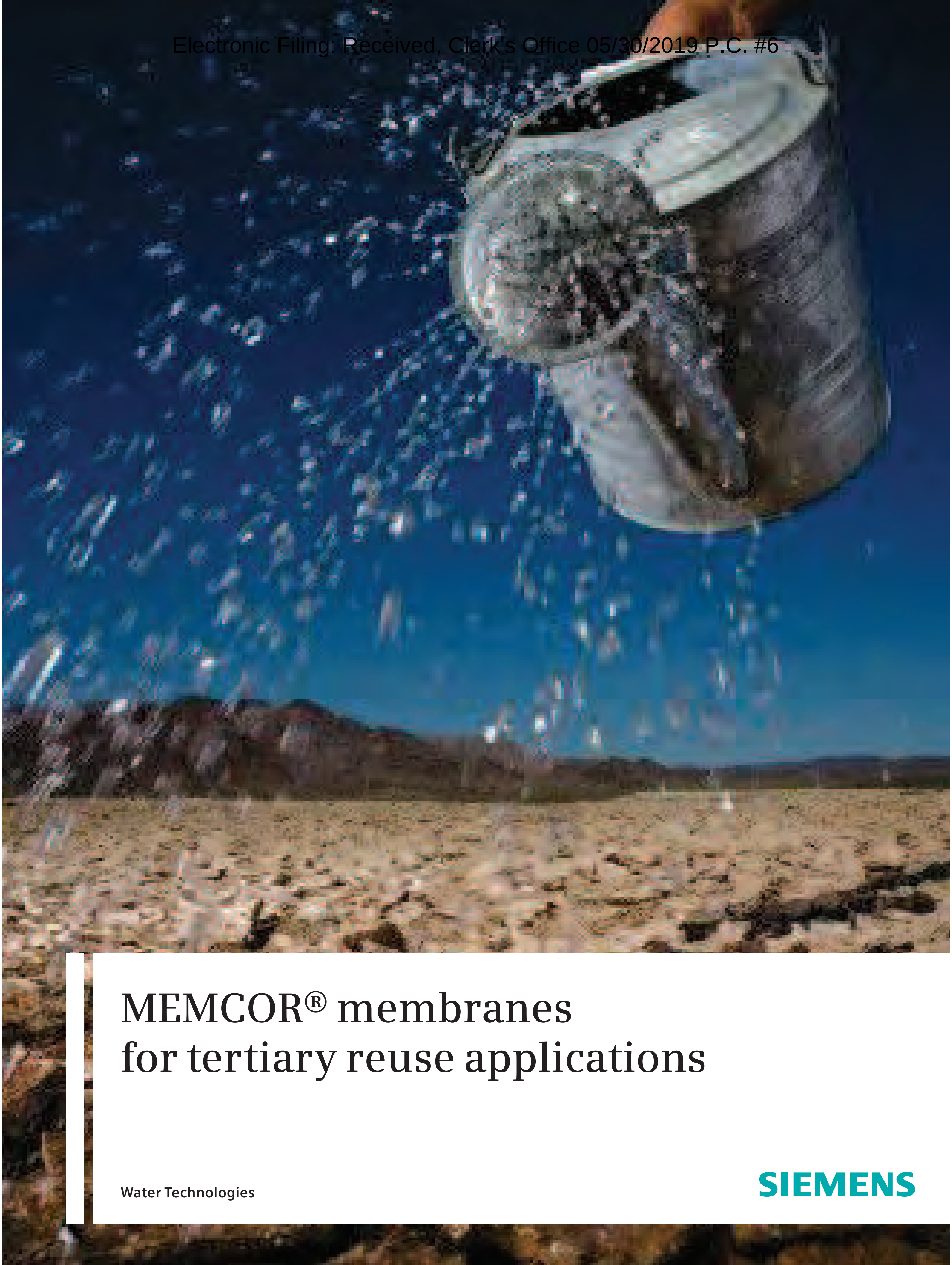


MEMCOR® membranes for tertiary reuse applications

Water Technologies

SIEMENS

MEMCOR® membranes for tertiary reuse applications

Wastewater reuse makes pure sense

The use of Memcor® membranes is allowing communities worldwide to augment current water supplies with wastewater reclamation. This sustainable and cost effective solution safely recycles water for use in agriculture, irrigation, industrial processes and groundwater replenishment.

Tertiary treatment using Memcor membranes provides a cost-effective solution when compared to other reclamation alternatives. Membranes provide a verifiable physical barrier ensuring that consistent high-quality water standards are met. With a compact footprint and ease of operation, Memcor membranes offer the lowest cost for treated water. Memcor membranes also provide a superior pretreatment to reverse osmosis, prolonging RO membrane life and reducing membrane fouling and operating costs.

MEMCOR® membrane advantages:

- Flexibility: Available in pressurized or submerged configurations suitable for multiple plant requirements.
- Superior fiber strength: Employs a robust membrane fiber that ensures long term integrity.
- Ease of Installation: Stand-alone pre-packaged units and components for larger projects have been designed to be assembled in the factory to the greatest extent possible to simplify installation.
- Reduced Capital Cost: System efficiency allows for greater capacity in a smaller footprint thereby reducing overall system cost.
- Reduced operational costs: Designed for minimal operational intervention and reduced chemical consumption make Memcor products the greatest overall value in the market today.

MEMCOR® Pressurized membrane system

MEMCOR® Submerged membrane system

MEMCOR® Membrane Technologies

Memcor membranes are used in hundreds of locations for the treatment of secondary wastewater effluent for urban reuse, golf course irrigation, groundwater replenishment or other beneficial use. Our modules are available in both pressurized or submerged configurations to meet specific project needs.

Pressurized

Memcor pressurized membrane systems operate in a closed environment. Feed water is pressurized through the units at 30 to 40 psi (200 to 275 kPA). Higher pressures can be used if additional residual pressure is needed for applications, such as pretreatment to reverse osmosis. The system has fully automated processes including backwash, cleaning and membrane integrity testing. All membrane modules are individually isolatable , ensuring consistent operation.

Submerged

Memcor submerged systems operate in an open tank design. Feedwater typically flows by gravity into the membrane cell. A suction pump draws filtrate water through the membranes up to 12 psi (83 kPA). Submerged systems are ideal for retrofitting existing basins, increasing capacity in a small footprint. The system has fully automated processes including backwash, cleaning and membrane integrity testing. Membrane modules are isolatable in groups of four or clovers.

Experience. Reliability. Proven performance.

MEMCOR® membrane systems are currently meeting the needs of communities in more than 1,000 installations around the world— and doing so with impressive reliability, economy and minimal operator intervention.

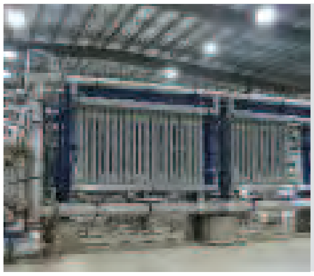
Featured reuse installations:

Orange County Water District, California
Reclaiming 70 MGD (265,000 m³/day)

Memcor membrane filtration provides consistent, high-quality water significantly enhancing the operation and life expectancy of reverse osmosis and thus reducing overall capital and operating costs.

Homebush Bay, Sydney, Australia
Reclaiming 2.5 MGD (9,500 m³/day) in filtered and desalinated water

Recycled water from the 2000 Olympics site is used for public space irrigation and is recycled to residential properties in a separated system for non-potable uses including garden irrigation and car washing.

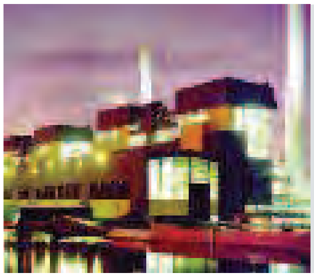


Bundamba, Queensland, Australia

The new water facility provides water to microelectronics manufacturers. The plant also provides water for potable use.

Bedok Water Reclamation Site, Singapore
Reclaiming 3.4 MGD (13,000 m³/day)

The reclaimed water from Bedok is used primarily for demanding industrial applications as the quality has a lower TDS and is more consistent than town water.



Eraring Power Station, NSW, Australia
Reclaiming 2 MGD (peak flow) (7,500 m³/day)

The first installation of low-pressure membrane and RO in the world used for boiler feed water, this plant achieved significant operating cost savings while producing high quality water.

MEMCOR® membranes for tertiary reuse applications

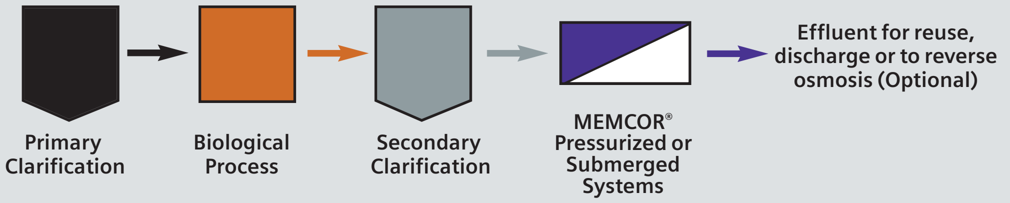
Advantages

- Simplified design reduces process steps, minimizing footprint.
- Physical barrier provides consistent, reliable water quality, day after day, exceeding the most stringent reuse regulations.
- Proven performance in hundreds of installations in operation for over 20 years.
- Simple, automated operation and direct on-line integrity monitoring ensures system membrane integrity is consistently met.

Typical Memcor® Membrane Results

Parameter	Result
Silt Density Index	<2.0
Total Suspended Solids	<1 mg/l
Total Coliform	Not Detected

Typical Tertiary Process Flow Diagram:



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Memcor® Submerged Membrane System Starts Up At Orange County Water District

Snapshot - Orange County, CA	
Location	USA
Source	Municipal Wastewater
Application	Reuse
Technology	Memcor® CS
Capacity	80 MGD (302.8 MLD)
Commissioned	2007

Background

Southern California is a semi-arid desert with a burgeoning population, and current water supplies are inadequate to supply future water needs. Orange County Water District supplies approximately 2 million people with potable water. The population is expected to increase to almost 3 million by 2020. In response, several agencies, such as Orange County Water District have pioneered the use of advanced water treatment systems that combine a dual membrane process that incorporates a microporous membrane process, such as microfiltration followed by reverse osmosis (RO) for the reclamation of municipal wastewater for agricultural, industrial and indirect potable reuse applications.

Challenge

The Orange County Water District (OCWD) of Fountain Valley, California needed to increase its potable water supplies to meet the future water demands of this fast-growing area. In 1997, the OCWD and the Orange County Sanitation District released a joint report proposing a groundwater replenishment project (GWRS) to serve the residents of Orange County. The project would reclaim secondary treated wastewater, reducing the amount of wastewater discharged to the ocean, and providing a new local water source. It would also improve the overall water quality in the groundwater basin by reducing the mineral content as well as preventing ocean water contamination.

The GWRS is designed to be built in three phases during the next 20 years, expected to cost between $400 and $450 Million, and upon completion will provide as much as 130 MGD of treated reclaimed water. The GWR System serves three key functions.

- a seawater barrier;
- a drought-proof source of high quality drinking water, and
- an alternative to wastewater discharge to the ocean.

Operational Data	Orange County, CA
Number of cells	24
Modules per skid	608
Total capacity	70 MGD (302.8 MLD)

Solution

The OCWD has started up an advanced water treatment facility to provide 70 MGD (265 MLD) of reclaimed water for agricultural, industrial and indirect potable use. Part of the GWRS, the water treatment facility consists of a Memcor® submerged membrane system from Siemens that supplies 87 MGD (329 MLD) of water to a reverse osmosis (RO) unit, followed by advanced oxidation (ultraviolet light plus hydrogen peroxide). Orange County awarded the $27M microfiltration contract to Siemens in 2002 after extensive pilot and demonstration-scale testing of equipment from three membrane suppliers at OCWD's previous 5-MGD (19 MLD) reclamation plant at the site, known as Water Factory-21. Orange County chose Siemens based on a life cycle cost analysis of the Memcor® submerged membrane system. The system is currently one of the largest in the world.

Secondary treated wastewater that was formerly discharged to the ocean is treated with the submerged membrane system to remove all suspended solids, bacteria and other harmful contaminants. The water is then pumped into recharge basins or barrier wells, where it is blended with other groundwaters, and then travels through the soil, which provides additional natural treatment of the water.

Results

The Memcor® membrane system is composed of 26 compact units that provide more than five times the treatment capacity of a conventional clarification system housed in the same footprint. It does not require chemical pretreatment except for pre-chlorination, and requires less maintenance and operator intervention. The high-quality effluent increases the reliability, and reduces the capital and operating costs, of the downstream RO system.

Each of the 26 units, or cells, contains 608 hollow fiber membrane modules. The cells are arranged in four trains, each having a dedicated MemSAP (service access platform) to facilitate system maintenance. Each cell is fitted with its own filtration pump that draws water through the membrane fibers. The modules are arranged in racks, and sit 14 feet (4.3m) below the raw water elevation. This allows the OCWD to make use of the hydraulic gradient, eliminating the need to pump water into the membrane cells.

Membrane Solutions

Memcor® membranes from Siemens Water Technologies represent the broadest range of low-pressure membrane filtration products -- submerged, pressurized, large capacity or small systems. They continue to be successfully employed in applications as diverse as wastewater reuse, potable water, RO pretreatment, high solids and sand filter retrofits.

Memcor® Products

Product	Pressurized	Submerged	Water Reuse	Potable Water	High Solids	Sand Filter Retrofits	Large Capacity	Small Systems
CP	■		■	■	■		■	
CS		■	■	■	■	■	■	
XP	■		■	■	■			■
XS		■	■	■	■			■

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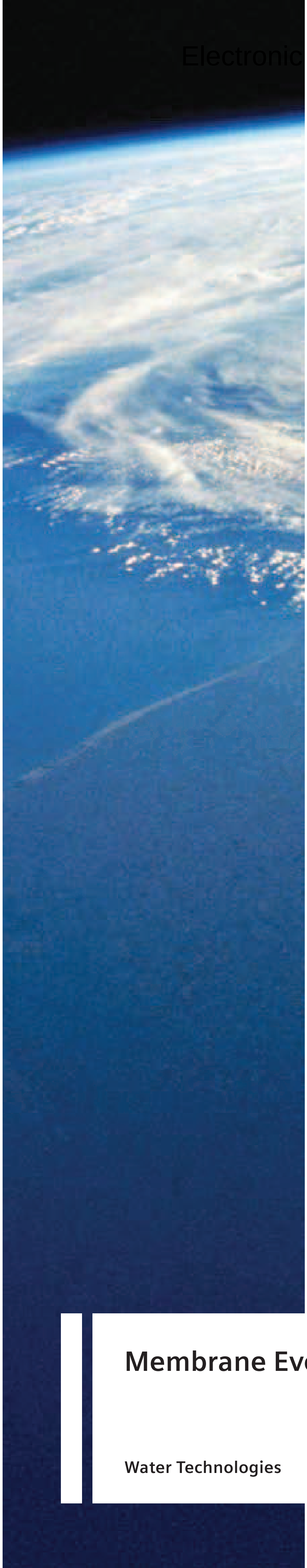
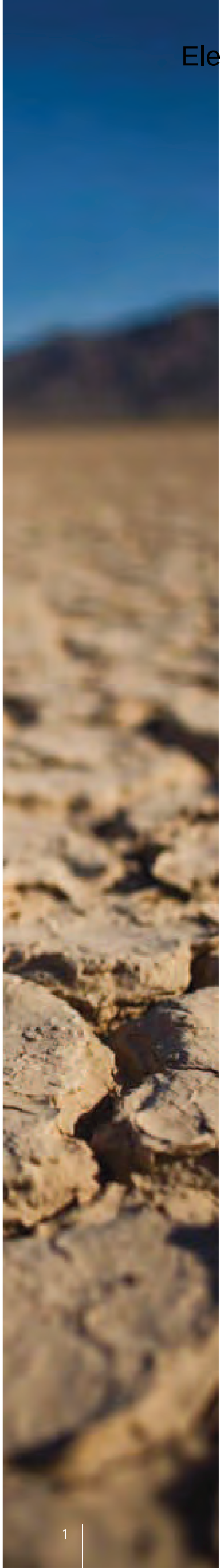


Are you ready for water reuse?

Membrane Evolution 6

Water Technologies

SIEMENS



Reuse.
Keeping the World's Water Flowing.

We live in a time of global concern about drought, water scarcity, water stress and water restrictions. According to the International Water Management Institute, water scarcity affects one-third of the world's population. As a result, cities around the world are facing escalating water costs and deteriorating water supplies. Additionally, natural disasters, including floods, hurricanes and wildfires, are contaminating our already depleted fresh water sources, affecting their quality.

The need for alternate water sources is more urgent than ever before. Today, more and more green initiatives are helping to reduce water usage, along with larger-scale solutions such as desalination, water reclamation, repurification or reuse. These terms are not trends, but a reality that many countries around the world have embraced to ensure sustainable water sources for years to come.

This sixth edition of *Evolution* answers your questions about water reuse and points to efficient and practical methods to address growing water scarcity concerns. Using innovative water reuse technologies, communities have the ability to treat existing water sources to a quality at or above their existing drinking water standards.

The goal of this piece is to help you maximize one of your community's most precious resources—water. By illustrating the applicability of water reuse, discussing its economic and environmental benefits, and presenting the safety and efficiency achieved by using membrane technology, large cities and small towns across the globe can conserve their water and ensure its availability for generations to come.

We hope you find this piece informative, and as always we welcome comments or input. E-mail us at memcor.water@siemens.com. You can also visit us at www.siemens.com/memcor_evo6.

Reuse makes pure sense.

Water is naturally recycled through the hydrologic cycle and eventually, makes its way back to fresh water supplies. The aim of water reuse is to incorporate advanced technologies to expedite this natural process. Using reclaimed or repurified water, scarce water sources are augmented, putting less strain on potable supplies and providing a sustainable resource for agriculture, irrigation, industrial operations and seawater intrusion prevention for coastal aquifers. Water reuse also reduces wastewater discharge to oceans, lakes and rivers, making it an environmentally conscious option.

In addition to being environmentally friendly, water reuse is also a prudent economic choice for communities seeking a solution to water shortages. For example, the capital costs to produce water from seawater, or desalination, are roughly two times the costs to reuse secondary effluent. Also, the costs for concentrate disposal and energy usage are much higher for desalination than for water reuse. Additionally, desalination is only a viable option for coastal areas. With the demand for global water reuse expected to rise more than 180 percent over the next decade **(Kolodziejski & Gasson, 2005, p. 5)**, it stands to reason that water reuse is an adaptable and comprehensive solution.

To achieve success, water reuse projects must use technologies that offer:

- Safe, high-quality water
- Long-term reliability
- Low operating costs
- Reduced use of chemicals
- Small, compact footprints

Membrane technology meets these criteria and enables wastewater to be reclaimed and reused for both potable and non-potable use, safely and reliably. MEMCOR® membranes have been implemented with great success all over the world, transforming alternative water sources into usable water.

Global Water Intelligence. (2005). *Water Reuse Markets 2005-2015: A Global Assessment and Forecast* (1st edition). Oxford, UK.: Kolodziejski, J. & Gasson, C.

MEMCOR® Membranes Provide Water Reuse Solutions.

Pressurized Membrane Filtration

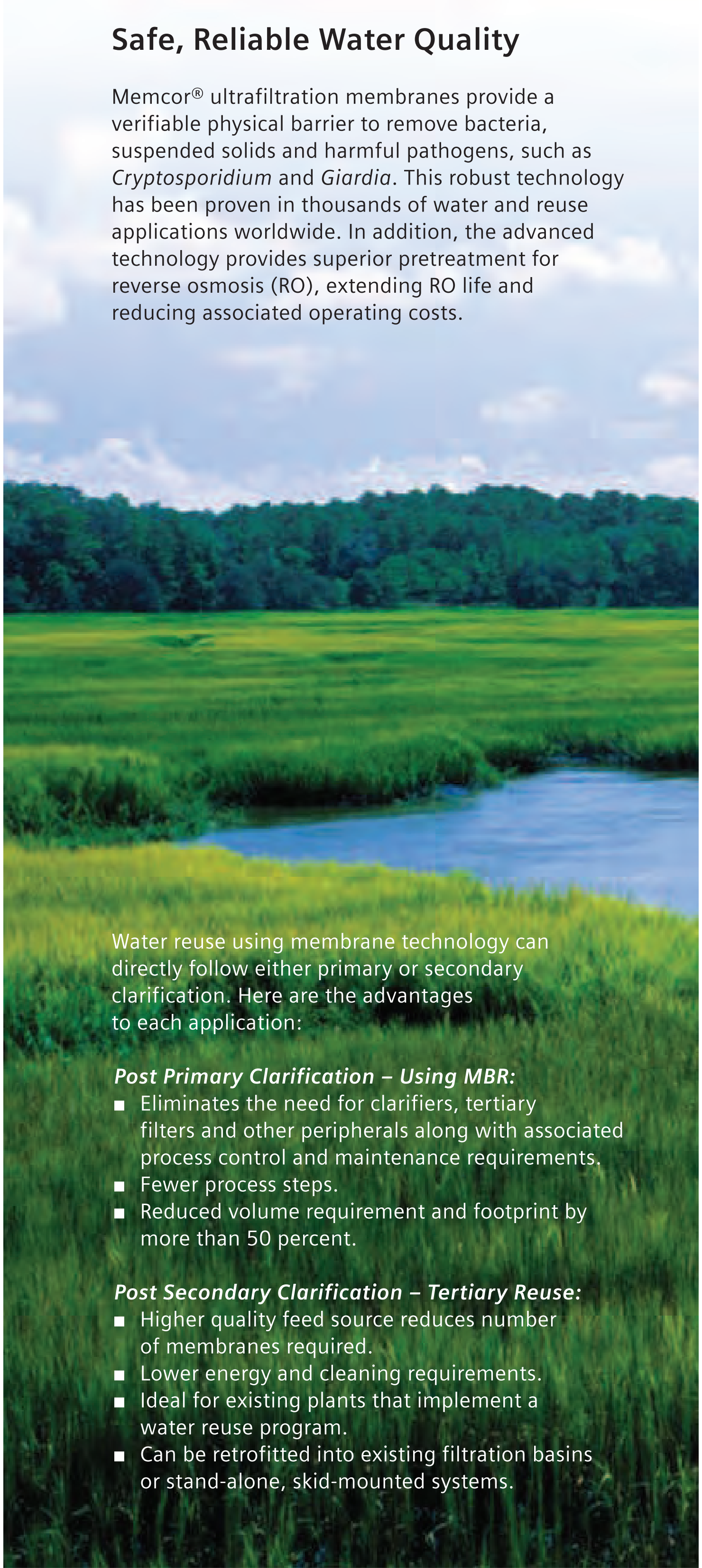
- Simple, slab-on-grade installation
- Operated in a closed environment
- All membrane modules individually isolatable
- Products — MEMCOR® CP and MEMCOR® XP Membranes

Submerged Membrane Filtration

- Operated in open tank design
- Feedwater flows by gravity into membrane cell
- Ideal for retrofitting existing filter basins
- Low energy usage, compact footprint
- Products — MEMCOR® CS and MEMCOR® XS Membranes

Membrane Bioreactor (MBR)

- Operated in open tank design
- Mixed liquor is pumped into the membrane bundles
- Modules are separated from biological treatment, optimizing both processes for enhanced performance
- Products available — Orbal® Multichannel Oxidation System, VertiCel® Aeration Process, VLR® Loop Reactor, MemJet® MBR, Cannibal® Solids Reduction System



Safe, Reliable Water Quality

Memcor® ultrafiltration membranes provide a verifiable physical barrier to remove bacteria, suspended solids and harmful pathogens, such as *Cryptosporidium* and *Giardia*. This robust technology has been proven in thousands of water and reuse applications worldwide. In addition, the advanced technology provides superior pretreatment for reverse osmosis (RO), extending RO life and reducing associated operating costs.

Water reuse using membrane technology can directly follow either primary or secondary clarification. Here are the advantages to each application:

Post Primary Clarification – Using MBR:

- Eliminates the need for clarifiers, tertiary filters and other peripherals along with associated process control and maintenance requirements.
- Fewer process steps.
- Reduced volume requirement and footprint by more than 50 percent.

Post Secondary Clarification – Tertiary Reuse:

- Higher quality feed source reduces number of membranes required.
- Lower energy and cleaning requirements.
- Ideal for existing plants that implement a water reuse program.
- Can be retrofitted into existing filtration basins or stand-alone, skid-mounted systems.

Existing Technology	Key Reuse Technology	Intended Use
Secondary Clarification	Membrane Filtration →	High-Quality Non-Potable Uses
Secondary Clarification	Membrane Filtration → Reverse Osmosis → UV Disinfection	Direct and Indirect Potable Uses High-Quality Industrial Uses
Primary Clarification	Membrane Bioreactor →	High-Quality Non-Potable Uses
Primary Clarification	Membrane Bioreactor → Reverse Osmosis → UV Disinfection	Direct and Indirect Potable Uses High-Quality Industrial Uses
Municipal Sewer Line	Packaged Membrane Bioreactor →	High-Quality Non-Potable Uses

	Advantages	Limitations
Membrane Filtration	Positive physical barrier to pathogens, biosolids and turbidity Handles widely changing feedwater conditions and flow rates Simple, automated operation with minimal labor required Significant reduction in footprint and low cost per gallon	Higher capital cost than granular media filters Will require membrane replacement at some point
Membrane Bioreactor (MBR)	Same advantages as Membrane Filtration, plus: Increased SRT for more complete destruction of nutrients Higher density sludge for easier dewatering or transport	Higher capital cost than granular media filters Will require membrane replacement at some point
Reverse Osmosis (RO)	Reduces TDS and THM precursors Provides water suitable for direct or indirect potable use with disinfection Provides high-quality water for industrial uses	Requires effective pretreatment for scaling by sparingly soluble salts Fouling by suspended solids Degradation from oxidants and metals

Water Reuse Answers From the Global Community

So how do you choose the best alternative for your community?
Here are some questions that we are frequently asked.

Q Can water be reused for more than non potable uses

A Yes, in fact, using innovative technologies, water can be repurified for potable use. In some areas, drought coupled with a high cost to import water forces communities to look to these alternative methods. In Singapore, a country with 4.5 million people living on only 693 sq. km (267 sq. miles) of landmass, source water is at a premium and water scarcity is impending. In an effort to ensure a sustainable water supply for the future development of Singapore, a NEWater study determined the efficacy of a new source of high-quality water by combining dual membrane technology and UV.

The success of the study led to the construction of the full-scale reuse plants. The Kranji Reclamation Plant combines the Memcor® CS submerged membrane system with RO and UV disinfection to produce safe, reliable, high-purity water from secondary effluent.

Q Drought and water scarcity continue to be a major concerns in my area: What measures are other communities taking to mitigate these issues

A Perhaps one of the most talked about global water reuse undertakings is currently ongoing in Brisbane, Australia. Drought and population increase have created a severe water shortage, resulting in Level 5 water restrictions for much of the region.

State and local officials implemented measures to ensure the existence of a reliable source of water for non-potable use. The Western Corridor Recycled Water Project will provide 310,000 m3/d (80 MGD) for both domestic and industrial use. The project will take municipal wastewater from existing local wastewater plants and treat it to high-quality standards at three separate facilities using a tertiary low-pressure membrane approach. A major facility in the scheme will be the Bundamba Advanced Water Treatment Plant (BAWTP), which will treat 66,000 m3/d (17 MGD) by mid-2008 with ultimate expansion to 100,000 m3/d (26.4 MGD). At this facility, domestic wastewater is harvested from four wastewater treatment plants. Effluent is combined and sent to the BAWTP, where it is treated using a Memcor® CP ultrafiltration system and reverse osmosis.

Q What technology is the best option once we are ready for water reuse

A Traditional dual membrane technology (UF/RO) using secondary effluent as feed has become a widely accepted option for water reuse and has been in use for over a decade. However, MBR technology is a viable solution that offers unique advantages. In planning to host the largest sporting event in the world, water officials in China had to determine which technology would best serve the increased demand for water. In August of 2008, tourists, participants and officials from all over the world will descend on Beijing for the 29th Olympiad. After evaluating their options, the Beijing Drainage Corporation, the entity responsible for providing much of the non-potable water supply, selected MBR technology in order to meet their goal of producing high quality water, increasing overall production capacity and remaining in a small footprint. Once complete, the MemJet® MBR will expand the capacity of the existing Bei Xiao He plant from 40,000 m3/d (10.6 MGD) to 100,000 m3/d (26.4 MGD). Moreover, the water from the plant will meet stringent quality criteria.

Q I manage a small community: Is water reuse a viable option

A Yes. Lanzarote, one of the seven Canary Islands, was facing an inescapable water shortage. The need arose for a drought-proof, reliable, tailored, quality water source at a lower cost than that offered through desalination. As a result, multiple small water reuse facilities were developed. The Memcor® membrane system, the industry standard for reliable pretreatment for RO on secondary sewage, resolved the island's problem of accessing a non-potable water source. The benefits of using the Memcor system at the Lanzarote installations included a silt density index of <2, reliable pretreatment for RO on variable sources, automatic validation of the system integrity and remote monitoring that reduced operating overheads.

Q I have an existing reuse plant but need to reduce operating costs: What’s the most economic solution

A Membranes can provide significant cost savings for water reuse. For California’s Orange County Water District—Water Factory 21 (WF21), the threat of seawater intruding into the groundwater basin and the need to recharge its reservoir prompted the water district to maximize the operations of its 30-year-old reuse plant and, simultaneously, minimize its operating costs. To deal with this, the water district teamed with Orange County Sanitation District (OCSD) in a joint development program. The initiative, the Groundwater Replenishment System (GWRS), is set to reclaim 492 m3/d (130 MGD) of secondary effluent wastewater, making it one of the largest ventures of its kind in the world.

After many years of operation, the water district confirmed that the key issue to be addressed was more effective reverse osmosis (RO) pretreatment. As a result, in 1992, the water district began a series of extensive pilot studies with low-pressure membrane systems.

Pilot studies revealed that the effluent from the membrane system removed micro-organisms and suspended solids, had significantly reduced turbidity, and most importantly, produced an SDI that was a factor of four lower than the best SDI value for the existing lime pretreatment. Because of the lower SDI, RO system life would be extended and operating costs were dramatically reduced.

The GWRS Advanced Water Treatment facility has since replaced lime clarification with low-pressure membranes. The new facility includes Memcor membranes, RO and UV. The Memcor® CS submerged system is composed of 26 compact modular units that provide more than twice the capacity of a conventional treatment system in the same footprint. It does not require chemical pretreatment other than pre-chlorination, is highly automated and less maintenance-intensive, resulting in less operator attendance.

Dual Membranes for Water Reuse Operation for Over a Decade

Eraring Power Station in New South Wales, Australia, was the world’s first dual membrane water reuse system and has been operating for over a decade. The project grew out of the pressing need to reduce the demand on the local water supply and to protect the local environment from the impact of wastewater discharge. In the early 1990s, the facility, owned and operated by Eraring Energy, purchased its boiler feedwater from Hunter Water Corporation, a New South Wales water utility. As part of a wastewater treatment plant upgrade, Hunter Water was faced with an expensive 6 km (3.7 mi) outfall pipe to the ocean.

At the advice of a visionary power plant chemist, the facility decided to build an advanced treatment system that included Memcor® low-pressure membrane filtration and reverse osmosis. This dual membrane process reused the wastewater, producing quality water and eliminating the need for a costly pipeline.

This project freed up as much as 3,100 m3/d (820,000 gpd) of potable water from the local community. It also significantly minimized the plant’s boiler feedwater costs while providing higher-quality water. Even better, it prevented effluent discharge to the environment.

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Eraring Power

Eraring Power Station consists of 4 x 660MW generators. In 1993, Eraring used approx 4.2ML/day of potable water from the regions potable supply. By 1999, 56.7% of this demand was provided from reclaimed water produced by the dual membrane (MF/RO) water reclamation plant. This percentage is expected to exceed 90% as increased quantities of secondary effluent become available.

Plant capacity was increased in Dec 1988 to capture the increasing quantity of effluent available (the plant was designed for modular capacity increases)

Reclaimed water is primarily used for Boiler makeup (via demin plant) and Auxiliary cooling.

In 1993/94 Hunter Water Corporation built the Dora Creek wastewater treatment plant to service the expanding sewerage system west of Lake Macquarie. Eraring is located close to the Dora Creek plant, so the potential for water reuse was good.

Pacific Power undertook an environmental assessment and cost benefit analysis with support from Hunter Water Corporation.

The results of the study showed potential operating cost savings of around $700,000/annum in potable water consumption and production of demineralised water for the high-pressure boilers (reclaimed water has lower TDS potable water reducing chemical consumption in the IX demineraliser).

Additional benefits included:

- An economically practical option
- Water conservation
- Minimum disturbance to the environment.

This was also an opportunity to "bench mark" the best available technology for the reuse of secondary treated sewage.

In addition, the reclamation plant saved Hunter Water over $5 million by:

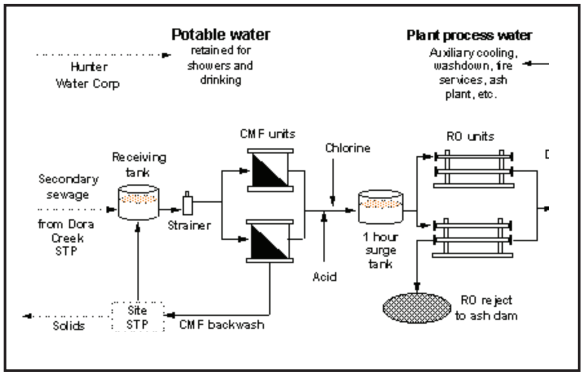
- delaying the construction of the 11.4km sewer link between Dora Creek and the ocean outfall by 15 years.
- Delaying augmentation of the existing potable water infrastructure.

While wastewater had been widely regarded as a potential water resource it had not been used widely in demanding applications. The Memcor® reuse technology featured at Eraring Power Station, demonstrates the potential to use this valuable resource in power and industrial facilities sited near municipal wastewater plants.

Process Design

Influent from Dora Creek Wastewater plant flows, under gravity from a 70ML elevated tank through a 500mm pipeline, to the suction of 3 x 100% centrifugal pumps. The pumps deliver the feedwater via a single in-line motorised self cleaning strainer to the three CMF units.

Application	Effluent Polishing/Reuse
Market	Power Generation
Country	Australia
Client	Pacific Power Corporation NSW
Capacity	3.5 ML/day of feed (7.6 ML/day peak flow)
Influent Quality	NFR



Each membrane unit comprises 90 filtration modules containing polypropylene hollow fibre membranes having a average pore size of 0.2µm. The membrane modules remove virtually all suspended solids, including faecal coliforms and giardia cysts, significantly reducing human virus.

MF pretreatment allows the RO membranes to be operated at 30% higher flux than allowed by traditional conventional lime coagulation/sedimentation/filtration pretreatment. Silt Density Index (SDI) of RO feed is less than 3.

Filtrate from the membrane units is dosed with sodium hypochlorite for control of biological growth. Sulphuric acid is also dosed to reduce pH and minimise hydrolysis of RO membranes. Microfiltered water is then dosed with antiscalant and passed through a 1µm disposable cartridge guard filter. The RO system comprises 2x50%, two stage trains in a 6:3 array, performing at 98% rejection. Salts and organics are rejected allowing only water to pass through.
Treated water, is fed to the demin plant with the balance of the water used for non-potable water applications around the power plant.

The RO concentrate (reject or brine) passes to the station ash dam. Backwash from membrane plant is sent to Eraring's onsite wastewater treatment facility and recycled back to the feed receiving tank.

Plant Specifications:

CMF:
3 x 90M10C (90 modules per array) CMF Membrane

RO:
6:3 array, 2 x 50% Trains - combined output 3.75 ML/day RO

Membrane Solutions

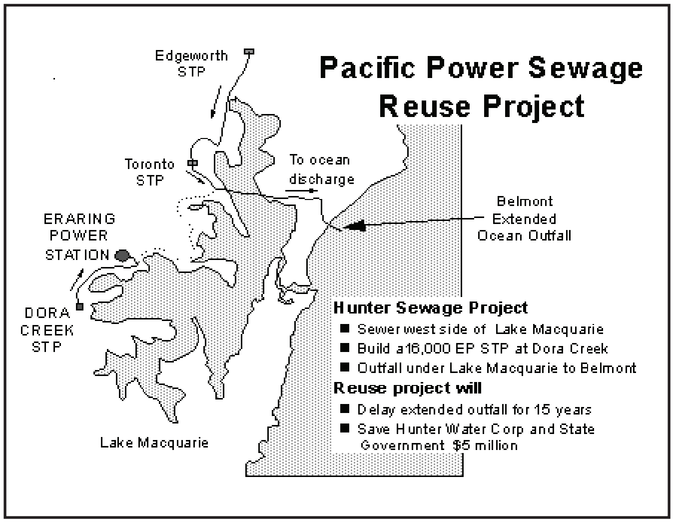
Memcor® membranes from Siemens Water Technologies represent the broadest range of low-pressure membrane filtration products -- submerged, pressurized, large capacity or small systems. They continue to be successfully employed in applications as diverse as wastewater reuse, potable water, RO pretreatment, high solids and sand filter retrofits.

Economics and Benefits

The total project cost was appro. $4.5 million, including design, equipment supply, civil, electrical and mechanical work, plus equipment associated with transfer and pretreatment of wastewater to the facility. Performance since startup in 1994 has proven a payback of 6-7 years with potential savings of M$1.2/annum. Other major benefits include conservation of the fragile environment and considerably reduced demand on the local water supply.

Summary

The innovative combination of membrane filtration and RO technology achieves near "boiler feed quality" and was a world first. The simplicity and reliability of Memcor® membranes, as an RO pretreatment, greatly enhances the economic viability of wastewater reuse. The plant at the Eraring Power Station demonstrates the potential for water users and water authorities to achieve economic and environmental benefits.



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CASE STUDY

RESTORING HAWAII'S GREEN

USFILTER WATER REUSE HONOULIULI PROJECT

Challenge

For years, the City of Honouliuli discharged primary and secondary effluent from its wastewater treatment plant into the Pacific Ocean - an acceptable solution by many standards for some time. But in the late 1990's, as environmental standards changed, the city found itself under a federal consent decree to improve its wastewater treatment and disposal. At the same time, the city's potable or drinkable water resources were strained by population and tourist growth. As a result, the city faced the costly challenge of finding a new solution for water treatment that would be as cost effective as possible for tax payers and comply with a changing environmental regulatory environment.

Solution

The city entered into a 30-year partnership with USFilter to design, build, finance and operate a multi-faceted water reclamation facility to preserve its limited potable water resources and meet federal mandates. In other words, USFilter will treat and reuse the city's wastewater for irrigation and industrial uses, reducing environmental concerns and reducing the strains placed on the city's drinking water resources. In addition, this public-private partnership with USFilter will save the city and taxpayers millions of dollars in construction, maintenance and operating costs by spreading out costs over a 20-year period and outsourcing specialized water management to USFilter, a company whose core competency is water.

Results

The reclamation facility, commissioned August 2000, is the first of its kind in Oahu and the largest in the Hawaiian Islands. It will produce 12 million gallons per day (MGD) of beneficial reuse water from effluent previously discharged into the Pacific Ocean. The process will generate two grades of water. One grade will be extremely high in purity and is sold to power and petro-refining companies. Like most industrial manufacturers, power and petro-refining companies need a tremendous amount of high purity water for their businesses. The second grade of water will be purchased by the city for irrigation purposes. As a result, the amount of available potable water for residential needs will increase 2 million gallons per day - an important aspect for an island surrounded by salt water.

During the first year of operation, the costs for RO product water was $2.10/gallon, based on power costs of $0.11 per KWH. Customers are saving between $2.00 and $7.00 per 1000 gallons, depending on their daily usage.

USFilter

CASE STUDY

RESTORING HAWAII'S GREEN

USFILTER WATER REUSE
HONOULIULI PROJECT

Process

The facility uses fine-media filtration, microfiltration and reverse osmosis processes to treat secondary effluent now discharged into the Pacific Ocean. USFilter's Zimpro Products Hydro-Clear® filter system is used for wastewater polishing, followed by ultraviolet disinfection to produce irrigation water. USFilter's Memcor® CMF, followed by a reverse osmosis supplied by USFilter, turns secondary effluent into "Ultrapure" water. USFilter's Memcor CMF continuous microfiltration process, which has been used worldwide for wastewater reuse applications, is used to remove particles and bacteria from the wastewater prior to reverse osmosis treatment. The CMF has consistently produced filtrate water with turbidity less than 0.1 NTU, even with temporary secondary effluent conditions as high as 45 mg/l suspended solids. USFilter's reverse osmosis technology is used to create product water specific for industrial use as boiler feedwater. From the first day of operation, the RO product water quality continues to exceed water quality requirements for industrial use as boiler feed water. During the first year of operation, the RO product water quality exceeded the original specification by almost 50%. One customer of the RO product water, alone has saved 507.3 million gallons of potable water by using ultrapure water created from reclaimed wastewater.

"This project helps bring the 'green' back to Ewa. Ewa Water Recycling will not only benefit Ewa but all of Oahu by helping to save our extremely valuable potable water resource." - Ken Windram, USFilter's Project Manager for Ewa Water Recycling and a 15-year resident of Oahu

"We view (this agreement) as a win for rate payers, the city, the environment and a number of businesses that will have a guaranteed supply of quality water." - Jeremy Harris, Mayor of Honolulu

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a VIVENDI Environnement company

Evoqua - RO

AECOM

CHLORIDE REMOVAL FROM WASTEWATER

Plant Capacity - Feedwater Flow Rate 15 MGD (10,420 GPM) - Permeate Flow Rate 12.11 MGD (8,410 GPM)

Feedwater Analysis - "Water Quality Information for Chloride Treatment Study Wastewater Plant Basis of Design Water Quality Data

A. Base Design

1 System Description

a. Ammonium Hydroxide feed followed by chlorine addition to form ~ 4 ppm of chloramine
b. Automatic Backflushable Self Cleaning Wedgewire Screen Filters
c. Pressurized Ultrafiltration (UF)
d. UF Clean-In-Place System Operating at 95% Recovery
e. UF Filtrate Tank (by Purchaser)
f. Four (4) Filtrate Transfer Pumps
g. Acid Feed System
h. Anti-Scalant Feed System
i. Safety Cartridge Filters
j. Five (5) High Pressure Reverse Osmosis Feed Pumps
k. Five (5) 20% Reverse Osmosis (RO) Systems Operating at 85% Recovery
l. RO Clean-In-Place System
m. PLC Control System

2 Operating Costs Based Upon Treated Water

a. Chlorine - 0.059 lbs/1000 gal
b. Ammonium Hydroxide - 0.012 lbs/1000 gal
c. Anti-scalant - $0.049/1000 gal
d. Sulfuric Acid (based upon 27 deg. C the worst case) - 0.62 lbs/1000 gal
e. Cartridge Filter Replacement based upon six (6) month life - $0.001/1000 gal
f. RO membrane Replacement based upon three (3) year life and $600/element - $0.124/1000 gal
g. RO membrane Cleaning Chemicals based upon six (6) month cleaning cycle - $0.025/1000 gal
h. Power for filtrate transfer pumps and RO high pressure Pumps (based upon 9 deg. C the worst case) - 1.24 kwh/1000 gal

3 Capital Cost

The total selling price for the equipment described above in Item 1 less b.,c.,and d. is:

$9,426,000

Not included in this price are:

a. Freight to the jobsite
b. Unloading and proper storage of equipment
c. All civil site work, foundations, anchors, and design
d. All required buildings
e. Installation and erection
f. Interconnecting piping and supports
g. Interconnecting wiring and conduit
h. MCC
i. Cable trays
j. Insulation and supports

B. Optional Brine Recovery System

Plant Capacity - Feedwater Flow Rate 2.138 MGD (1,485 GPM) - Permeate Flow Rate 1.07 to 0.75 MGD (745 to 520 GPM)

Feedwater Analysis - "Water Quality Information for Chloride Treatment Study Wastewater Plant Basis of Design Water Quality Data

1 System Description

a. Brine Recovery Feed Tank (by Purchaser)
b. Three (3) Brine Recovery Transfer Pumps
c. Acid Feed System
d. Anti-Scalant Feed System
e. Safety Cartridge Filters

CHLORIDE REMOVAL FROM WASTEWATER

f. Five (5) High Pressure Reverse Osmosis Feed Pumps
g. Five (5) Brine Recovery Reverse Osmosis (RO) Units Operating at 35 or 50% Recovery
h. RO Clean-In-Place System
i. PLC Control System

2 Operating Costs Based Upon Treated Water

a. Sulfuric Acid (based upon 9 deg. C and 35% recovery the worst case) - 17.0 lbs/1000 gal
b. Anti-scalant - $0.119/1000 gal
c. Cartridge Filter Replacement based upon twelve (12) month life - $0.006/1000 gal
d. RO membrane Replacement based upon three (3) year life and $600/element - $0.021/1000 gal
e. RO membrane Cleaning Chemicals based upon six (6) month cleaning cycle - $0.052/1000 gal
f. Power for filtrate transfer pumps and RO high pressure Pumps (based upon 9 deg. C and 35% recovery) - 6.93 kwh/1000 gal

3 Capital Cost
The total selling price for the equipment described above in Item 1 less b.,c.,and d. is:

$1,280,000

Not included in this price are:

a. Freight to the jobsite
b. Unloading and proper storage of equipment
c. All civil site work, foundations, anchors, and design
d. All required buildings
e. Installation and erection
f. Interconnecting piping and supports
g. Interconnecting wiring and conduit
h. MCC
i. Cable trays
j. Insulation and supports

Vanorman, Eric

From:	Cohoon, Kevin L <kevin.cohoon@evoqua.com>
Sent:	Monday, December 22, 2014 11:24 AM
To:	Vanorman, Eric
Cc:	Pugh, Lucy B.
Subject:	RE: Wisconsin Chloride Removal/Softening
Attachments:	AECOM.9C.Rev1.pdf; AECOM.27C.Rev1.pdf; AECOM.BR.27C.50R.Rev1.pdf; AECOM.BR.9C.35R.Rev1.pdf

Hi Eric,

Please see below in regards to the RO questions. Unless Russ responds to the questions on the UF, I doubt I will be able to get any further info on this until after the new year. I hope it helps. Merry Christmas!

In response to the AECOM email, I reviewed the previous information and have the following responses:

- I reran the RO design based upon a feedwater flow rate of 15 MGD. The primary RO system will increase slightly with the array going from a 54 x 24 to a 56 x 26. Please see the attached projections. The brine recovery RO will be unchanged other than the fact the permeate flow for the two different design temperatures will increase slightly.
- It can be assumed any changes in the operating costs previously provided for the primary and recovery RO's will remain unchanged as they were provided as cost per 1,000 gallons.
- The previously provided Avista scaling calculations will also be unchanged as they are based upon recoveries and not flow rates.
- The original proposal was based upon five (5) 20% primary and brine recovery RO's. The revised total selling price for the increased feedwater flow rate and the addition of a standby primary RO would be $11,877,000 and the revised total selling price for the addition of a brine recovery RO would be $1,536,000.
- I don't have a feel for the labor costs associated with the O&M for the primary and brine recovery RO. These units are highly automated and are not complex to operate so I would think the labor costs would be minimal when given as a cost per gallon of the treated water.
- Concerning the operation of the RO's, they should consider RO is a constant rate operation so the only means to modulate flow would be to place trains on-line or take them on off-line. If the permeate from the RO's were sent to a treated water storage tank, the level in the tank would determine when the trains would be placed in operation or taken off-line. The concern with this type of operation is any train in the standby position would be vulnerable to bio-fouling if it were to be off-line for an extended period of time. To avoid this condition, all the RO trains should be cycled (first on, first off). When a train is taken off-line, it would include a forward flush or preferably a permeate flush. Based upon the objective to reduce wastewater, I believe the primary RO flushes could be recovered to the UF feed but it would probably be best not to try and recover the brine recovery RO flush water. The controls would ensure whenever a primary RO train were in operation a corresponding brine recovery RO would also be placed into operation, one for one. If one could establish the wastewater flow rate would be reduced for an extended period of time (several months), it might be best to take an RO off-line and store it with a biocide until demand would justify having all the trains available of operation. The result of this variable type of operation will probably result in more frequent membrane cleanings so the costs provided for membrane cleanings should be doubled ort even tripled. I know of no way to calculating with accuracy the true increase in cleaning costs.

Kevin Cohoon

Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 19, 2014 3:01 PM
To: Cohoon, Kevin L; Cohoon, Kevin L
Cc: Pugh, Lucy B.
Subject: RE: Wisconsin Chloride Removal/Softening

Kevin:

Sorry…. your old email popped up first for some reason.

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
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Grand Rapids, Michigan 49512
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From: Vanorman, Eric
Sent: Friday, December 19, 2014 2:58 PM
To: Cohoon, Kevin (WT) (kevin.cohoon@siemens.com)
Cc: Pugh, Lucy B.
Subject: Wisconsin Chloride Removal/Softening

Kevin:

We are in the process of finalizing the chloride reduction preliminary engineering report for our Wisconsin client. Thank you for providing the information to date related to this project. For the final document we are looking to cleanup a few things and fill in a few remaining holes. To that end can you:

For the Wastewater UF system:

- Adjust the Memcor offering (if needed) to provide a permeate of 15MGD to feed to the RO. At this point we are assuming a total of 14 skids (12 duty and 2 standby).
- Confirm the UF systems efficiency
- Provide detail on the UF CP2 racks like membrane size, quantity, materials, assumed flux rate……
- Provide O&M costs including:
  - Utility consumption
  - Chemical usage
  - Labor
  - Replacement costs (Total # pre-filters and membranes, cost per pre-filter/membrane and life expectancy)
- Describe how the system would operate if only a 3 MGD permeate flow through the system would be required. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the

system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.

For the Wastewater RO system:

- Adjust the RO offering (if needed) to accommodate a 15MGD feed. At this point we are assuming a total of 6 skids (5 duty and 1 standby)
- Describe how the system would operate if only a 3 MGD flow through the system would be required. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide estimated labor costs associated with O&M of the RO system.

For the Wastewater recovery RO system:

- Adjust the recovery RO offering (if needed) based on the 15MGD feed to the main RO. At this point we are assuming a total of 6 skids (5 duty and 1 standby)
- Describe how the system would operate if only a 3 MGD flow through the main RO system would be required. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide estimated labor costs associated with O&M of the recovery RO system.

For Lime Softening of wastewater:
We have been exploring evaporator and crystallizer options but would need to soften the reject stream to get acceptable performance. The softening may also improve the recovery RO.

- Provide softening equipment including solids handling prior to the recovery RO (could look at concentrate after recovery RO if no benefit to recovery RO). This would include capital cost, equipment sizes (capacity and foot prints), materials of construction and O&M costs including labor.

For Softening of Source Water

- WELL OPTION - Provide a membrane softening option which can provide softened blended water from a 3.0 MGD raw water supply (quality data previously sent). Assume two units combined (or suggest alternate) would be required to accomplish this. Further assume that the reject from this system could be discharged to the sanitary, minimizing the overall foot print and processes at each site. Information on the processing rate and an estimate on the % reject would be required as well.
- CENTRALIZED OPTION - Provide a membrane softening option which can provide 50 MGD of softened blended water (quality data previously sent). Further assume that the reject from this system could be discharged to the sanitary, minimizing the overall foot print and processes. Information on the processing rate and an estimate on the % reject would be required as well.
- Provide information on each proposed softening systems equipment including capital cost, equipment sizes (capacity and foot prints), materials of construction and O&M costs including labor.

We are hoping this is something which can be updated by the end of the year. If this is not feasible please let us now when the information could be provided. If you have any questions please don't hesitate to contact either myself or Lucy.

Thanks,

Eric Van Orman, P.E.

Project Manager, Water
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www.aecom.com

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	157.00	gpm
HP Pump flow:	314.0	gpm	Raw water flow:	314.0	gpm
Feed pressure:	212.1	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	10.5	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	157.0	34.9	17.4	10.5	1.10	205.4	0.0	ESPA2-LD	54	9x6

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	507.6	1265.8	507.6	1265.8	2.890	7.2	1012.3	2524.5
Mg	283.5	1166.7	283.5	1166.7	1.614	6.6	565.4	2326.7
Na	1567.0	3406.5	1567.0	3406.5	42.555	92.5	3091.4	6720.5
K	81.0	103.8	81.0	103.8	2.744	3.5	159.3	204.2
NH4	1.9	5.3	1.9	5.3	0.064	0.2	3.7	10.4
Ba	0.700	0.5	0.700	0.5	0.004	0.0	1.4	1.0
Sr	0.700	0.8	0.700	0.8	0.004	0.0	1.4	1.6
CO3	4.3	7.2	0.0	0.1	0.000	0.0	0.1	0.1
HCO3	1751.7	1435.8	661.3	542.1	22.848	18.7	1299.8	1065.4
SO4	670.5	698.4	1536.0	1600.0	7.448	7.8	3064.6	3192.3
Cl	2638.2	3721.0	2638.2	3721.0	50.910	71.8	5225.5	7370.2
F	4.4	11.6	4.4	11.6	0.169	0.4	8.6	22.7
NO3	101.4	81.8	101.4	81.8	14.051	11.3	188.7	152.2
B	0.00		0.00		0.000		0.00	
SiO2	77.7		77.7		1.20		154.20	
CO2	118.17		945.18		945.18		945.18	
TDS	7690.6		7461.5		146.5		14776.5	
pH	7.40		6.20		4.72		6.34	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	24%	52%	124%
SrSO4 / Ksp * 100:	2%	5%	11%
BaSO4 / Ksp * 100:	2590%	5646%	12460%
SiO2 saturation:	82%	81%	163%
Langelier Saturation Index	1.33	-0.29	0.41
Stiff & Davis Saturation Index	0.99	-0.65	-0.17
Ionic strength	0.15	0.16	0.32
Osmotic pressure	68.4 psi	62.2 psi	123.1 psi

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	157.00	gpm
HP Pump flow:	314.0	gpm	Raw water flow:	314.0	gpm
Feed pressure:	212.1	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	10.5	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	psi	Element Type	Elem. No.	Array
1-1	157.0	34.9	17.4	10.5	1.10	205.4	0.0	ESPA2-LD	54	9x6

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Ca	Cumulative Perm Ion levels Mg	Cl	B	SiO2
1-1	1	212.1	1.6	3.6	12.8	1.10	84.2	69.2	1.48	0.83	31	0.00	0.67
1-1	2	210.5	1.4	3.3	12.0	1.10	91.8	77.4	1.63	0.91	34	0.00	0.74
1-1	3	209.2	1.2	3.1	11.1	1.10	101.7	86.8	1.82	1.02	38	0.00	0.83
1-1	4	208.0	1.0	2.8	10.1	1.10	113.9	97.7	2.04	1.14	42	0.00	0.93
1-1	5	207.0	0.8	2.5	8.9	1.10	128.9	109.8	2.32	1.30	48	0.00	1.05
1-1	6	206.2	0.7	2.1	7.7	1.10	147.2	122.9	2.65	1.48	55	0.00	1.20

Stage	NDP psi
1-1	118.7

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	157.00	gpm
HP Pump flow:	314.0	gpm	Raw water flow:	314.0	gpm
Feed pressure:	212.1	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	10.5	gfd	Feed type:	Wastewater	

****
**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***
****

Concentrate saturation of BaSO4 too high (12460%)
Concentrate saturation of SiO2 too high (163%)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
8.0 inches	75 gpm (283.9 lpm)	12 gpm (45.4 lpm)
8.0 inches(Full Fit)	75 gpm (283.9 lpm)	30 gpm (113.6 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor.
Without scale inhibitor, concentrate saturation should not exceed 100%.

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	110.00	gpm
HP Pump flow:	314.3	gpm	Raw water flow:	314.3	gpm
Feed pressure:	174.0	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.8	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	7.3	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	110.0	34.9	22.7	7.3	1.06	166.2	0.0	ESPA2-LD	54	9x6

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	510.2	1272.3	510.2	1272.3	3.762	9.4	782.9	1952.4
Mg	284.9	1172.4	284.9	1172.4	2.101	8.6	437.2	1799.1
Na	1605.3	3489.8	1605.3	3489.8	56.557	123.0	2439.2	5302.7
K	83.5	107.1	83.5	107.1	3.672	4.7	126.5	162.2
NH4	1.9	5.3	1.9	5.3	0.084	0.2	2.9	8.0
Ba	0.200	0.1	0.200	0.1	0.001	0.0	0.3	0.2
Sr	0.700	0.8	0.700	0.8	0.005	0.0	1.1	1.2
CO3	10.3	17.2	0.9	1.5	0.002	0.0	1.4	2.3
HCO3	2097.0	1718.9	1861.2	1525.6	66.160	54.2	2827.8	2317.8
SO4	430.3	448.2	631.0	657.3	3.139	3.3	969.1	1009.5
Cl	2677.1	3775.9	2677.1	3775.9	53.073	74.9	4090.0	5768.7
F	4.5	11.8	4.5	11.8	0.178	0.5	6.8	18.0
NO3	112.7	90.9	112.7	90.9	16.243	13.1	164.6	132.8
B	0.00		0.00		0.000		0.00	
SiO2	79.0		79.0		1.58		120.69	
CO2	70.91		266.00		266.00		266.00	
TDS	7897.6		7853.1		206.6		11970.5	
pH	7.70		7.20		5.70		7.24	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	15%	22%	38%
SrSO4 / Ksp * 100:	1%	2%	3%
BaSO4 / Ksp * 100:	475%	690%	1129%
SiO2 saturation:	80%	85%	129%
Langelier Saturation Index	1.71	1.16	1.55
Stiff & Davis Saturation Index	1.37	0.81	1.07
Ionic strength	0.15	0.15	0.23
Osmotic pressure	71.4 psi	70.1 psi	106.8 psi

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	110.00	gpm
HP Pump flow:	314.3	gpm	Raw water flow:	314.3	gpm
Feed pressure:	174.0	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.8	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	7.3	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	psi	Element Type	Elem. No.	Array
1-1	110.0	34.9	22.7	7.3	1.06	166.2	0.0	ESPA2-LD	54	9x6

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels Ca	Mg	Cl	B	SiO2
1-1	1	174.0	1.7	2.4	8.8	1.07	146.4	75.3	2.00	1.12	42	0.00	1.04
1-1	2	172.4	1.5	2.3	8.3	1.10	152.9	80.9	2.16	1.20	45	0.00	1.13
1-1	3	170.9	1.3	2.1	7.6	1.10	163.9	86.8	2.34	1.31	49	0.00	1.22
1-1	4	169.5	1.2	1.9	7.0	1.10	177.4	93.2	2.55	1.42	53	0.00	1.33
1-1	5	168.3	1.1	1.8	6.3	1.07	192.8	99.7	2.78	1.55	58	0.00	1.45
1-1	6	167.2	1.0	1.6	5.7	1.06	210.4	106.4	3.04	1.70	64	0.00	1.59

Stage	NDP psi
1-1	85.7

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	110.00	gpm
HP Pump flow:	314.3	gpm	Raw water flow:	314.3	gpm
Feed pressure:	174.0	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.8	H2SO4	Flux decline % per year:	7.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	7.3	gfd	Feed type:	Wastewater	

****
**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***
****

Concentrate saturation of SiO2 too high (129%)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
8.0 inches	75 gpm (283.9 lpm)	12 gpm (45.4 lpm)
8.0 inches(Full Fit)	75 gpm (283.9 lpm)	30 gpm (113.6 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor.
Without scale inhibitor, concentrate saturation should not exceed 100%.

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	JA				
Project name:	AECOM		Permeate flow:	1771.00	gpm
HP Pump flow:	2083.5	gpm	Raw water flow:	2083.5	gpm
			Permeate throttling(1st st.)	10.0	psi
Feed pressure:	132.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	27.0	C(81F)			
Feed water pH:	6.70		Element age:	3.0	years
Chem dose, ppm (100%):	62.6	H2SO4	Flux decline % per year:	15.2	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	psi	Element Type	Elem. No.	Array
1-1	1344.1	37.2	13.2	12.3	1.20	124.7	10.0	ESPA2-LD	392	56x7
1-2	426.9	28.4	12.0	8.4	1.12	116.3	0.0	ESPA2-LD	182	26x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	77.0	192.0	77.0	192.0	0.907	2.3	508.2	1267.3
Mg	43.0	177.0	43.0	177.0	0.506	2.1	283.8	1167.9
Na	248.0	539.1	248.0	539.1	13.765	29.9	1575.3	3424.6
K	13.0	16.7	13.0	16.7	0.897	1.1	81.6	104.6
NH4	0.3	0.8	0.3	0.8	0.021	0.1	1.9	5.2
Ba	0.030	0.0	0.030	0.0	0.000	0.0	0.2	0.1
Sr	0.110	0.1	0.110	0.1	0.001	0.0	0.7	0.8
CO3	0.3	0.5	0.1	0.1	0.000	0.0	0.4	0.7
HCO3	355.0	291.0	277.5	227.5	15.710	12.9	1761.2	1443.6
SO4	40.0	41.7	101.3	105.6	0.819	0.9	671.0	699.0
Cl	408.0	575.5	408.0	575.5	13.010	18.4	2646.3	3732.4
F	0.7	1.8	0.7	1.8	0.044	0.1	4.4	11.6
NO3	19.0	15.3	19.0	15.3	4.068	3.3	103.6	83.6
B	0.00		0.00		0.000		0.00	
SiO2	12.0		12.0		0.36		77.94	
CO2	32.92		93.95		93.95		93.95	
TDS	1216.5		1200.1		50.1		7716.6	
pH	7.20		6.70		5.42		7.38	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	1%	2%	20%
SrSO4 / Ksp * 100:	0%	0%	2%
BaSO4 / Ksp * 100:	34%	84%	732%
SiO2 saturation:	9%	9%	60%
Langelier Saturation Index	0.07	-0.54	1.70
Stiff & Davis Saturation Index	0.11	-0.50	1.34
Ionic strength	0.02	0.02	0.15
Osmotic pressure	11.8 psi	11.4 psi	73.0 psi

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	JA				
Project name:	AECOM		Permeate flow:	1771.00	gpm
HP Pump flow:	2083.5	gpm	Raw water flow:	2083.5	gpm
			Permeate throttling(1st st.)	10.0	psi
Feed pressure:	132.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	27.0	C(81F)			
Feed water pH:	6.70		Element age:	3.0	years
Chem dose, ppm (100%):	62.6	H2SO4	Flux decline % per year:	15.2	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1344.1	37.2	13.2	12.3	1.20	124.7	10.0	ESPA2-LD	392	56x7
1-2	426.9	28.4	12.0	8.4	1.12	116.3	0.0	ESPA2-LD	182	26x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Ca	Mg	Cl	B	SiO2
									Cumulative Perm Ion levels				
1-1	1	132.4	1.8	3.8	13.7	1.10	11.3	12.7	0.15	0.08	3	0.00	0.08
1-1	2	130.6	1.5	3.7	13.3	1.11	12.0	14.2	0.17	0.09	4	0.00	0.08
1-1	3	129.1	1.3	3.6	12.9	1.12	13.1	16.1	0.18	0.10	4	0.00	0.09
1-1	4	127.8	1.1	3.5	12.4	1.14	14.5	18.6	0.21	0.11	4	0.00	0.10
1-1	5	126.8	0.9	3.3	12.0	1.15	16.4	21.7	0.23	0.13	5	0.00	0.12
1-1	6	125.9	0.7	3.2	11.4	1.17	18.9	25.9	0.27	0.15	6	0.00	0.13
1-1	7	125.2	0.5	3.0	10.7	1.20	22.3	31.6	0.32	0.18	7	0.00	0.16
1-2	1	121.7	1.2	3.0	10.8	1.10	24.2	35.6	0.34	0.19	7	0.00	0.17
1-2	2	120.5	1.0	2.8	10.1	1.10	26.8	39.9	0.38	0.21	8	0.00	0.19
1-2	3	119.5	0.9	2.6	9.4	1.10	30.0	45.0	0.43	0.24	9	0.00	0.21
1-2	4	118.6	0.7	2.4	8.6	1.12	34.0	50.8	0.49	0.27	10	0.00	0.24
1-2	5	117.9	0.6	2.1	7.7	1.12	39.0	57.5	0.56	0.31	12	0.00	0.28
1-2	6	117.2	0.5	1.9	6.7	1.10	44.6	64.9	0.64	0.36	13	0.00	0.32
1-2	7	116.7	0.4	1.6	5.7	1.10	51.2	72.9	0.74	0.41	16	0.00	0.36

Stage	NDP psi
1-1	97.5
1-2	69.1

BASIC DESIGN

RO program licensed to:					
Calculation created by:	JA				
Project name:	AECOM		Permeate flow:	1771.00	gpm
HP Pump flow:	2083.5	gpm	Raw water flow:	2083.5	gpm
Feed pressure:	193.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.00		Element age:	3.0	years
Chem dose, ppm (100%):	25.3	H2SO4	Flux decline % per year:	15.2	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	10.0	
Average flux rate:	11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1308.2	37.2	13.8	12.0	1.20	185.6	0.0	ESPA2-LD	392	56x7
1-2	462.8	29.8	12.0	9.2	1.15	176.7	0.0	ESPA2-LD	182	26x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	77.0	192.0	77.0	192.0	0.499	1.2	510.5	1273.1
Mg	43.0	177.0	43.0	177.0	0.278	1.1	285.1	1173.2
Na	248.0	539.1	248.0	539.1	7.633	16.6	1610.1	3500.2
K	13.0	16.7	13.0	16.7	0.499	0.6	83.8	107.5
NH4	0.3	0.8	0.3	0.8	0.012	0.0	1.9	5.4
Ba	0.030	0.0	0.030	0.0	0.000	0.0	0.2	0.1
Sr	0.110	0.1	0.110	0.1	0.001	0.0	0.7	0.8
CO3	0.3	0.5	0.1	0.2	0.000	0.0	0.7	1.1
HCO3	355.0	291.0	323.6	265.3	9.646	7.9	2103.0	1723.8
SO4	40.0	41.7	64.8	67.5	0.272	0.3	430.6	448.6
Cl	408.0	575.5	408.0	575.5	6.807	9.6	2681.4	3782.0
F	0.7	1.8	0.7	1.8	0.023	0.1	4.5	11.9
NO3	19.0	15.3	19.0	15.3	2.237	1.8	114.0	91.9
B	0.00		0.00		0.000		0.00	
SiO2	12.0		12.0		0.19		78.90	
CO2	43.95		73.31		73.31		73.31	
TDS	1216.5		1209.7		28.1		7905.5	
pH	7.20		7.00		5.45		7.69	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	1%	1%	15%
SrSO4 / Ksp * 100:	0%	0%	1%
BaSO4 / Ksp * 100:	34%	54%	473%
SiO2 saturation:	13%	13%	80%
Langelier Saturation Index	-0.32	-0.56	1.70
Stiff & Davis Saturation Index	-0.40	-0.64	1.36
Ionic strength	0.02	0.02	0.15
Osmotic pressure	11.1 psi	11.0 psi	71.5 psi

BASIC DESIGN

RO program licensed to:						
Calculation created by:	JA					
Project name:	AECOM			Permeate flow:	1771.00	gpm
HP Pump flow:		2083.5	gpm	Raw water flow:	2083.5	gpm
Feed pressure:		193.4	psi	Permeate recovery:	85.0	%
Feedwater Temperature:		9.0	C(48F)			
Feed water pH:		7.00		Element age:	3.0	years
Chem dose, ppm (100%):		25.3	H2SO4	Flux decline % per year:	15.2	
				Fouling Factor	0.61	
				Salt passage increase, %/yr:	10.0	
Average flux rate:		11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1308.2	37.2	13.8	12.0	1.20	185.6	0.0	ESPA2-LD	392	56x7
1-2	462.8	29.8	12.0	9.2	1.15	176.7	0.0	ESPA2-LD	182	26x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels Ca	Mg	Cl	B	SiO2
1-1	1	193.4	1.8	3.5	12.7	1.09	7.2	12.1	0.09	0.05	2	0.00	0.05
1-1	2	191.6	1.5	3.5	12.5	1.10	7.5	13.5	0.10	0.06	2	0.00	0.05
1-1	3	190.1	1.3	3.4	12.3	1.11	8.1	15.2	0.11	0.06	2	0.00	0.05
1-1	4	188.8	1.1	3.4	12.1	1.13	8.9	17.4	0.12	0.07	3	0.00	0.06
1-1	5	187.7	0.9	3.3	11.8	1.15	9.9	20.2	0.13	0.07	3	0.00	0.07
1-1	6	186.8	0.7	3.2	11.5	1.17	11.2	23.9	0.15	0.08	3	0.00	0.08
1-1	7	186.1	0.6	3.1	11.1	1.20	13.0	29.2	0.18	0.10	4	0.00	0.09
1-2	1	182.6	1.3	2.9	10.5	1.10	14.0	32.5	0.20	0.11	4	0.00	0.10
1-2	2	181.2	1.1	2.8	10.1	1.10	15.4	36.2	0.21	0.12	5	0.00	0.11
1-2	3	180.1	1.0	2.7	9.7	1.11	17.1	40.7	0.24	0.13	5	0.00	0.12
1-2	4	179.2	0.8	2.6	9.3	1.12	19.2	46.2	0.27	0.15	6	0.00	0.13
1-2	5	178.4	0.7	2.4	8.8	1.13	21.8	52.9	0.30	0.17	6	0.00	0.15
1-2	6	177.7	0.5	2.3	8.2	1.14	24.9	61.2	0.34	0.19	7	0.00	0.17
1-2	7	177.2	0.4	2.1	7.4	1.15	28.6	71.5	0.39	0.22	8	0.00	0.19

Stage	NDP psi
1-1	169.7
1-2	131.3

Vanorman, Eric

From: Cohoon, Kevin L <kevin.cohoon@evoqua.com>
Sent: Friday, December 12, 2014 12:27 PM
To: Vanorman, Eric
Cc: Pugh, Lucy B.; Gerald Alexander
Subject: RE: Softening and Chloride Removal (2)

Hi Eric,

Below is the e-mail I had received from Jerry. I do not know if he had a drawing. My understanding was he estimated the area required for basically the primary RO system. I hope this helps clarify. Thanks!

I have made a very crude attempt to determine the footprint for the equipment I described in my previous email. First, my footprint does not include the UF system and its auxiliary equipment. Also, the footprint does not include the UF filtrate tank and its transfer pumps nor the brine recovery tank and its transfer pumps. I estimate the balance of the equipment will require a footprint of approximately 80 feet wide by 250 feet long.

Kevin Cohoon
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NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 12, 2014 10:14 AM
To: Cohoon, Kevin L
Cc: Pugh, Lucy B.; Gerald Alexander
Subject: RE: Softening and Chloride Removal

Gerald:

You had mentioned that you had a sketch showing the RO equipment sizing/layout. Is that something which you could forward to me? I thought Kevin had it and was going to forward but it looks like he is on vacation. We are laying out a preliminary conceptual site plan and would like to incorporate this information.

Thanks,

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From: Vanorman, Eric
Sent: Friday, December 12, 2014 9:29 AM
To: 'Cohoon, Kevin L'
Cc: Pugh, Lucy B.; Gerald Alexander
Subject: RE: Softening and Chloride Removal

Hi Kevin:

Thanks for the feedback on the questions. As you suggest we may want to setup a conference call to discuss a few things.

With regards to softening on the production side of things I agree that CLS for individual wells is likely not a good approach due to the number of wells and the solids handling issues. However, please pull together a membrane softening option which can produce approximately 2.6 MGD of blended, softened water. Assume two units combined would be required to accomplish this. It is assumed that the reject from this system could be discharged to the sanitary, minimizing the overall foot print and processes at each site. An estimate on the % reject would be a key piece of information as well.

With regards to a centralized location there are significant hurdles which would need to be addressed, but the client has asked that we put a number to it. For this option either CLS or membranes could be evaluated based on which would be the most cost effective. If you could provide some rough equipment selections, sizing and pricing on a system that can produce in the neighborhood of 50 MGD it would be much appreciated.

Please let me know if you want to discuss.

Thanks,

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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Wednesday, December 10, 2014 5:06 PM
To: Vanorman, Eric
Cc: Pugh, Lucy B.; Gerald Alexander; Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Hi Eric,

Concerning the first bullet, they could take the RO concentrate from the primary RO and treat it with a conventional silica removal precipitator, and pressure filters before sending it to the brine recovery RO. It should be noted there is no reason to drive the silica to the lowest possible value since it would consume chemicals and create sludge with no payback. The silica end point would be determined by the desired recovery of the brine recovery RO. As mentioned, to do this would use a lot of chemicals, require a large amount of dewatering equipment, and generate a large amount of sludge to dispose of. So we are unsure I there would be any benefit from doing this.

Concerning the second bullet, there is no alternative to chloramines that we are aware of that would be effective in controlling bio-fouling of the RO membranes without damaging them. We are not talking about a large quantity of chloramines as the target is 2-4 ppm. The ammonia should be dosed to the water to achieve a 3:1 or 4:1 ratio of chlorine to nitrogen. For 2.5 mg/L of chlorine, the operator should dose the ammonium sulfate or ammonium chloride to achieve 0.83 mg/L of total ammonia. The actual dosage will depend on the type of ammonia compound used. I would move the addition of the chloramine after the UF and ahead of the primary RO.

Concerning the third bullet, the UF is capable of operating at varying rates while the RO is a constant rate machine so it must be run at the design rate or shut down. We believe they will simply modulate the feed pressure to obtain the desired flow rate. I'm not sure if they have a minimum flow rate but I assume it would be quite low. The five RO trains would be either on or off depending upon the downstream demand. With the wide and variable demand, it will result in units operating in a continuous on/off mode. Actually this could require the addition of a UF permeate tank to accept the RO off-spec water to avoid dumping it to drain. The five RO trains would be cycled to ensure they do not remain out of service for an extended period of time. We may want to discuss this issue.

In response to the last point, there are a couple options for treating the well water: RO or cold lime softening (CLS). RO would require balancing the hardness of the permeate to make sure the water is not too aggressive. To do a partial treat and blend will be difficult because of the number of wells and any variances in the well water quality.

For CLS, it is possible, but would generate a tremendous amount of sludge and require a lot of dewatering equipment.

In our previous discussions, I did not think a centralized treatment location was an option because there are a number of wells owned by multiple companies. We can discuss these options further though, if you feel it may be workable.

Hope this helps. Thanks!

Kevin Cohoon
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NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Tuesday, December 09, 2014 10:59 AM
To: Cohoon, Kevin L
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Hi Kevin:

I have a few follow-up items to yesterday's conversation:

- Please provide a recommendation (sizing & equipment foot print) and pricing for softening of the recovery RO stream. It's is limiting for the evaporator process and we need to evaluate the cost of the system vs the reduced effectiveness of the evaporator process.
- We understand the effectiveness of the chloramines in the RO process for water reuse. However, the WWTP is looking at the possibility of stringent new nitrogen values TN <3 mg/L. What is the expected nitrogen contribution as part of this process and what alternatives are available to chloramines?
- With regards to reduced production could you provide a better description and limitation of how units would be put in standby or off-line status. By standby I am assuming the units are potentially recirculating (under reduced power) without generating permeate and could be brought back on-line quickly. By off-line I am seeing the units as off and able to remain in this status indefinitely. The flow requirements for this system are highly variable and could range from 0 to 15 MGD on any given day we need to make sure we understand the

operational limitations of this system. Are there other similar systems which Evoqua has in service which operate in this manner?

On another note I still have the alternate of softening on the production side which I need information on. As indicated in the initial 10/12 email we are looking at the option of treatment at individual wells. The target value for each well is 1.5 MGD firm capacity, so two 1.5 MGD units would be ideal. The other option is centralized treatment in which we would be looking at softening 50 MGD firm capacity. Please provide information on options for these systems as soon as possible.

Let me know if you have any questions.

Thanks,

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From: Vanorman, Eric
Sent: Monday, December 08, 2014 9:35 AM
To: 'Cohoon, Kevin L'
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Kevin:

Thanks for the information! I took a quick look through it and will begin going through in more detail. A couple initial comments:

- It does not appear that the UF system sizing, details or pricing (including operating cost) is included in the budget proposal. Is this correct?
- The capital cost for both the base RO and the recovery RO state "described above in Item 1 less b., c., and d." Is this accurate and the wedge wire screens, pressurized UF, UF filtrate tank, brine recovery transfer pumps, recovery acid and anti-scalant feed systems are excluded from the scope of supply?
- It appears you are proposing 5 trains for both the RO and recovery RO to meet the design flow. We will likely look to add a sixth train to meet the firm capacity with one train out of service. How does this impact price? *6/5?
- 5 trains +1 standby should be acceptable provided there is enough turndown on the system. There may be times when they are running just one skid at a flow of <1 MGD through the system. Can the system be turned down to this level? Would it be efficient to run at this level or would smaller skids be more appropriate?
- We are thinking that the UF permeate/RO feed buffer tanks will likely be concrete.
    - Is there enough pressure from the UF to place these tanks above grade, if desired, without additional pumping of the permeate?
    - We would expect to have two buffer tanks in parallel so that one tank can be taken out of service for cleaning, repairs, etc… if needed. I envision common discharge and suction header from the UF and feeding the RO respectively. What size buffer tank is recommended between the UF and RO process?
- Similar question to above with regards to RO/Recovery RO buffer tanks.
- What, if any additional, tanks would be required for such things as permeate retention for CIP or backwashing? Capacities?

- Would you propose common CIP systems or CIPs dedicated to each train.
- Hardness is not a limiting factor for recovery? Would the recovery RO benefit from a softening system upstream? It appears it may be limiting if we take the recovery RO concentrate to an evaporator.
- Are there any additional treatment requirements upstream of the UF unit? Granular media filtration, carbon…..? or will the MF be sufficient given the water quality data?
- We need to pull together some conceptual layouts. Any cut sheets of the UF and RO systems, CIP, ancillary equipment would be helpful. At a minimum we would need some maximum foot print dimensions for the various equipment items.

I'm available to talk if you want to discuss or have any questions.

Thanks,

Eric Van Orman, P.E.
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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Sunday, December 07, 2014 1:39 PM
To: Vanorman, Eric
Cc: Pugh, Lucy B.; Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Hi Eric,

I apologize for the delay in responding to your request. I will be sending a couple e-mails with information regarding this project. Attached is a conceptual proposal, which includes an equipment list and budget price, along with estimated operating costs. I am also including the projections for your reference.

In addition to the Paper on the Pebble Beach wastewater reclamation I sent earlier, I will forward you various information on Memcor's experience in reclaiming municipal wastewater in a separate email. The Memcor information still contains reference to Siemens, so please disregard this. The one attachment that is the most comprehensive was prepared by the Memcor Australia concentrates on their experience so it does not mention most of the activities in the USA. Bottom line is we have more experience and knowhow than any other organization.

The proposed design is based upon a feedwater flow rate of 15 MGD. We assumed the UF would operate at a recovery of 95% which should be very conservative based upon my experience. This may be increased by 2-3% but we thought we should be conservative in the absence of input from Memcor at this time. The RO recovery will be limited by the state of the metals (iron, manganese, and aluminum) that are reported in the wastewater. The wastewater data presented would infer the metals that are given are soluble which is what we assumed so there would be no reduction in its content as a result of filtration by the UF. Also, some of the metals (aluminum and iron) are reported as less than. In our evaluation, we used the less than as the actual value so if the actual value is less, the recovery can be increased without risk. The only other item that requires clarification concerns silica. The wastewater analysis indicates 12 ppm silica unfiltered and 8.5 ppm silica filtered. We used the 8.5 ppm value in the projections assuming there is 3.5 ppm of colloidal silica that the UF will remove.

The primary RO has been designed for a recovery of 85% which could be subject to change once we get more information. The limiting factor for the brine recovery RO is silica. Using the 8.5 ppm silica value and the coldest water temperature of 9 deg C which would result in the lowest silica solubility. In addition, the pH of the water will also impact silica solubility with a pH of about 7 resulting in the lowest solubility. Increasing the pH will increase its solubility as will lowering it although to a much lesser degree. If silica is the limiting factor for recovery, they may wish to include provisions for increasing the temperature of the wastewater. I ran projections for 9 and 27 deg C. At 9 deg C the recovery of the primary RO concentrate will only be about 35% whereas at 27 deg C it will be in the range of 50%.

The industry accepted practice for treating municipal secondary wastewater is to include provisions for the presence of chloramine to minimize RO bio-fouling. If the wastewater contains ammonia, the chloramines can be produced by the simple addition of chlorine. In this case there is no ammonia present so we must add ammonium hydroxide. We have assumed the wastewater will have adequate pressure to eliminate the need to provide UF feed pumps. The chemical addition ahead of the primary RO will consist of an acid feeder and an anti-scalant feeder. In sizing the primary RO, we arbitrarily used five (5) 20 % trains as well as for the brine recovery ROs.

I am attaching the following supporting documentation for your use:

- Primary Hydranautics RO Projection for a single RO train at 9 deg C and an Avista report with projected solubilities.
- Primary Hydranautics RO Projection for a single RO train at 27 deg C and an Avista report with projected solubilities.
- Brine Recovery Hydranautics RO projection for a single RO train at 9 deg C and an Avista report with projected solubilities.
- Brine Recovery Hydranautics RO Projection for a single RO train at 27 deg C and an Avista report with projected solubilities.

Please review and let us know if you have any questions. We should be available to discuss early this week before your meeting, if needed.

Thanks!

Kevin Cohoon
Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Wednesday, December 03, 2014 4:55 PM
To: Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Kevin:

Thanks for the update! If you happen to have any P&ID's for some of those other facilities it would be great to take a peek at them. It may help as we give thought to module layout, train configuration, etc….

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490

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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Wednesday, December 03, 2014 9:25 AM
To: Vanorman, Eric
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Hi Eric and Lucy,

I was able to get Jerry Alexander to assist with putting this together. He is retired from Evoqua but still does contract work.

We have done a number of projects like this over the years. The famous "Toilet to Tap" project in Orange County (LA). And the project in Singapore taking WW to drinking water. This will be a similar approach and Jerry is very familiar with these types of projects.

I'll keep you updated and pass any info along as I get it. Thanks!

Kevin Cohoon
Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Tuesday, December 02, 2014 2:29 PM
To: Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Kevin:

I had also mentioned that the treatment capability of the wastewater effluent RO option maybe refined. We have refined the firm design capacity to 15 MGD (down from the 26.4 MGD previously provided). Likely this only impacts the final number of trains and the subsequent recovery systems. Please let me know if you have any questions.

Thanks,

Eric Van Orman, P.E.
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From: Vanorman, Eric
Sent: Tuesday, December 02, 2014 11:52 AM
To: 'Cohoon, Kevin L'
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Hi Kevin:

Hope you had a good Thanksgiving!

By next Tuesday (12/9) morning we are supposed to have process flow diagrams, equipment lists, layouts and other conceptual design information pulled together for the various options and in the owners hands. Is there any way conceptual information, to support this effort, can be in my hands by **Thursday (12/4)** so that we can begin to develop these documents?

Thanks,

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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Tuesday, November 25, 2014 12:51 PM
To: Vanorman, Eric
Subject: RE: Softening and Chloride Removal

Hi Eric,

I finally was able to pin down our AE group on getting some info for you on this. Unfortunately it will be a few weeks because of the holidays and significant amount of projects we are working on. Would this be acceptable?

I apologize for the delay. Thanks!

Kevin Cohoon
Industrial Capital Sales
Evoqua Water Technologies LLC
317-557-8395
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Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Monday, November 10, 2014 3:25 PM
To: Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Hi Kevin:

Just looking for an update on the status of all this.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
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From: Vanorman, Eric
Sent: Friday, October 31, 2014 1:25 PM
To: 'Cohoon, Kevin L'
Subject: RE: Softening and Chloride Removal

Hi Kevin:

Thanks for the update. Treating effluent at the plant is the primary direction which we have received from the client and was our original scope. However, they also wanted us to look at the source side and the softening options. While the softening has a lot of benefits it also has many draw backs, including:

- Major infrastructure improvements for centralized softening.
- Numerous wells around 40 for softening at well heads
- Producing more water (which also needs to be treated at the WW plant) to account for softening reject
- Requirement to treat essentially all of the potable water rather than just a percentage of the wastewater

While we need costs on the softening to compare against chloride removal at the WWTP our main alternate will be removal of chloride at the WWTP effluent. I'm not saying one way or the other that this is the "best" approach but it is the direction which we have been given.

Please let me know if you have any questions or require more clarification.

Thanks,

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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Friday, October 31, 2014 12:44 PM
To: Vanorman, Eric
Subject: RE: Softening and Chloride Removal

Hi Eric,

We are in the process of reviewing. Based on what I am hearing, they are looking at treating the well water as the best option. But they have not had time to do a thorough review and assessment yet. They plan on spending more time Monday and I should know more.

Thanks!

Kevin Cohoon
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Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, October 31, 2014 11:35 AM
To: Cohoon, Kevin L
Subject: RE: Softening and Chloride Removal

Kevin:

Just following up on this to find out the status. Please let me know if you have any questions or would like to discuss.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
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eric.vanorman@aecom.com

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From: Vanorman, Eric
Sent: Thursday, October 23, 2014 1:53 PM
To: 'Cohoon, Kevin L'
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

The issue is going to be dealing with the reject ☺

Eric Van Orman, P.E.
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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Thursday, October 23, 2014 1:51 PM
To: Vanorman, Eric

Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Thanks Eric,

That is what I was looking for. Just didn't want to focus on chloride and find out we create another issue.

Kevin Cohoon
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317-557-8395
NEW E-MAIL ADDRESS
Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Thursday, October 23, 2014 1:49 PM
To: Cohoon, Kevin L
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Hi Kevin:

The constituent of concern is the chloride. As the flow sheet shows we are assuming 95% chloride removal across the treatment system and looking for a target blended (treated and untreated) effluent of 300 mg/L chloride.

pH limit 6.0 to 9.0

Does this answer your question or am I missing something?

Thanks,

Eric Van Orman, P.E.
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From: Cohoon, Kevin L [mailto:kevin.cohoon@evoqua.com]
Sent: Thursday, October 23, 2014 1:39 PM
To: Vanorman, Eric
Cc: Pugh, Lucy B.
Subject: RE: Softening and Chloride Removal

Hi Eric,

I am getting the process started here to review the info.

Can you tell me any effluent limits (ppm) for chloride, TDS, etc? Or numbers to design to. THansk!

Kevin Cohoon

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Kevin.cohoon@evoqua.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Thursday, October 23, 2014 9:29 AM
To: Cohoon, Kevin L
Cc: Pugh, Lucy B.
Subject: Softening and Chloride Removal

Kevin:

Per out discussion we are working with a Wisconsin municipality to reduce chloride in their wastewater effluent. We are looking at two main scenarios to reduce chloride with multiple treatment alternatives under each scenario. They are summarized as follows:

1. Softening of Source Water (residential water softeners contribute the majority of the chloride to the system. Softened source water will provide the opportunity for removal of these residential softeners and associated chloride inputs).
    a. Membrane Softening - assume reject streams can be discharged to the sanitary sewer
    b. Lime Softening

   Source water softening at a combined location shall be evaluated as a well as softening at individual wells. Assume that blending will be utilized to achieve acceptable water quality for distribution to the municipal system. For softening at individual wells pretreatment may need to include iron and manganese removal (up to Iron 0.56 mg/L and Manganese 49.6 ug/L). Please include Iron and Manganese removal as an optional adder as some wells will not require this.

   Attached is a Basis of Design for the well source blended water quality. We are still working on finalizing flows for both the centralized and individual well flow sizing. I'll follow up with flows once they are finalized, but wanted to get you the water quality data so you could start thinking about it. As a starting point average day flows for the centralized treatment would likely be in the 50 MGD range and average day flows for the individual well treatment would likely be in the range of 1.5 MGD for an average day. We'll have to add peaking factors on these to get the true capacity of the softening systems. The ultimate design flows are the required water sent to distribution. Please provide a reject or waste stream rate so an estimate of pumped raw water can be determined.

2. Chloride removal at the wastewater treatment plant.
    a. Reverse Osmosis
    b. Ion Exchange

   RO (and possibly the IE) reject stream will need to be minimized. Provide a recommendation based on water quality for concentration of the waste stream which may include additional MF/RO, softening & MF/RO or others. In addition, AECOM will be reviewing evaporation and concentrator/crystallizer options for further brine reduction. If you could provide contact information for working partners which could provide details on these additional technologies it would be appreciated.

   See the attached Basis of Design Water Quality and Flow Data at the wastewater treatment plant. The water quality which will be seen by the chloride removal equipment is the effluent data as the equipment will be installed just prior to the disinfection step. The design Flow Rate shall be 26.4 MGD to meet the 2030 design condition. We are shooting for 95% chloride removal. Ideally the equipment can be partially off line or turned down as current average conditions only require 46.2% of the chloride treatment design capacity as shown. Flow rates required for treatment are even further reduced under high flow conditions at the plant.

Ultimately we will be looking for the following information for the above options:

- Equipment capital cost delivered to the site for main treatment and ancillary equipment Provide a general break out of the various equipment components.
- Equipment list including pretreatment recommendations
- Equipment sizes (capacity and foot prints)
- Materials of construction
- Anticipated labor required for operation
- Electrical consumption
- Natural gas consumption
- Chemical usage
- Consumables (membranes/media/etc.)
- Anticipated waste stream volume
- Maintenance costs/labor

The attached Basis of Design data sheets are for the softening option as well as the chloride removal at the treatment plant option. Please don't hesitate to contact me with any questions or if you would like to discuss in more detail.

Thanks,

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Newterra (Koch) - UF

Vanorman, Eric

From:	Jordan, James <jtjordan@kochmembrane.com>
Sent:	Thursday, November 06, 2014 2:12 PM
To:	Vanorman, Eric
Cc:	Harry Cummings (hcummings@newterra.com); Blake, Melanie
Subject:	WI WWT Chloride Project
Attachments:	AECOM-WI OPEX.pdf; MP Puron Brochure 10-14.pdf; MP puron data sheet 10-14.pdf; MP Puron Study 10-14.pdf

Eric:

Please find attached OPEX for UF portion of the WWTP WI project. We have budgeted for 5 trains of 6 Racks (71 membranes/Rack) each.

PURON® MP Budget capital price: $2.4m/train, total $12m.

Estimate 7 year life on the membranes.

Please contact us if you need additional information.

Thanks,

Tim

Mr. Tim Jordan
Koch Membrane Systems, Inc.
Midwest Regional Sales Manager
850 Main
Wilmington, MA 01887
O: 248-788-0502
C: 734-604-2268
http://www.kochmembrane.com/Water-Wastewater.aspx

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MEMBRANE SYSTEMS
A Koch Chemical Technology Group, LLC Company

Internal Memorandum

From: Melanie Blake

Date: November 6, 2014

Subject: **KMS PURON® MP OPERATING COSTS SUMMARY**

Design Criteria

The KMS PURON® MP system proposed for the AECOM Grand Rapids project will treat 26.4 MGD feed of tertiary wastewater. The ultrafiltration design is for 5 trains, each containing 6 x MP80/71 units for a total of 2130 PURON® MP cartridges. The OPEX analysis presented in this document is based on an average feed water quality and a temperature of 18 °C.

Membrane System Cleaning Chemical and Power Consumption

Estimates of the cleaning chemical requirements, power consumption and membrane replacement costs for the membrane system are shown in Tables 1, 2 and 3 below.

Table 1: Membrane System Cleaning Chemical Consumption Estimate

Sodium Hypochlorite Usage	**Units**	**OPEX Estimate**
Sodium Hypochlorite Concentration - Maintenance Clean	mg/L	200
Sodium Hypochlorite Clean Frequency - Maintenance Clean	No./yr	365
Sodium Hypochlorite Concentration - Recovery Clean	mg/L	500
Sodium Hypochlorite Clean Frequency - Recovery Clean	No./yr	12
Sodium Hypochlorite Concentration, Stock Solution	%	12.5%
Total Sodium Hypochlorite Consumption Estimate	gal/yr	23,735
Sodium Hypochlorite, 12.5%, Bulk Cost	$/gal	$1
Total Sodium Hypochlorite Annual Cost	**$/yr**	**$23,735**

Citric Acid Usage	**Units**	**OPEX Estimate**
Citric Acid Concentration - Maintenance Clean	mg/L	2,000
Citric Acid Clean Frequency – Maintenance Clean	No./yr	52
Citric Acid Concentration - Recovery Clean	mg/L	5000
Citric Acid Clean Frequency - Recovery Clean	No./yr	12
Citric Acid Concentration, Stock Solution	%	50%
Total Citric Acid Consumption Estimate	gal/yr	10,415
Citric Acid, 50%, Bulk Cost	$/gal	$5
Total Citric Acid Annual Cost	**$/yr**	**$52,065**

Note: Actual chemical consumption may vary depending on wastewater composition. HCl may be used for pH adjustment as required.

Table 2: Membrane System Power Consumption Estimate

UF Feed Pumps	**Units**	**OPEX Estimate**
Average Flow Rate	gpm	12,035
Operational Pressure	psi	23.745
Pump Power Consumption	kWh/year	2,171,175
UF Backflush Pumps		
Average Flow Rate	gpm	1,346
Operational Pressure	psi	38.745
Pump Power Consumption	kWh/year	122,505
UF CIP Pumps		
Average Flow Rate	gpm	808
Operational Pressure	psi	21.745
Pump Power Consumption	kWh/year	43,905
UF Membrane Air Scour Blowers		
Average Air Flow Rate	scfm	465
Operational Pressure	psi	4
Blower Power Consumption	kWh/year	182,325
UF CIP Tank Heater		
Average Flow Rate	gpd	777.5
Temperature Rise	°C	18
Heater Power Consumption	kWh/year	44,975
Total Power Consumption Estimate	kWh/yr	2,564,880
Cost of Power	$/kWh	$0.10
Total Power Annual Cost	**$/yr**	**$256,485**

Table 3: Membrane Replacement Estimate

Membranes	**Units**	**OPEX Estimate**
UF Membrane Life	yr	7
Annual UF Membrane Replacement Cost	$/yr	$3000
Total Annual Cost of Membrane Replacement	**$/yr**	**$912,855**

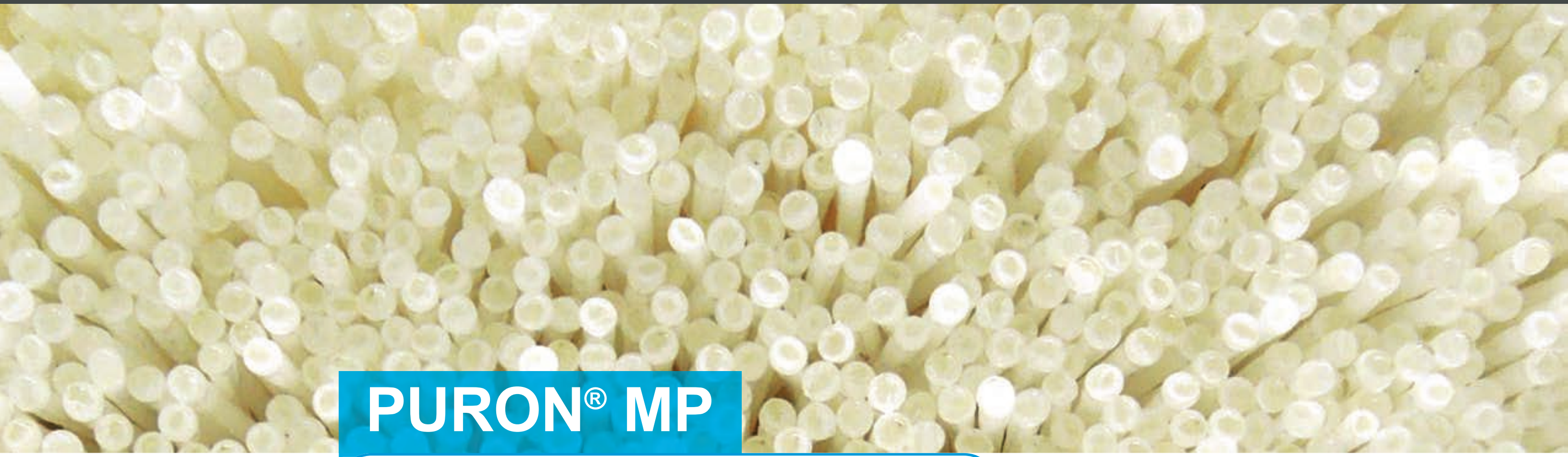
Power and Cleaning Chemicals Present Worth

Table 4 summarizes the overall yearly cost estimates for membrane replacement, power, and cleaning chemicals of the proposed membrane system below.

Table 4: Membrane System Power, Chemicals, and Membrane Replacement Costs

Parameter	Units	Costs
Total Annual Cost of Sodium Hypochlorite	$/yr	$23,735
Total Annual Cost of Citric Acid	$/yr	$52,065
Total Annual Cost of Power	$/yr	$256,485
Total Annual Cost of Membrane Replacement	$/yr	$912,855
Annual Chemical, Power and Membrane Costs	**$/yr**	**$1,245,140**

Water & Wastewater



PURON® MP

Solutions

Hollow Fiber Treatment System for
High Solids Water and Wastewater

KOCH
MEMBRANE SYSTEMS

Market-Driven Solutions

Complete Solids Tolerance Solutions

Koch Membrane Systems offers a wide range of ultrafiltration products to meet any application challenge.

TARGA® II
Up to 50 mg/L

PURON® MP
Up to 250 mg/L

PURON® HF
Up to 2,000 mg/L

PURON® MBR
Up to 15,000 mg/L

ABCOR®
Up to 500,000 mg/L

Meet the new standard in high solids water and wastewater treatment...

The PURON® MP hollow fiber ultrafiltration system is an innovative, cost-effective solution for a variety of water treatment applications.

The PURON MP System Advantage:

AVOID PRETREATMENT – The PURON MP system’s high flux and solids tolerance properties can eliminate the need for costly clarifiers and chemical pretreatments in tough applications.

LESS DOWNTIME – Polyester reinforced membranes and a unique single potting design help to avoid downtime associated with frequent cleaning cycles, sludging and fiber repair.

LESS CHEMICALS – Superior chemistry and a tight pore structure deliver more stable membrane performance without the need for extensive chemical cleans.

EASY **SIMPLE OPERATION –** Minimal system connections, an intelligent user interface and outstanding membrane reliability make PURON MP one of the easiest-running filtration systems available.

$ **SAVE MONEY –** Superior output, simplified operation, reduced maintenance and pretreatment costs and a compact footprint all add up to cost savings for you!

Primary Applications:

Industrial Water Solutions

- Achieves higher recoveries
- Removes suspended and colloidal solids
- Saves space versus conventional treatment

Tertiary Wastewater Treatment

- Can handle clarifier upsets
- Able to tolerate high coagulant doses for Phosphorus removal

Seawater Pre-treatment

- Requires significantly less space
- Longer RO membrane life
- Low overall operating cost

Potable Water Treatment

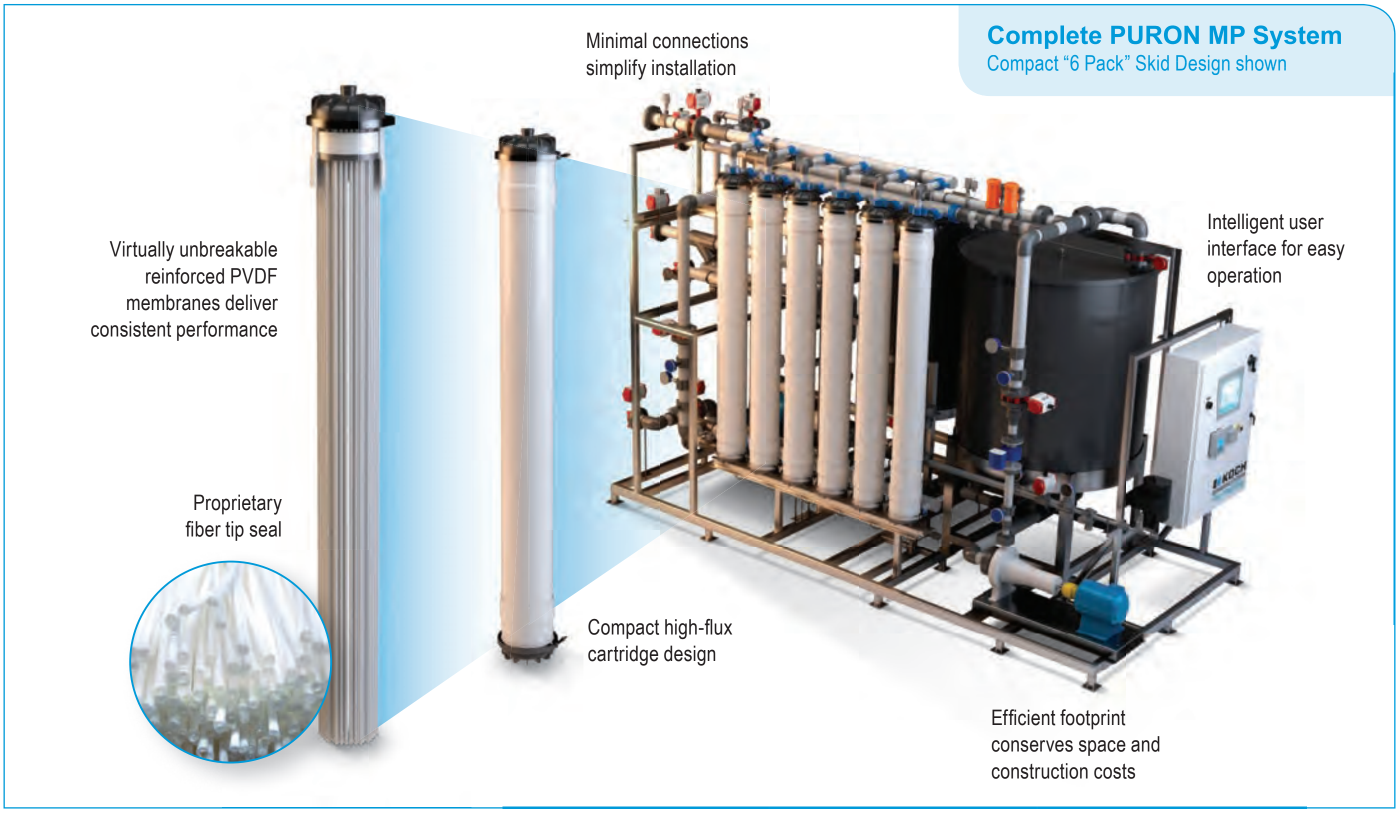
- Greater than 4-log removal of Giardia and Crypto
- Suited for turbid surface waters
- Handles high coagulant doses for TOC/Color removal

Meaningful Product Features

Easily installed and serviced, PURON® MP systems are designed for longevity and performance.

Whether it's one of our packaged plants or a custom-designed solution, the PURON MP system offers robust engineering and reliable operation in a fully scalable filtration system ranging from 6 to 64 high-output UF cartridges.

The PURON MP System Design



Complete PURON MP System

Compact "6 Pack" Skid Design shown

Minimal connections simplify installation

Virtually unbreakable reinforced PVDF membranes deliver consistent performance

Intelligent user interface for easy operation

Proprietary fiber tip seal

Compact high-flux cartridge design

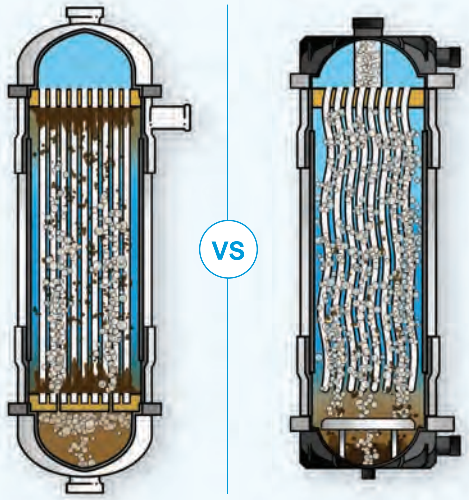
Efficient footprint conserves space and construction costs

A New Configuration in Hollow Fiber Membranes

The unique free fiber construction offers the most effective solids management in the market

Traditional Designs – Potting at Both Ends

Tightly packed dual-header designs restrict fiber movement creating dead zones where solids can accumulate. This "fiber sludging" reduces membrane surface area, system output and energy efficiency.



PURON MP Design – Single Potting

The innovative single-potting design allows the membrane fibers to move freely within the cartridge. This open configuration permits aeration to penetrate the fiber bundle and release filtered solids during air scouring.

The PURON® MP Solution

Our best-in-class designs provide a truly integrated solution, from membrane chemistry and fabrication to process and application design, with dedicated technical support every step of the way.

KMS isn't just a membrane company. The KMS global team of Design Specialists is ready to assist you with:

- Process & System Design
- Project Management
- Mechanical Design
- Start Up and Commisioning
- Global Fabrication
- KMS ASSIST® Service and Maintenance Program

Piloting – Unique solutions are our specialty...

> *Not all process streams are alike. New and specialized applications can benefit from pilot testing to validate system designs.*

Our Process Technology Group stands ready to support those applications that require more process expertise, attention or testing. With a sizeable inventory of pilot systems in our fleet, a unique testing program can be up and running at your facility in a matter of days.

The PURON MP Pilot unit is a skid-mounted, fully automated, and easily installed system.

Contact your local Koch Membrane Systems representative for more information:

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Sao Paulo, Brazil

For complete contact information, visit:

www.kochmembrane.com

KOCH MEMBRANE SYSTEMS®

KOCH MEMBRANE SYSTEMS

PURON® MP HOLLOW FIBER CARTRIDGE

8-inch Ultrafiltration Cartridge for Water and Wastewater Filtration

PRODUCT DESCRIPTION

Membrane Chemistry:	Proprietary PVDF
Membrane Type:	Braided hollow fiber for outside-in operation
Fiber Support Chemistry:	Polyester
Nominal Pore Size:	0.03 µm
Outside Fiber Diameter:	0.1 inch (2.6 mm)
Housing Shell:	PVC
Potting Material:	Proprietary Epoxy Compound
Storage Solution:	Glycerin/Water
Regulatory Status:	Classified by UL to NSF/ANSI Standard 61 and in accordance with NSF/ANSI Standard 372

PRODUCT SPECIFICATIONS

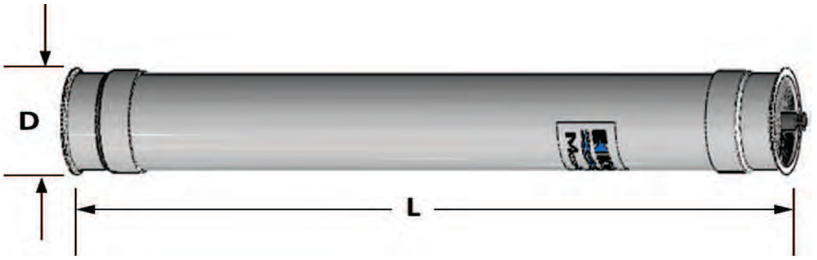
Part Number	Model	Membrane Area [ft^2 (m^2)]	Typical Production Range [gpm (m^3/hr)]
0728000	PURON® MP 8081-102	546 (51)	9 - 30 (2 – 6.8)

OPERATING & DESIGN INFORMATION*

Maximum Pressure (water):	45 psi (3.0 bar) @ 104º F (40º C) or less
Temperature Range:	32º F (0º C) - 104º F (40º C)
Maximum Production Transmembrane Pressure:	25 psi (1.7 bar)
Maximum Backflush Transmembrane Pressure:	10 psi (0.7 bar)
Allowable pH Range:	1.8 – 10.5
Maximum Total Chlorine @ 77º F (25º C) or lower:	1,000 ppm @ pH <10.5
Maximum Air Scour Rate per Cartridge:	9 scfm (15 Nm^3/hr)
Typical Backflush Flow Rate per Cartridge:	19 gpm (4.3 m^3/hr)

* Consult KMS Process Engineering group for specific applications

NOMINAL DIMENSIONS*



Model	D Inches (mm)	L Inches (mm)
PURON® MP 8081-102	8.6 (220)	81 (2060)

* Dimensions are provided for reference only and should not be interpreted as accurate specifications.

CARTRIDGE STORAGE CONDITIONS:

New cartridges are packaged in a glycerin/water solution. The glycerin/water solution should be removed from new cartridges before their initial use with a water rinse followed by a chlorine clean. See the pre-startup cleaning instruction sheet packed with each cartridge shipment for more details. Prior to installation, cartridges should be stored in their original packaging under the following conditions:

- Indoors, out of direct sunlight.
- Temperatures between 50 – 85°F (10 – 30°C).
- Relative humidity below 70%.
- In a horizontal position.

It is best to use new cartridges within one year of shipment. Consult KMS for recommendations for longer term storage.

Used cartridges should be cleaned, rinsed and impregnated before storage using a solution of 80 – 100% glycerin. New cartridge storage conditions should also be used for used cartridges. Used cartridges must be drained, rinsed, and cleaned after storage per the pre-startup cleaning instruction sheet.

CARTRIDGE ASSEMBLY AND COMPONENTS:

Item	Description	Quantity Required
1	PURON® MP Cartridge	1 each
2	8” Seal	2 each
3	8” Clamp	2 each
4	8” Top End Cap	1 each
5	8” Bottom End Cap	1 each
6	Vent Port O-rings	2 each
7	Vent 1½” groove end coupling	1 each

PURON® MP Pass Kit (Items 2-7) Part Number – 1021034

Notes:

- Feed, permeate and vent ports are 1½” groove end couplings
- Air scouring connection is ½” OD tubing

The information contained in this publication is believed to be accurate and reliable, but is not to be construed as implying any warranty or guarantee of performance. We assume no responsibility, obligation or liability for results obtained or damages incurred through the application of the information contained herein. Refer to Standard Terms and Conditions of Sale and Performance Warranty documentation for additional information.

Koch Membrane Systems, Inc., www.kochmembrane.com

Corporate Headquarters: 850 Main Street, Wilmington, Massachusetts 01887-3388, US, Tel. Toll Free: 1-888-677-5624, Telephone: 1-978-694-7000, Fax: 1-978-657-5208
European Headquarters: Koch Chemical Technology Group Ltd., Units 3-6, Frank Foley Way, Stafford ST16 2ST, GB, Telephone: +44-178-527-2500, Fax: +44-178-522-3149

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08/14 Rev. 14-1

Application Bulletin

Water Reuse for Lagoon Wastewater Treatment

KOCH MEMBRANE SYSTEMS®

Highlights

1. Pilot Testing with new Ultrafiltration Product
2. Feed water consisted of high fouling Lagoon wastewater plant effluent with high Total Organic Carbon (TOC) and incomplete nitrification
3. Unit ran through winter with cold feed water
4. TOC reduction was observed with different coagulants including Polyaluminum Chloride (PACl) and Ferric Chloride
6. Phosphorus removal was evaluated with different coagulants and detention times
7. Coagulant dosing was controlled with UV$_{254}$ instrument
8. Demonstrated high coagulant dosing tolerance

Abstract

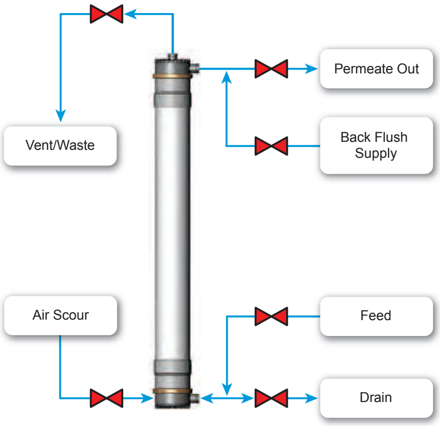
Wastewater reuse has become more important over the years. Ultrafiltration (UF) is a key process in multiple applications of wastewater reuse requiring suspended solids removal including Reverse Osmosis (RO) pretreatment. This poster will discuss the pilot test results of UF treated wastewater effluent from a lagoon wastewater plant in New Hampshire.

Introduction

The pilot used a new pressurized hollow fiber UF cartridge. The membrane cartridge is designed to produce high quality permeate at low fouling rates with difficult feed water. The cartridge design incorporates a single header design with free floating fibers that allow for solids removal during cleaning.

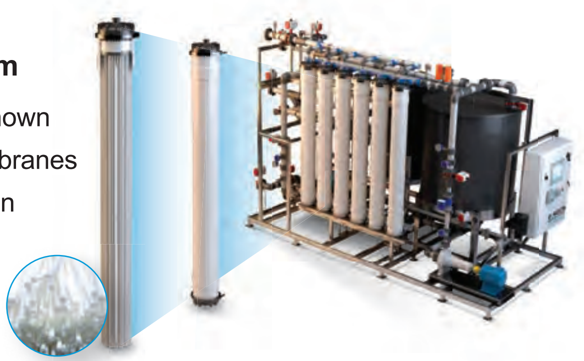
Membrane Area (ft^2/m^2)	546/51
Filtration Type	UltraFiltration
Pore Size (µm)	0.03
pH Range	2-10.5
Maximum Total Chlorine (ppm)	1000
Maximum Transmembrane Pressure (TMP), (psi/bar)	25/1.7

Cartridge Flow



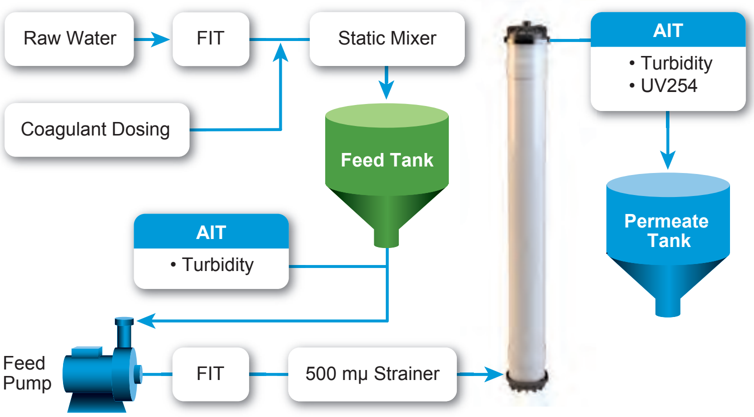
Complete PURON® MP System

- Compact “6 Pack” Skid Design shown
- Virtually unbreakable PVDF membranes
- Compact high-flux cartridge design
- Proprietary Fiber Tip Seal

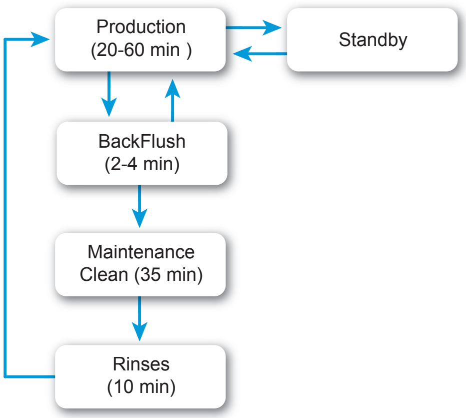


Pilot Setup and Feed Water

System Flow



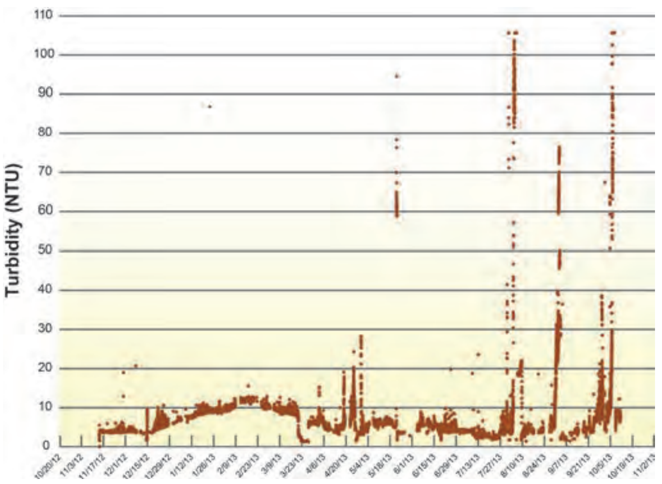
Process Modes



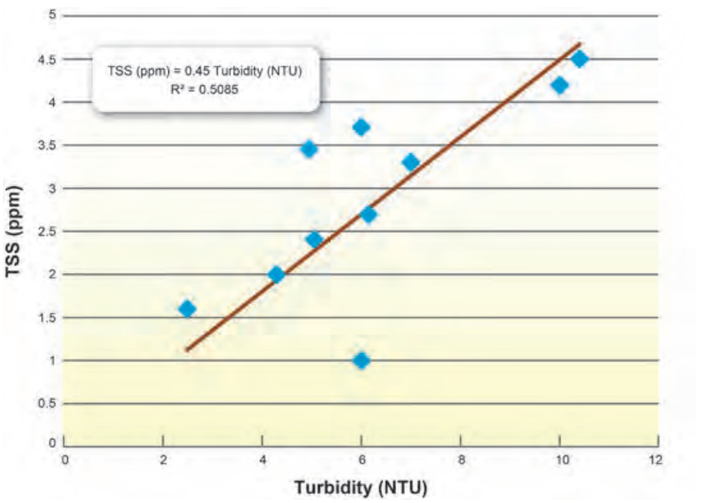
Pilot Feed Water Data (Lagoon Effluent)

Parameter	Min	Average	Max
pH	5.6	7.0	7.9
Turbidity	1	8.1	105
Total Suspended Solids, TSS (ppm)	1.0	3.7	12
Apparent Color (ACU)	48	106	187
UV_{254} (cm^{-1})	0.067	0.21	0.83
TOC (ppm)	12	15	23
Ammonia	2.0	19	29
Hardness (ppm)	60	63	70
Total Iron (ppm)	0.10	1.1	12
Dissolved Iron (ppm)	0.00	0.05	0.3
Total Manganese (ppm)	0.04	0.09	0.1
Dissolved Manganese (ppm)	0.02	0.09	0.1
Aluminum (ppm)	0.00	0.04	0.3
Dissolved Aluminum (ppm)	0.00	0.01	0.2
Total Phosphorus (ppm)	9.2	13	17

Feed Turbidity

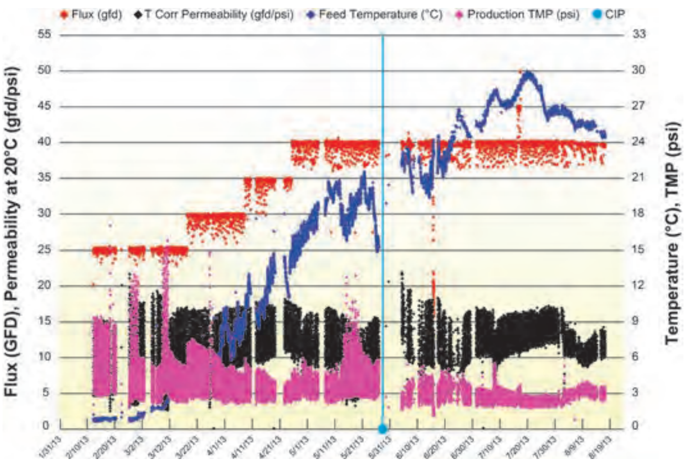


Feed TSS vs.Turbidity

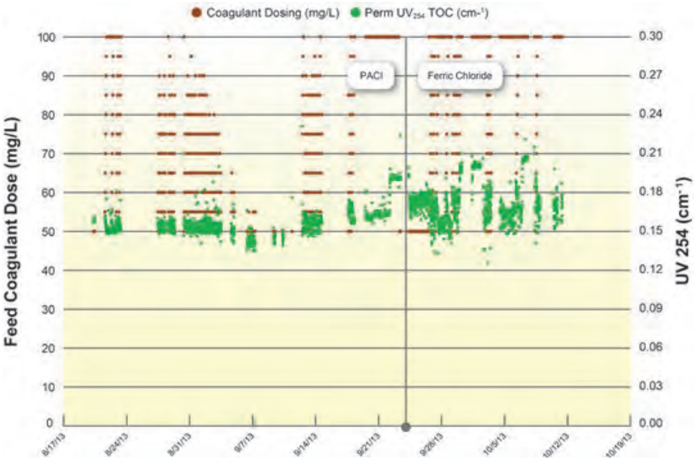


Pilot Results

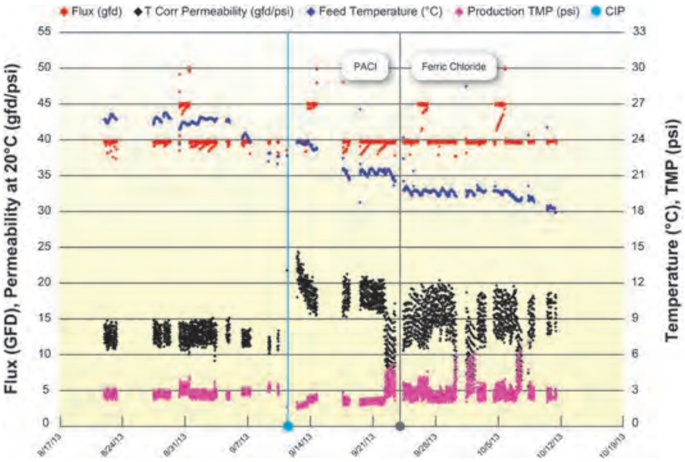
Run with PACl Coagulant



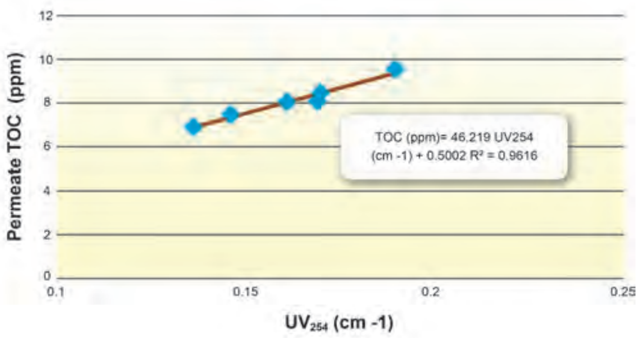
Permeate UV_{254} and Coagulant



Run with PACl & Ferric Chloride Coagulant



Online UV_{254} vs TOC



Permeate Quality

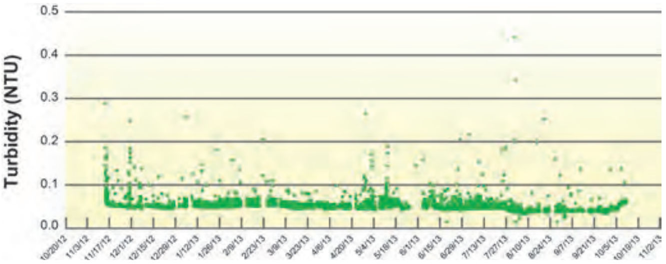
Water Quality

Parameter	Min	Average	Max
Turbidity (NTU)	0.014	0.06	0.7
SDI	0.43	1.2	2.7
True Color (TCU)	9.0	30.3	170.0
UV_{254} (cm^{-1})	0.0	0.11	0.2
pH	4.7	6.4	7.3
Iron (ppm)	0.0	0.0	0.3
TOC (ppm)	6.5	9.6	22.3
Manganese (ppm)	0.0	0.1	0.1
Aluminum (ppm)	0.0	0.0	0.2
Phosphorus (ppm)	0.0	8.7	16.9

Average TOC Reductions

Feed Water Treament	%
With No Coagulant	34
With PACl	40
With Ferric Chloride	42

Permeate Turbidity



Permeate Quality

Phosphorus Removal

Coagulant	Coagulant Dose	Detention Time	Feed Phosphorus (P)	Permeate P	P Removal
	ppm as 100% product	min	ppm	ppm	%
None	NA	NA	10.8	10.1	6.5
PACl	50	3	16.8	11.1	34
PACl	75	3	16.1	10.2	37
PACl	100	3	14.7	8.7	41
PACl	55	10	10.4	8.5	18
PACl	100	10	9.2	2.6	72
Ferric Chloride	50	10	16.2	3.6	78
Ferric Chloride	100	10	11.5	1.95	83
Ferric Chloride	100	10	14.7	1.66	88

Results Summary

- The membrane cartridge was able to consistently produce permeate with very low turbidity and SDI values regardless of the feed water turbidity and TOC values, demonstrating excellent water reuse potential
- The pilot was able to operate with very low temperatures and high feed TOC conditions at 25 gfd with a CIP interval of 30 days
- The pilot was able to operate at 40 gfd with a peak daily flux of 45 gfd and peak hour flux of 50 gfd, with feed water temperatures greater than 20°C and a CIP interval greater than 90 days
- Coagulant dosing resulted in low TMP values and thus lower energy consumption
- Dosing a coagulant resulted in lower permeate TOC values
- Basing the coagulant dosage on a target UV_{254} value produced higher, more consistent quality permeate due to more consistent TOC values
- Ferric chloride dosing resulted in very low permeate Phosphorus values

Potential Applications

- Reverse osmoses pretreatment
- Irrigation
- Industrial water reuse
- Ground Water Recharge
- Reuse or discharge applications focused on the following:
  - Phosphorus reduction
  - TOC reduction
  - Cold source water
  - Processes requiring high coagulant tolerance

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Newterra - RO

From:	Harry Cummings <hcummings@newterra.com>
Sent:	Tuesday, December 30, 2014 1:36 PM
To:	Vanorman, Eric; Jordan, James <jtjordan@kochmembrane.com> (jtjordan@kochmembrane.com)
Cc:	Pugh, Lucy B.
Subject:	RE: Wisconsin Chloride Removal/Softening
Attachments:	AECOM-WI OPEX.pdf; AECOM Wastewater Treatment PFD.pdf; AECOM Wisconsin Waste Water RO Operating Costs.xlsx; Wisconsin WW 27C.pdf; Wisconsin WW 9C.pdf

Eric,

Attached is information on the Wastewater Recycle system. This system includes the UF skids (four trains), the primary RO skids (twelve skids), and the brine recovery RO skids (two skids). The system is laid out in the attached Process Flow Diagram. Also attached is operating cost estimates for the UF and RO systems. Note that the UF operating costs are based on a 26.4 mgpd feed of tertiary wastewater, and will have to be scaled down to 15 mgpd wastewater feed.

The total capital cost of the UF/RO/Brine RO equipment is $13.5 million.

The RO skids will be about the same size as the well water RO skids sent previously. The UF trains will be about 40'L x 6'w x 10'h. I would put 3' of maintenance clearance around each UF skid to remove membranes.

As for how the system operates with varying flow rates, that depends on the tankage upstream and downstream of the system, and how we would know what the feedwater flow rate is. Normally these types of system have large storage both upstream and downstream, so the equipment turns on and off based on the storage volumes. So if you are expecting a low flow rate, you can manually turn off some of the skids. We can put VFDs on the various pumps to control the skids, but this can be tricky if you get too many (competing) control loops.

Let me know if you have further questions.

Harry Cummings
Senior Application Engineer
T: 610.631.7700 | **F:** 610.630.6656 | **Direct Dial:** 484.690.2461
Cell: 484.238.7973
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Trooper, PA. 19403
hcummings@newterra.com | industrial.newterra.com

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 19, 2014 2:59 PM
To: Jordan, James <jtjordan@kochmembrane.com> (jtjordan@kochmembrane.com); Harry Cummings

Cc: Pugh, Lucy B.
Subject: Wisconsin Chloride Removal/Softening

Tim/Harry:

We are in the process of finalizing the chloride reduction preliminary engineering report for our Wisconsin client. Thank you for providing the information to date related to this project. For the final document we are looking to cleanup a few things and fill in a few remaining holes. To that end can you:

For the Wastewater UF system:

- Adjust the Puron offering to provide a permeate of 15MGD to feed to the RO. Please incorporate 1 standby unit in the capital cost so that we have a 15MGD firm permeate capacity from the system with one unit out of service.
- Provide the UF systems efficiency.
- Provide general arrangement drawing including overall dimensions.
- Include system sizing including layout, flux rate……
- Describe how the system would operate if only one unit would be required to be in service. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide estimated labor costs associated with O&M of the RO system.

For the Wastewater RO system:

- Adjust the RO offering to accommodate a 15MGD feed. Please incorporate 1 standby unit in the capital cost so that we have a 15MGD raw flow capacity from the system with one unit out of service.
- Describe how the system would operate if only one unit would be required to be in service. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide a general arrangement drawing including dimensions.
- Provide O&M costs including:
  - Utility consumption
  - Chemical usage
  - Labor
  - Replacement costs (Total # pre-filters and membranes, cost per pre-filter/membrane and life expectancy)

For the Wastewater recovery RO system:

- Adjust the recovery RO offering based on the 15MGD feed to the main RO. At this point we are assuming a total of 6 skids (5 duty and 1 standby)
- Describe how the system would operate if only a 3 MGD flow through the main RO system would be required. How would the remaining skids operate, if at all? There are going to be times when this system may be operating at a minimum flow rate or possibly not at all. We need to understand how the system must be operated under these conditions. Ultimately we need to estimate O&M costs (if any) associated with the system being in an offline or standby mode of operation as well as the requirements needed to transition between modes of operation.
- Provide a general arrangement drawing including dimensions.
- Provide O&M costs including:
  - Utility consumption
  - Chemical usage

  - Labor
  - Replacement costs (Total # pre-filters and membranes, cost per pre-filter/membrane and life expectancy)

For Softening of Source Water

- WELL OPTION - Adjust the well softening offering (if needed) to provide softened blended water from a 3.0 MGD raw water supply. Assume two units combined (or suggest alternate) would be required to accomplish this.
- CENTRALIZED OPTION - Provide a membrane softening option which can provide 50 MGD of softened blended water (quality data previously sent). Further assume that the reject from this system could be discharged to the sanitary, minimizing the overall foot print. Information on the processing rate and an estimate on the % reject would be required as well.
- Provide information on proposed softening equipment options including capital cost, equipment sizes (capacity and foot prints), materials of construction and O&M costs including labor.
- Provide O&M costs including:
  - Utility consumption
  - Chemical usage
  - Labor
  - Replacement costs (Total # pre-filters (if needed) and membranes, cost per pre-filter/membrane and life expectancy)

We are hoping this is something which can be updated by the end of the year. If this is not feasible please let us now when the information could be provided. If you have any questions please don’t hesitate to contact either myself or Lucy.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
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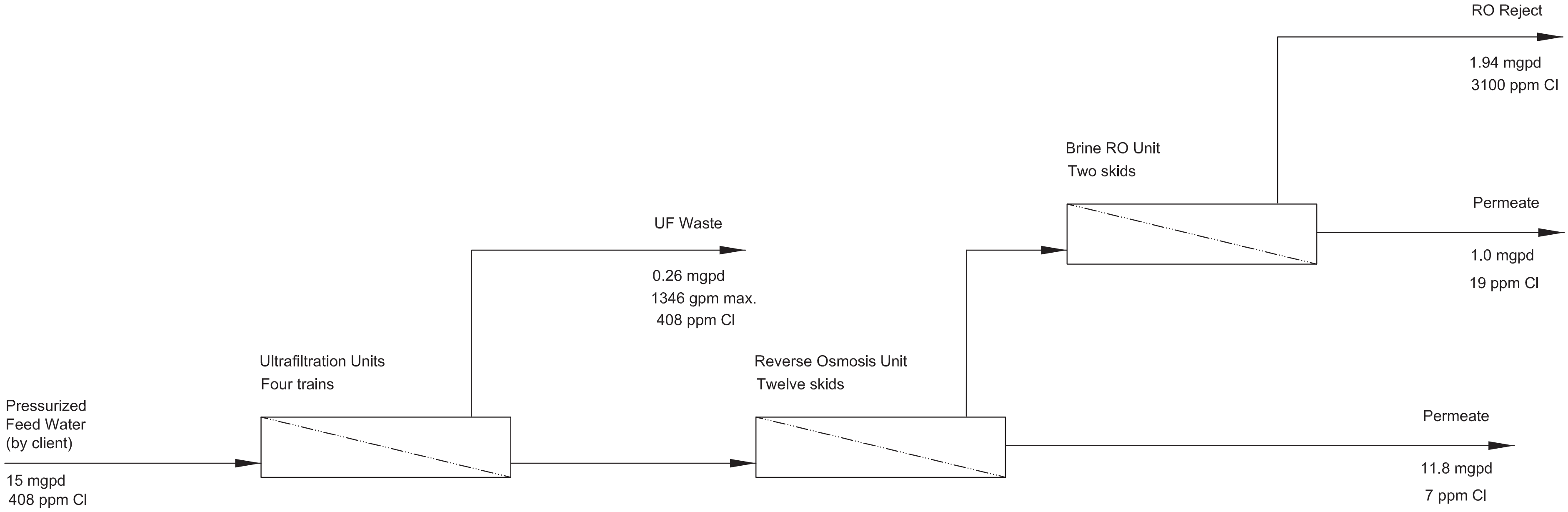

NOTES

DRAWING IS NOT TO SCALE
NOT ALL PROCESS LINES AND EQUIPMENT HAVE BEEN SHOWN FOR CLARITY

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LEVEL	REVISION	DATE (mm/dd/yy)	BY

PROJECT NUMBER xxx

TITLE AND LOCATION
PROCESS FLOW DIAGRAM
WASTEWATER TREATMENT

CUSTOMER AECOM

DRAWN BY HGC
DATE 12/28/14
SHEET
SHEETS

Reverse Osmosis System Analysis for FILMTEC™ Membranes ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - WW Case: 1
HGC, newterra 11/20/2014

Project Information:

Case-specific:

System Details

Feed Flow to Stage 1	937.50 gpm	Pass 1 Permeate Flow	749.94 gpm	Osmotic Pressure:	
Raw Water Flow to System	937.50 gpm	Pass 1 Recovery	79.99 %	Feed	10.54 psig
Feed Pressure	318.22 psig	Feed Temperature	9.0 C	Concentrate	49.92 psig
Flow Factor	0.85	Feed TDS	1213.65 mg/l	Average	30.23 psig
Chem. Dose	None	Number of Elements	184	Average NDP	253.96 psig
Total Active Area	80960.00 ft^2	Average Pass 1 Flux	13.34 gfd	Power	162.25 kW
Water Classification: Wastewater with DOW Ultrafiltration, SDI < 2.5				Specific Energy	3.61 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30-440i	16	8	937.50	313.22	0.00	391.85	270.45	545.65	13.95	30.00	0.00	7.37
2	BW30-440i	7	8	391.85	265.45	0.00	187.56	223.39	204.30	11.94	0.00	0.00	20.41

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	14.00	14.00	32.46	65.53	0.75	2.09	1.11
Na	237.00	247.82	591.24	1231.35	1.20	3.58	1.85
Mg	43.00	43.00	102.71	214.22	0.12	0.34	0.18
Ca	77.00	77.00	183.94	383.64	0.20	0.60	0.31
Sr	0.11	0.11	0.26	0.55	0.00	0.00	0.00
Ba	0.03	0.03	0.07	0.15	0.00	0.00	0.00
CO3	0.39	0.39	2.61	12.70	0.00	0.00	0.00
HCO3	355.05	355.05	843.68	1742.56	2.13	5.14	2.91
NO3	19.00	19.00	43.25	85.49	1.59	4.47	2.37
Cl	408.00	408.00	974.32	2031.32	1.30	3.92	2.01
F	0.75	0.75	1.79	3.72	0.00	0.01	0.01
SO4	40.00	40.00	95.61	199.57	0.06	0.18	0.09
SiO2	8.50	8.50	20.30	42.34	0.03	0.07	0.04
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	35.05	35.00	36.00	40.14	34.93	36.93	35.50
TDS	1202.83	1213.65	2892.25	6013.15	7.37	20.41	10.88
pH	7.20	7.20	7.51	7.71	5.12	5.47	5.25

*Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area. DISCLAIMER: NO WARRANTY, EXPRESSED OR IMPLIED, AND NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, IS GIVEN. Neither FilmTec Corporation nor The Dow Chemical Company assume any obligation or liability for results obtained or damages incurred from the application of this information. Because use conditions and applicable laws may differ from one location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. FilmTec Corporation and The Dow Chemical Company assume no liability, if, as a result of customer's use of the ROSA membrane design software, the customer should be sued for alleged infringement of any patent not owned or controlled by the FilmTec Corporation nor The Dow Chemical Company.

Reverse Osmosis System Analysis for FILMTEC™ Membranes ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - WW Case: 1
HGC, newterra 11/20/2014

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.08	4.67	4.41	58.59	1213.65	313.22
2	0.08	4.53	4.96	53.93	1318.33	304.99
3	0.09	4.41	5.62	49.39	1438.88	297.69
4	0.10	4.30	6.43	44.98	1579.39	291.26
5	0.10	4.19	7.44	40.68	1745.49	285.66
6	0.11	4.10	8.69	36.49	1945.12	280.83
7	0.12	4.00	10.31	32.40	2189.77	276.72
8	0.14	3.90	12.45	28.40	2496.60	273.28

Stage 2 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.07	4.19	12.70	55.98	2892.25	265.45
2	0.08	4.04	14.35	51.79	3125.10	257.69
3	0.08	3.88	16.27	47.75	3387.65	250.75
4	0.09	3.73	18.52	43.87	3685.47	244.59
5	0.09	3.58	21.18	40.14	4025.62	239.13
6	0.09	3.42	24.36	36.56	4416.63	234.34
7	0.10	3.26	28.21	33.14	4869.23	230.15
8	0.10	3.09	32.93	29.88	5396.09	226.51

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.20	7.20	7.71
Langelier Saturation Index	-0.35	-0.35	1.50
Stiff & Davis Stability Index	0.04	0.04	1.29
Ionic Strength (Molal)	0.02	0.02	0.11
TDS (mg/l)	1202.83	1213.65	6013.15
HCO3	355.05	355.05	1742.56
CO2	35.05	35.05	40.12
CO3	0.39	0.39	12.70
CaSO4 (% Saturation)	0.62	0.62	6.14
BaSO4 (% Saturation)	39.86	39.86	211.38
SrSO4 (% Saturation)	0.07	0.07	0.39
CaF2 (% Saturation)	5.76	5.76	707.44
SiO2 (% Saturation)	9.14	9.14	45.52
Mg(OH)2 (% Saturation)	0.00	0.00	0.02

To balance: 10.82 mg/l Na added to feed.

Reverse Osmosis System Analysis for FILMTEC™ Membranes	ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - WW	Case: 1
HGC, newterra	11/20/2014

Project Information:

Case-specific:

System Details

Feed Flow to Stage 1	937.50 gpm	Pass 1 Permeate Flow	750.05 gpm	Osmotic Pressure:	
Raw Water Flow to System	937.50 gpm	Pass 1 Recovery	80.01 %	Feed	11.22 psig
Feed Pressure	183.77 psig	Feed Temperature	27.0 C	Concentrate	52.47 psig
Flow Factor	0.85	Feed TDS	1214.03 mg/l	Average	31.85 psig
Chem. Dose	None	Number of Elements	184	Average NDP	127.05 psig
Total Active Area	80960.00 ft²	Average Pass 1 Flux	13.34 gfd	Power	93.69 kW
Water Classification: Wastewater with DOW Ultrafiltration, SDI < 2.5				Specific Energy	2.08 kWh/kgal

Stage	Element	#PV	#Ele	Feed Flow (gpm)	Feed Press (psig)	Recirc Flow (gpm)	Conc Flow (gpm)	Conc Press (psig)	Perm Flow (gpm)	Avg Flux (gfd)	Perm Press (psig)	Boost Press (psig)	Perm TDS (mg/l)
1	BW30-440i	16	8	937.50	178.77	0.00	376.11	147.25	561.39	14.35	30.00	0.00	21.02
2	BW30-440i	7	8	376.11	142.25	0.00	187.45	112.28	188.67	11.03	0.00	0.00	64.83

Pass Streams
(mg/l as Ion)

Name	Feed	Adjusted Feed	Concentrate		Permeate		
			Stage 1	Stage 2	Stage 1	Stage 2	Total
NH4+ + NH3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K	14.00	14.00	31.83	58.26	2.06	5.56	2.94
Na	237.00	247.99	612.55	1216.73	3.75	12.26	5.89
Mg	43.00	43.00	106.64	212.79	0.36	1.17	0.57
Ca	77.00	77.00	190.98	381.12	0.64	2.07	1.00
Sr	0.11	0.11	0.27	0.55	0.00	0.00	0.00
Ba	0.03	0.03	0.07	0.15	0.00	0.00	0.00
CO3	0.60	0.60	4.33	17.98	0.00	0.00	0.00
HCO3	355.05	355.05	871.46	1712.66	5.40	17.00	8.29
NO3	19.00	19.00	40.74	69.54	4.43	12.13	6.37
Cl	408.00	408.00	1010.85	2014.44	4.10	13.74	6.53
F	0.75	0.75	1.85	3.67	0.01	0.04	0.02
SO4	40.00	40.00	99.42	198.88	0.19	0.61	0.29
SiO2	8.50	8.50	21.06	42.03	0.08	0.23	0.12
Boron	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	25.77	25.73	27.34	32.67	25.97	28.76	26.69
TDS	1203.04	1214.03	2992.07	5928.82	21.02	64.83	32.01
pH	7.20	7.20	7.50	7.66	5.51	5.94	5.68

*Permeate Flux reported by ROSA is calculated based on ACTIVE membrane area. DISCLAIMER: NO WARRANTY, EXPRESSED OR IMPLIED, AND NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE, IS GIVEN. Neither FilmTec Corporation nor The Dow Chemical Company assume any obligation or liability for results obtained or damages incurred from the application of this information. Because use conditions and applicable laws may differ from one location to another and may change with time, customer is responsible for determining whether products are appropriate for customer's use. FilmTec Corporation and The Dow Chemical Company assume no liability, if, as a result of customer's use of the ROSA membrane design software, the customer should be sued for alleged infringement of any patent not owned or controlled by the FilmTec Corporation nor The Dow Chemical Company.

Reverse Osmosis System Analysis for FILMTEC™ Membranes	ROSA 9.1 ConfigDB u399339_282
Project: Wisconsin - WW	Case: 1
HGC, newterra	11/20/2014

Design Warnings

-None-

Solubility Warnings

Langelier Saturation Index > 0
Stiff & Davis Stability Index > 0
BaSO4 (% Saturation) > 100%
CaF2 (% Saturation) > 100%
Antiscalants may be required. Consult your antiscalant manufacturer for dosing and maximum allowable system recovery.

Stage Details

Stage 1 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.09	5.18	10.92	58.59	1214.03	178.77
2	0.09	4.92	12.88	53.41	1330.66	172.52
3	0.10	4.67	15.26	48.50	1464.17	167.06
4	0.10	4.46	18.15	43.82	1618.60	162.32
5	0.11	4.25	21.72	39.37	1799.56	158.22
6	0.12	4.06	26.19	35.12	2014.63	154.72
7	0.12	3.87	31.88	31.06	2274.27	151.75
8	0.14	3.68	39.27	27.19	2593.09	149.28

Stage 2 Element	Recovery	Perm Flow (gpm)	Perm TDS (mg/l)	Feed Flow (gpm)	Feed TDS (mg/l)	Feed Press (psig)
1	0.08	4.42	36.70	53.73	2992.07	142.25
2	0.08	4.11	42.99	49.31	3256.62	136.70
3	0.08	3.81	50.47	45.20	3548.49	131.78
4	0.08	3.51	59.42	41.39	3869.82	127.44
5	0.08	3.21	70.20	37.87	4222.20	123.61
6	0.08	2.92	83.27	34.66	4606.23	120.23
7	0.08	2.63	99.27	31.74	5021.13	117.25
8	0.08	2.34	118.99	29.11	5463.85	114.61

Scaling Calculations

	Raw Water	Adjusted Feed	Concentrate
pH	7.20	7.20	7.66
Langelier Saturation Index	0.07	0.07	1.86
Stiff & Davis Stability Index	0.39	0.39	1.58
Ionic Strength (Molal)	0.02	0.02	0.11
TDS (mg/l)	1203.04	1214.03	5928.82
HCO3	355.05	355.05	1712.66
CO2	25.77	25.77	32.66
CO3	0.60	0.60	17.98
CaSO4 (% Saturation)	0.62	0.62	6.12
BaSO4 (% Saturation)	39.86	39.86	211.35
SrSO4 (% Saturation)	0.07	0.07	0.39
CaF2 (% Saturation)	5.76	5.76	683.39
SiO2 (% Saturation)	6.59	9.14	32.58
Mg(OH)2 (% Saturation)	0.00	0.00	0.02

To balance: 10.99 mg/l Na added to feed.

AECOM Waste Water RO Operating Cost

Note: Costs below are for entire wastewater treatment system (15 mgpd feed)

1. Electricity Cost

RO High pressure Pump -	Flow rate	10243	gpm	(for eleven skids in operation)
	Pump head	330.0	psi	
	Pump Eff.	70.0%		
	bHP	2816.8		
	KW	2101.4		
Control Panel	KW	1.0		
Net KW		2102.4		
		35.04	KWHr/kgal	
RO Permeate Flow Rate		1000	gpm	
Average daily usage		2000000	gpd	
Power Cost		$0.10	per KWHr	
Power Cost per day		$7,007.84		
Power Cost per year		$2,557,861		

1b. Brine RO Electricity Cost

RO High pressure Pump -	Flow rate	2057	gpm	(for one skid in operation)
	Pump head	500.0	psi	
	Pump Eff.	70.0%		
	bHP	857.1		
	KW	639.4		
Control Panel	KW	1.0		
Net KW		640.4		
		10.67	KWHr/kgal	
RO Permeate Flow Rate		1000	gpm	
Average daily usage		2000000	gpd	
Power Cost		$0.10	per KWHr	
Power Cost per day		$2,134.61		

Power Cost per year		$779,134	

2. Chemical Costs

Antiscalant Dosage		3	ppm
Feed Flow Rate		10243	gpm
Chemical Use		511.95	lbs. per day
		51.19	gallons per day
Chemical Cost		$6.00	per lbs
Antiscal Cost per day		$3,071.67	
Antiscal Cost per year		$1,121,160	
SBS Dosage		3	ppm
Feed Flow Rate		10243	gpm
Chemical Use		511.95	lbs. per day
		51.19	gallons per day
Chemical Cost		$1.00	per lbs
SBS Cost per day		$511.95	
SBS Cost per year		$186,860	

3. Filter Bag Changeout

Number of Cartridge Filter Elements		728	
Changeout frequency	once per	1	month
Filter Cost		$3.00	per element
Filter Cost per year		$26,208	

4. RO Membrane Replacement

Number of RO Membranes Installed		2352	
Changeout frequency		3	years
Membrane Cost		$700.00	per membrane
Membrane Cost per year		$548,800	

5. RO Cleaning Chemicals

Chemicals wieght per cleaning		8400	lbs.
Cleaning frequency	once every	6	months
Chemical Cost		$6.00	per lbs
Cleaning Chemical Cost per year		$100,800	

Total Operating Cost per year **$4,541,689**

RO Model Output

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	JA				
Project name:	AECOM		Permeate flow:	1690.00	gpm
HP Pump flow:	1988.2	gpm	Raw water flow:	1988.2	gpm
			Permeate throttling(1st st.)	10.0	psi
Feed pressure:	131.8	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	27.0	C(81F)			
Feed water pH:	6.70		Element age:	3.0	years
Chem dose, ppm (100%):	62.6	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1297.6	36.8	12.8	12.4	1.20	124.4	10.0	ESPA2-LD	378	54x7
1-2	392.4	28.8	12.4	8.4	1.11	115.8	0.0	ESPA2-LD	168	24x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	77.0	192.0	77.0	192.0	1.006	2.5	507.6	1265.9
Mg	43.0	177.0	43.0	177.0	0.562	2.3	283.5	1166.6
Na	248.0	539.1	248.0	539.1	15.238	33.1	1567.0	3406.5
K	13.0	16.7	13.0	16.7	0.992	1.3	81.0	103.9
NH4	0.3	0.8	0.3	0.8	0.023	0.1	1.9	5.2
Ba	0.030	0.0	0.030	0.0	0.000	0.0	0.2	0.1
Sr	0.110	0.1	0.110	0.1	0.001	0.0	0.7	0.8
CO3	0.3	0.5	0.1	0.1	0.000	0.0	0.4	0.7
HCO3	355.0	291.0	277.5	227.5	17.397	14.3	1751.7	1435.8
SO4	40.0	41.7	101.3	105.6	0.909	0.9	670.5	698.4
Cl	408.0	575.5	408.0	575.5	14.429	20.4	2638.2	3721.1
F	0.7	1.8	0.7	1.8	0.049	0.1	4.4	11.6
NO3	19.0	15.3	19.0	15.3	4.459	3.6	101.4	81.8
B	0.00		0.00		0.000		0.00	
SiO2	12.0		12.0		0.40		77.71	
CO2	32.92		93.95		93.95		93.95	
TDS	1216.5		1200.1		55.5		7686.3	
pH	7.20		6.70		5.46		7.37	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	1%	2%	20%
SrSO4 / Ksp * 100:	0%	0%	2%
BaSO4 / Ksp * 100:	34%	84%	732%
SiO2 saturation:	9%	9%	59%
Langelier Saturation Index	0.07	-0.54	1.69
Stiff & Davis Saturation Index	0.11	-0.50	1.34
Ionic strength	0.02	0.02	0.15
Osmotic pressure	11.8 psi	11.4 psi	72.7 psi

Permeate THROTTLING(1ST STAGE)

RO program licensed to:					
Calculation created by:	JA				
Project name:	AECOM		Permeate flow:	1690.00	gpm
HP Pump flow:	1988.2	gpm	Raw water flow:	1988.2	gpm
			Permeate throttling(1st st.)	10.0	psi
Feed pressure:	131.8	psi	Permeate recovery:	85.0	%
Feedwater Temperature:	27.0	C(81F)			
Feed water pH:	6.70		Element age:	3.0	years
Chem dose, ppm (100%):	62.6	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	11.1	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1297.6	36.8	12.8	12.4	1.20	124.4	10.0	ESPA2-LD	378	54x7
1-2	392.4	28.8	12.4	8.4	1.11	115.8	0.0	ESPA2-LD	168	24x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Ca	Mg	Cl	B	SiO2
									Cumulative Perm Ion levels				
1-1	1	131.8	1.7	3.8	13.7	1.10	12.6	12.7	0.17	0.09	4	0.00	0.08
1-1	2	130.1	1.5	3.7	13.3	1.11	13.3	14.3	0.19	0.10	4	0.00	0.09
1-1	3	128.6	1.2	3.6	12.9	1.12	14.6	16.2	0.20	0.11	4	0.00	0.10
1-1	4	127.4	1.0	3.5	12.5	1.14	16.3	18.7	0.23	0.13	5	0.00	0.11
1-1	5	126.3	0.8	3.3	12.0	1.16	18.4	21.9	0.26	0.15	6	0.00	0.13
1-1	6	125.5	0.7	3.2	11.4	1.18	21.2	26.3	0.30	0.17	6	0.00	0.15
1-1	7	124.9	0.5	3.0	10.6	1.20	25.2	32.2	0.36	0.20	8	0.00	0.18
1-2	1	121.4	1.2	3.0	10.7	1.10	27.3	36.3	0.38	0.21	8	0.00	0.19
1-2	2	120.1	1.1	2.8	10.0	1.10	30.2	40.6	0.43	0.24	9	0.00	0.21
1-2	3	119.1	0.9	2.6	9.3	1.10	33.8	45.6	0.48	0.27	10	0.00	0.24
1-2	4	118.2	0.8	2.4	8.5	1.12	38.2	51.3	0.54	0.30	11	0.00	0.27
1-2	5	117.4	0.6	2.1	7.6	1.10	43.5	57.8	0.62	0.35	13	0.00	0.31
1-2	6	116.8	0.5	1.9	6.7	1.10	49.6	65.0	0.71	0.40	15	0.00	0.35
1-2	7	116.3	0.4	1.6	5.7	1.10	56.7	72.7	0.82	0.46	17	0.00	0.40

Stage	NDP psi
1-1	96.8
1-2	68.5

BASIC DESIGN

RO program licensed to:						
Calculation created by:	JA					
Project name:	AECOM			Permeate flow:	1690.00	gpm
HP Pump flow:	1988.2	gpm		Raw water flow:	1988.2	gpm
Feed pressure:	192.6	psi		Permeate recovery:	85.0	%
Feedwater Temperature:	9.0	C(48F)				
Feed water pH:	7.00			Element age:	3.0	years
Chem dose, ppm (100%):	25.3	H2SO4		Flux decline % per year:	15.0	
				Fouling Factor	0.61	
				Salt passage increase, %/yr:	15.0	
Average flux rate:	11.1	gfd		Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1263.7	36.8	13.4	12.0	1.20	184.9	0.0	ESPA2-LD	378	54x7
1-2	426.3	30.2	12.4	9.1	1.15	175.9	0.0	ESPA2-LD	168	24x7

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	77.0	192.0	77.0	192.0	0.554	1.4	510.2	1272.3
Mg	43.0	177.0	43.0	177.0	0.309	1.3	284.9	1172.5
Na	248.0	539.1	248.0	539.1	8.473	18.4	1605.3	3489.8
K	13.0	16.7	13.0	16.7	0.553	0.7	83.5	107.1
NH4	0.3	0.8	0.3	0.8	0.013	0.0	1.9	5.4
Ba	0.030	0.0	0.030	0.0	0.000	0.0	0.2	0.1
Sr	0.110	0.1	0.110	0.1	0.001	0.0	0.7	0.8
CO3	0.3	0.5	0.1	0.2	0.000	0.0	0.7	1.1
HCO3	355.0	291.0	323.6	265.3	10.708	8.8	2097.0	1718.8
SO4	40.0	41.7	64.8	67.5	0.303	0.3	430.5	448.4
Cl	408.0	575.5	408.0	575.5	7.563	10.7	2677.1	3775.9
F	0.7	1.8	0.7	1.8	0.026	0.1	4.5	11.9
NO3	19.0	15.3	19.0	15.3	2.470	2.0	112.7	90.9
B	0.00		0.00		0.000		0.00	
SiO2	12.0		12.0		0.22		78.77	
CO2	43.95		73.31		73.31		73.31	
TDS	1216.5		1209.7		31.2		7888.0	
pH	7.20		7.00		5.50		7.69	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	1%	1%	15%
SrSO4 / Ksp * 100:	0%	0%	1%
BaSO4 / Ksp * 100:	34%	54%	474%
SiO2 saturation:	13%	13%	80%
Langelier Saturation Index	-0.32	-0.56	1.70
Stiff & Davis Saturation Index	-0.40	-0.64	1.36
Ionic strength	0.02	0.02	0.15
Osmotic pressure	11.1 psi	11.0 psi	71.4 psi

BASIC DESIGN

RO program licensed to:						
Calculation created by:	JA					
Project name:	AECOM			Permeate flow:	1690.00	gpm
HP Pump flow:	1988.2	gpm		Raw water flow:	1988.2	gpm
Feed pressure:	192.6	psi		Permeate recovery:	85.0	%
Feedwater Temperature:	9.0	C(48F)				
Feed water pH:	7.00			Element age:	3.0	years
Chem dose, ppm (100%):	25.3	H2SO4		Flux decline % per year:	15.0	
				Fouling Factor	0.61	
				Salt passage increase, %/yr:	15.0	
Average flux rate:	11.1	gfd		Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	1263.7	36.8	13.4	12.0	1.20	184.9	0.0	ESPA2-LD	378	54x7
1-2	426.3	30.2	12.4	9.1	1.15	175.9	0.0	ESPA2-LD	168	24x7

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels Ca	Mg	Cl	B	SiO2
1-1	1	192.6	1.7	3.5	12.8	1.10	8.0	12.1	0.10	0.06	2	0.00	0.05
1-1	2	190.8	1.5	3.5	12.6	1.10	8.4	13.5	0.11	0.06	2	0.00	0.06
1-1	3	189.3	1.3	3.4	12.3	1.12	9.0	15.3	0.12	0.07	3	0.00	0.06
1-1	4	188.0	1.1	3.4	12.1	1.13	9.9	17.5	0.13	0.07	3	0.00	0.07
1-1	5	187.0	0.9	3.3	11.8	1.15	11.1	20.4	0.15	0.08	3	0.00	0.07
1-1	6	186.1	0.7	3.2	11.5	1.17	12.6	24.3	0.17	0.10	4	0.00	0.08
1-1	7	185.4	0.5	3.1	11.1	1.20	14.6	29.8	0.20	0.11	4	0.00	0.10
1-2	1	181.9	1.3	2.9	10.4	1.09	15.8	33.1	0.22	0.12	5	0.00	0.11
1-2	2	180.6	1.1	2.8	10.1	1.10	17.4	36.9	0.24	0.13	5	0.00	0.12
1-2	3	179.4	1.0	2.7	9.7	1.11	19.2	41.3	0.27	0.15	6	0.00	0.13
1-2	4	178.4	0.8	2.6	9.2	1.12	21.5	46.8	0.30	0.17	6	0.00	0.15
1-2	5	177.6	0.7	2.4	8.7	1.13	24.4	53.4	0.34	0.19	7	0.00	0.17
1-2	6	176.9	0.6	2.3	8.1	1.14	27.8	61.4	0.38	0.21	8	0.00	0.19
1-2	7	176.3	0.5	2.1	7.4	1.15	31.8	71.3	0.44	0.24	9	0.00	0.22

Stage	NDP psi
1-1	168.7
1-2	130.3

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	150.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	241.2	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	10.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	150.0	33.3	16.7	10.0	1.10	234.9	0.0	ESPA2-LD	54	9x6

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	507.6	1265.8	507.6	1265.8	3.340	8.3	1011.9	2523.3
Mg	283.5	1166.7	283.5	1166.7	1.866	7.7	565.1	2325.7
Na	1567.0	3406.5	1567.0	3406.5	49.136	106.8	3084.9	6706.2
K	81.0	103.8	81.0	103.8	3.168	4.1	158.8	203.6
NH4	1.9	5.3	1.9	5.3	0.074	0.2	3.7	10.3
Ba	0.700	0.5	0.700	0.5	0.005	0.0	1.4	1.0
Sr	0.700	0.8	0.700	0.8	0.005	0.0	1.4	1.6
CO3	4.3	7.2	0.0	0.1	0.000	0.0	0.1	0.1
HCO3	1751.7	1435.8	661.3	542.1	26.382	21.6	1296.3	1062.5
SO4	670.5	698.4	1536.1	1600.1	8.613	9.0	3063.5	3191.2
Cl	2638.2	3721.0	2638.2	3721.0	58.831	83.0	5217.6	7359.1
F	4.4	11.6	4.4	11.6	0.195	0.5	8.6	22.6
NO3	101.4	81.8	101.4	81.8	16.139	13.0	186.7	150.5
B	0.00		0.00		0.000		0.00	
SiO2	77.7		77.7		1.39		154.01	
CO2	118.17		945.18		945.18		945.18	
TDS	7690.6		7461.5		169.1		14753.9	
pH	7.40		6.20		4.77		6.33	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	24%	52%	124%
SrSO4 / Ksp * 100:	2%	5%	11%
BaSO4 / Ksp * 100:	2590%	5647%	12462%
SiO2 saturation:	82%	81%	163%
Langelier Saturation Index	1.33	-0.29	0.41
Stiff & Davis Saturation Index	0.99	-0.65	-0.18
Ionic strength	0.15	0.16	0.32
Osmotic pressure	68.4 psi	62.2 psi	122.9 psi

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	150.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	241.2	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	10.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel		Flux gfd	Beta	Conc.&Throt. Pressures		Element Type	Elem. No.	Array
		Feed gpm	Conc gpm			psi	psi			
1-1	150.0	33.3	16.7	10.0	1.10	234.9	0.0	ESPA2-LD	54	9x6

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels				
									Ca	Mg	Cl	B	SiO2
1-1	1	241.2	1.5	3.3	11.8	1.10	101.9	68.9	1.79	1.00	37	0.00	0.81
1-1	2	239.7	1.3	3.1	11.2	1.10	110.0	76.7	1.96	1.09	41	0.00	0.89
1-1	3	238.4	1.1	2.9	10.5	1.11	120.7	85.9	2.16	1.21	45	0.00	0.98
1-1	4	237.3	0.9	2.7	9.7	1.11	134.0	96.5	2.41	1.34	50	0.00	1.09
1-1	5	236.3	0.8	2.5	8.8	1.12	150.2	108.8	2.71	1.51	56	0.00	1.23
1-1	6	235.5	0.7	2.2	7.9	1.10	170.0	122.7	3.07	1.71	63	0.00	1.39

Stage	NDP psi
1-1	148.6

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	150.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	241.2	psi	Permeate recovery:	50.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	6.20		Element age:	3.0	years
Chem dose, ppm (100%):	883.2	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	10.0	gfd	Feed type:	Wastewater	

****
**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***
****

Concentrate saturation of BaSO4 too high (12462%)
Concentrate saturation of SiO2 too high (163%)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
8.0 inches	75 gpm (283.9 lpm)	12 gpm (45.4 lpm)
8.0 inches(Full Fit)	75 gpm (283.9 lpm)	30 gpm (113.6 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor.
Without scale inhibitor, concentrate saturation should not exceed 100%.

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	105.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	194.1	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.9	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	7.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel Feed gpm	Flow/Vessel Conc gpm	Flux gfd	Beta	Conc.&Throt. Pressures psi	Conc.&Throt. Pressures psi	Element Type	Elem. No.	Array
1-1	105.0	33.3	21.7	7.0	1.07	186.7	0.0	ESPA2-LD	54	9x6

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3	mg/l	CaCO3
Ca	510.2	1272.3	510.2	1272.3	4.371	10.9	782.6	1951.5
Mg	284.9	1172.4	284.9	1172.4	2.441	10.0	437.0	1798.3
Na	1605.3	3489.8	1605.3	3489.8	65.667	142.8	2434.3	5292.0
K	83.5	107.1	83.5	107.1	4.262	5.5	126.2	161.8
NH4	1.9	5.3	1.9	5.3	0.097	0.3	2.9	8.0
Ba	0.200	0.1	0.200	0.1	0.002	0.0	0.3	0.2
Sr	0.700	0.8	0.700	0.8	0.006	0.0	1.1	1.2
CO3	10.3	17.2	0.9	1.5	0.002	0.0	1.4	2.3
HCO3	2097.0	1718.9	1861.2	1525.6	76.825	63.0	2822.0	2313.1
SO4	430.3	448.2	631.1	657.4	3.649	3.8	969.0	1009.3
Cl	2677.1	3775.9	2677.1	3775.9	61.664	87.0	4085.4	5762.2
F	4.5	11.8	4.5	11.8	0.206	0.5	6.8	17.9
NO3	112.7	90.9	112.7	90.9	18.785	15.1	163.3	131.7
B	0.00		0.00		0.000		0.00	
SiO2	79.0		79.0		1.84		120.55	
CO2	70.91		266.00		266.00		266.00	
TDS	7897.6		7853.2		239.8		11952.7	
pH	7.70		7.20		5.77		7.24	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	15%	22%	38%
SrSO4 / Ksp * 100:	1%	2%	3%
BaSO4 / Ksp * 100:	475%	690%	1130%
SiO2 saturation:	80%	85%	129%
Langelier Saturation Index	1.71	1.16	1.55
Stiff & Davis Saturation Index	1.37	0.81	1.07
Ionic strength	0.15	0.15	0.23
Osmotic pressure	71.4 psi	70.1 psi	106.6 psi

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	105.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	194.1	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.9	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	7.0	gfd	Feed type:	Wastewater	

Stage	Perm. Flow gpm	Flow/Vessel		Flux gfd	Beta	Conc.&Throt. Pressures		Element Type	Elem. No.	Array
		Feed gpm	Conc gpm			psi	psi			
1-1	105.0	33.3	21.7	7.0	1.07	186.7	0.0	ESPA2-LD	54	9x6

Stg	Elem no.	Feed pres psi	Pres drop psi	Perm flow gpm	Perm Flux gfd	Beta	Perm sal TDS	Conc osm pres	Cumulative Perm Ion levels				
									Ca	Mg	Cl	B	SiO2
1-1	1	194.1	1.6	2.2	8.1	1.06	177.7	75.0	2.43	1.36	51	0.00	1.27
1-1	2	192.5	1.4	2.1	7.7	1.10	183.9	80.4	2.59	1.45	54	0.00	1.35
1-1	3	191.1	1.3	2.0	7.2	1.10	195.2	86.3	2.79	1.56	58	0.00	1.45
1-1	4	189.8	1.1	1.9	6.8	1.10	209.2	92.6	3.00	1.68	63	0.00	1.57
1-1	5	188.7	1.0	1.7	6.3	1.10	225.4	99.3	3.25	1.82	68	0.00	1.70
1-1	6	187.7	0.9	1.6	5.7	1.10	244.0	106.3	3.53	1.97	74	0.00	1.84

Stage	NDP psi
1-1	106.9

BASIC DESIGN

RO program licensed to:					
Calculation created by:	Jerry Alexander				
Project name:	AECOM.BR		Permeate flow:	105.00	gpm
HP Pump flow:	300.0	gpm	Raw water flow:	300.0	gpm
Feed pressure:	194.1	psi	Permeate recovery:	35.0	%
Feedwater Temperature:	9.0	C(48F)			
Feed water pH:	7.20		Element age:	3.0	years
Chem dose, ppm (100%):	204.9	H2SO4	Flux decline % per year:	15.0	
			Fouling Factor	0.61	
			Salt passage increase, %/yr:	15.0	
Average flux rate:	7.0	gfd	Feed type:	Wastewater	

****

**** THE FOLLOWING PARAMETERS EXCEED RECOMMENDED DESIGN LIMITS: ***

****

Concentrate saturation of SiO2 too high (129%)

The following are recommended general guidelines for designing a reverse osmosis system using Hydranautics membrane elements. Please consult Hydranautics for specific recommendations for operation beyond the specified guidelines.

Feed and Concentrate flow rate limits

Element diameter	Maximum feed flow rate	Minimum concentrate rate
8.0 inches	75 gpm (283.9 lpm)	12 gpm (45.4 lpm)
8.0 inches(Full Fit)	75 gpm (283.9 lpm)	30 gpm (113.6 lpm)

Concentrate polarization factor (beta) should not exceed 1.2 for standard elements

Saturation limits for sparingly soluble salts in concentrate

Soluble salt	Saturation
BaSO4	6000%
CaSO4	230%
SrSO4	800%
SiO2	100%

Langelier Saturation Index for concentrate should not exceed 1.8

The above saturation limits only apply when using effective scale inhibitor.
Without scale inhibitor, concentrate saturation should not exceed 100%.

The RTW Model Ver. 3.0

ID: **Madison,WI blended eff with RO permeate, case 1, A (26 mgd)+ B (15**

Blending Application Package

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	**1100**	mg/L
Temperature	**15**	deg C
pH	**7.2**	
Alkalinity, as CaCO3	**291**	mg/L
Ca, as CaCO3	**77**	mg/L
Cl	**408**	mg/L
SO4	**40**	mg/L

????

Water B

TDS	**25**	mg/L
Temperature	**15**	deg C
pH	**5.74**	
Alkalinity, as CaCO3	**8**	mg/L
Ca, as CaCO3	**1**	mg/L
Cl	**6**	mg/L
SO4	**0.2**	mg/L

STEP 2: Enter portion of blend that is Water A

% Water A in blend	**63.4**	%

Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending
Initial blended water characteristics.

TDS	706.55	mg/L
Temperature	15	deg C
pH	7.00	
Alkalinity, as CaCO3	187.422	mg/L
Ca, as CaCO3	49.184	mg/L
Cl	260.868	mg/L
SO4	25.4332	mg/L
Acidity	274	mg/L
Ca sat, as CaCO3	496	mg/L
DIC, as CaCO3	462	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).
Press Ctrl+C to select chemicals for this list.

Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	187	mg/L	> 40 mg/L	Interim pH	7.00		6.8-9.3
Interim Ca, as CaCO3	49	mg/L	> 40 mg/L	Precipitation potential	-56.56	mg/L	4-10 mg/L
Alk/(Cl+SO4)	0.7		> 5.0	Langelier index	-1.00		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	274	mg/L
Interim Ca sat, as CaCO3	496	mg/L
Ryznar index	9.01	
Interim DIC, as CaCO3	462	mg/L
Aggressiveness Index	10.96	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

The RTW Model Ver. 3.0

Blending Application Package

ID: **Madison,WI blended eff with RO permeate, case 2, A (26 mgd)+ B (15**

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	**1100**	mg/L	????
Temperature	**15**	deg C	
pH	**7.2**		
Alkalinity, as CaCO3	**291**	mg/L	
Ca, as CaCO3	**77**	mg/L	
Cl	**408**	mg/L	
SO4	**40**	mg/L	

Water B

TDS	**8.25**	mg/L	
Temperature	**15**	deg C	
pH	**5.32**		
Alkalinity, as CaCO3	**2.84**	mg/L	
Ca, as CaCO3	**0.28**	mg/L	????
Cl	**1.91**	mg/L	
SO4	**0.07**	mg/L	

STEP 2: Enter portion of blend that is Water A

% Water A in blend	**63.4**	%

Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending

Initial blended water characteristics.

TDS	700.4195	mg/L
Temperature	15	deg C
pH	6.99	
Alkalinity, as CaCO3	185.53344	mg/L
Ca, as CaCO3	48.92048	mg/L
Cl	259.37106	mg/L
SO4	25.38562	mg/L
Acidity	274	mg/L
Ca sat, as CaCO3	511	mg/L
DIC, as CaCO3	459	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).

Press Ctrl+C to select chemicals for this list.

Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	186	mg/L	> 40 mg/L	Interim pH	6.99		6.8-9.3
Interim Ca, as CaCO3	49	mg/L	> 40 mg/L	Precipitation potential	-57.64	mg/L	4-10 mg/L
Alk/(Cl+SO4)	0.7		> 5.0	Langelier index	-1.02		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	274	mg/L
Interim Ca sat, as CaCO3	511	mg/L
Ryznar index	9.03	
Interim DIC, as CaCO3	459	mg/L
Aggressiveness Index	10.95	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

The RTW Model Ver. 3.0

Blending Application Package

ID: **Madison,WI blended eff with RO permeate, case 3, A (26 mgd)+ B (15**

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	**1100**	mg/L	????
Temperature	**15**	deg C	
pH	**7.2**		
Alkalinity, as CaCO3	**291**	mg/L	
Ca, as CaCO3	**77**	mg/L	
Cl	**408**	mg/L	
SO4	**40**	mg/L	

Water B

TDS	**24.5**	mg/L	
Temperature	**15**	deg C	
pH	**5.77**		
Alkalinity, as CaCO3	**8.57**	mg/L	
Ca, as CaCO3	**0.93**	mg/L	????
Cl	**6.42**	mg/L	
SO4	**0.22**	mg/L	

STEP 2: Enter portion of blend that is Water A

% Water A in blend	**63.4**	%

Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending

Initial blended water characteristics.

TDS	706.367	mg/L
Temperature	15	deg C
pH	7.01	
Alkalinity, as CaCO3	187.63062	mg/L
Ca, as CaCO3	49.15838	mg/L
Cl	261.02172	mg/L
SO4	25.44052	mg/L
Acidity	274	mg/L
Ca sat, as CaCO3	482	mg/L
DIC, as CaCO3	462	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).

Press Ctrl+C to select chemicals for this list.

Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	188	mg/L	> 40 mg/L	Interim pH	7.01		6.8-9.3
Interim Ca, as CaCO3	49	mg/L	> 40 mg/L	Precipitation potential	-56.52	mg/L	4-10 mg/L
Alk/(Cl+SO4)	0.7		> 5.0	Langelier index	-0.99		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	274	mg/L
Interim Ca sat, as CaCO3	482	mg/L
Ryznar index	9.00	
Interim DIC, as CaCO3	462	mg/L
Aggressiveness Index	10.97	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

The RTW Model Ver. 3.0

Blending Application Package

ID: **Madison,WI blended eff with RO permeate, case 4, A (26 mgd)+ B (15**

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	**1100**	mg/L	????
Temperature	**15**	deg C	
pH	**7.2**		
Alkalinity, as CaCO3	**291**	mg/L	
Ca, as CaCO3	**77**	mg/L	
Cl	**408**	mg/L	
SO4	**40**	mg/L	

Water B

TDS	**8.91**	mg/L	
Temperature	**15**	deg C	
pH	**5.35**		
Alkalinity, as CaCO3	**3.04**	mg/L	
Ca, as CaCO3	**0.3**	mg/L	????
Cl	**2.07**	mg/L	
SO4	**0.07**	mg/L	

STEP 2: Enter portion of blend that is Water A

% Water A in blend	**63.4**	%

Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending

Initial blended water characteristics.

TDS	700.66106	mg/L
Temperature	15	deg C
pH	7.00	
Alkalinity, as CaCO3	185.60664	mg/L
Ca, as CaCO3	48.9278	mg/L
Cl	259.42962	mg/L
SO4	25.38562	mg/L
Acidity	273	mg/L
Ca sat, as CaCO3	498	mg/L
DIC, as CaCO3	459	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).

Press Ctrl+C to select chemicals for this list.

Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	186	mg/L	> 40 mg/L	Interim pH	7.00		6.8-9.3
Interim Ca, as CaCO3	49	mg/L	> 40 mg/L	Precipitation potential	-57.38	mg/L	4-10 mg/L
Alk/(Cl+SO4)	0.7		> 5.0	Langelier index	-1.01		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	273	mg/L
Interim Ca sat, as CaCO3	498	mg/L
Ryznar index	9.02	
Interim DIC, as CaCO3	459	mg/L
Aggressiveness Index	10.96	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

The RTW Model Ver. 3.0

ID: **Madison,WI blended eff with RO permeate A (26 mgd)+ B (15 mgd)**

Blending Application Package

STEP 1: Enter characteristics for waters to be blended.

Water A

TDS	**1100**	mg/L	????
Temperature	**15**	deg C	
pH	**7.2**		
Alkalinity, as CaCO3	**291**	mg/L	
Ca, as CaCO3	**77**	mg/L	
Cl	**408**	mg/L	
SO4	**40**	mg/L	

Water B

TDS	**169**	mg/L
Temperature	**15**	deg C
pH	**7.2**	
Alkalinity, as CaCO3	**61**	mg/L
Ca, as CaCO3	**5.2**	mg/L
Cl	**43**	mg/L
SO4	**2.4**	mg/L

STEP 2: Enter portion of blend that is Water A

% Water A in blend	**63.4**	%

Press PAGE DOWN for blended water characteristics and chemical treatment calculations.

Press PAGE UP to review characteristics of waters A & B prior to blending

Initial blended water characteristics.

TDS	759.254	mg/L
Temperature	15	deg C
pH	7.18	
Alkalinity, as CaCO3	206.82	mg/L
Ca, as CaCO3	50.7212	mg/L
Cl	274.41	mg/L
SO4	26.2384	mg/L
Acidity	271	mg/L
Ca sat, as CaCO3	302	mg/L
DIC, as CaCO3	477	mg/L

STEP 3: Enter amount of each chemical to be added to blended water (expressed as 100% chemical).

Press Ctrl+C to select chemicals for this list.

Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L
Ctrl+C to add to list	**0**	mg/L

STEP 4: Adjust at Step 3 until interim blended water characteristics meet your criteria.

Theoretical interim characteristics			Desired	Theoretical interim characteristics			Desired
Interim alkalinity	207	mg/L	> 40 mg/L	Interim pH	7.18		6.8-9.3
Interim Ca, as CaCO3	51	mg/L	> 40 mg/L	Precipitation potential	-38.72	mg/L	4-10 mg/L
Alk/(Cl+SO4)	0.7		> 5.0	Langelier index	-0.77		>0

Press PAGE DOWN for additional interim and final blended water characteristics if desired.

Press PAGE UP to review initial blended water characteristics, chemical addition quantities and additional interim blended water characteristics.

Theoretical interim blended water characteristics

Interim acidity	271	mg/L
Interim Ca sat, as CaCO3	302	mg/L
Ryznar index	8.73	
Interim DIC, as CaCO3	477	mg/L
Aggressiveness Index	11.20	

Theoretical final blended water characteristics after CaCO3 precipitation

Final alkalinity	N/A	mg/L
Final Ca	N/A	mg/L
Final acidity	N/A	mg/L
Final pH	N/A	
Final DIC, as CaCO3	N/A	mg/L

EDR VENDOR INFO – CHLORIDE REMOVAL

GE Water & Process Technologies

WATSYS^{TM} 3.0.30 EDR DESIGN PROGRAM

GE Water & Process Technologies

Project Name	Wisconsin WWTP
Company	AECOM
User	Patrick Girvin
WATSYS Run Date	Friday, November 14, 2014
Number of Lines	8
EDR System	2020-8L-3S with 8 Line(s) 3 Stage(s)
Anion Membrane	AR204
Cation Membrane	CR67
Spacer	Mark IV-2

EDR Product	1497600	USGPD	
Dilute In	1605256	USGPD	
Dilute Flow Losses	45256	USGPD	
Dilute Out	1560000	USGPD	
Off-Spec Product	62400	USGPD	4% OSP
Feed Pump	1664000	USGPD	
Concentrate Pump	1444730	USGPD	
Electrode Waste	14292	USGPD	
Concentrate Makeup Flow	44452	USGPD	
Net System Feed into EDR	1664000	USGPD	
Total System Waste	166400	USGPD	10% Waste w/o Bypass
Concentrate Blowdown	89708	USGPD	
System Feed w/ Bypass	1664000	USGPD	
Bypass Feed to Product	0	USGPD	
Minimum Velocity	9.64	cm/s	
First Stage Inlet Pressure	45.17	psig	
Last Stage Outlet Pressure	10	psig	
Temperature	15	C	
Pumping Power	1.45	kWh/kgal	
DC Power	2.61	kWh/kgal	
Total Power	4.05	kWh/kgal	
Total DC KVA	247.51	KVA	
Feed Pump Power	75.45	hp	
Concentrate Pump Power	45.57	hp	

		Raw Feed	Product	Conc. BD	Waste
Calcium	mg/l	76.90	5.23	1129.47	721.89
Magnesium	mg/l	43.00	3.41	624.69	399.35
Sodium	mg/l	340.00	39.27	4762.01	3046.57
Potassium	mg/l	12.90	1.10	186.23	119.07
Strontium	mg/l	0.11	0.01	1.64	1.05
Barium	mg/l	0.03	0.00	0.44	0.28
Ammonia	mg/l	0.30	0.10	3.33	2.14
Bicarbonate	mg/l	355.14	61.17	4188.60	2733.53
Sulphate	mg/l	39.70	2.37	587.83	375.64
Chloride	mg/l	565.00	42.98	8521.72	5307.15
Fluoride	mg/l	0.75	0.12	10.00	6.40
Nitrate	mg/l	18.70	1.53	270.97	173.23
Total PO4	mg/l	0.30	0.04	4.11	2.67
HPO4	mg/l	0.14	0.00	2.12	1.47
H2PO4	mg/l	0.16	0.04	1.98	1.20
Silica	mgl	12.00	12.00	12.00	12.00
CO2	mgl	42.40	42.40	416.15	237.21
Carbonate	mgl	0.21	0.01	2.93	2.19
Total Hardness	CaCO3	368.8	27.1	5388.8	3444.6
TDS	mg/l	1465.0	169.3	20305.9	12903.2
Conductivity	uS/cm	2356.6	270.3	27148.9	17871.3
pH		7.20	6.44	7.28	7.34
WATSYS % Saturation					
CaSO4		1.7	0.1	25.4	16.3
BaSO4		50.0	0.0	247.6	196.0
SrSO4		2.6	0.0	10.8	8.8
CaF2		42.2	0.0	578.9	370.7
CaHPO4		15.5	0.8	229.6	152.7
Ca3(PO4)2		16.5	0.4	263.7	183.6
Langelier Index (LI)		-0.18	-2.77	2.10	1.77
Stiff-Davis Index (SDI)		-0.38	-3.03	1.39	1.23
SAR		7.69	3.28	28.19	22.56
Flow Rate	USGPD	1664000	1497600	89708	166400

See table on PFD tab for additional chemical dosage information

Electrical Stages	1	2	3
Voltage (V)	481	431	442
Current (Amps)	19.5	10.3	5.5
Surge (Amps)	77.3	81.8	93.1
Hyd Stages / Elect Stage	1	1	1

Hydraulic Stages	1	2	3
% Polarization	55.00	55.02	55.02
Cut Fraction	0.51	0.54	0.55
Current Efficiency	0.85	0.80	0.71
% Manifold Shorting	28.62	25.78	26.54
Cell Pairs	600	600	600

Details of Acid Dosing to Concentrate Blowdown.

Acid Name	36% HCl	
Amount of Acid	222.07 lb/day	100.94 kg/day
pH after Acid Dosing	7.28	

The amount of acid used to reduce LI to 2.10 is as follows

62.70 USGPD of 36% HCl to reduce LI to 2.10

19.90 USGPD of 98% H2SO4 to reduce LI to 2.10

237.32 l/day of 36% HCl to reduce LI to 2.10

75.32 l/day of 98% H2SO4 to reduce LI to 2.10

ERROR IN DESIGN

This Design Case exceeds Design Limit.

Consult a GE Water representative before using this design.

WARNING

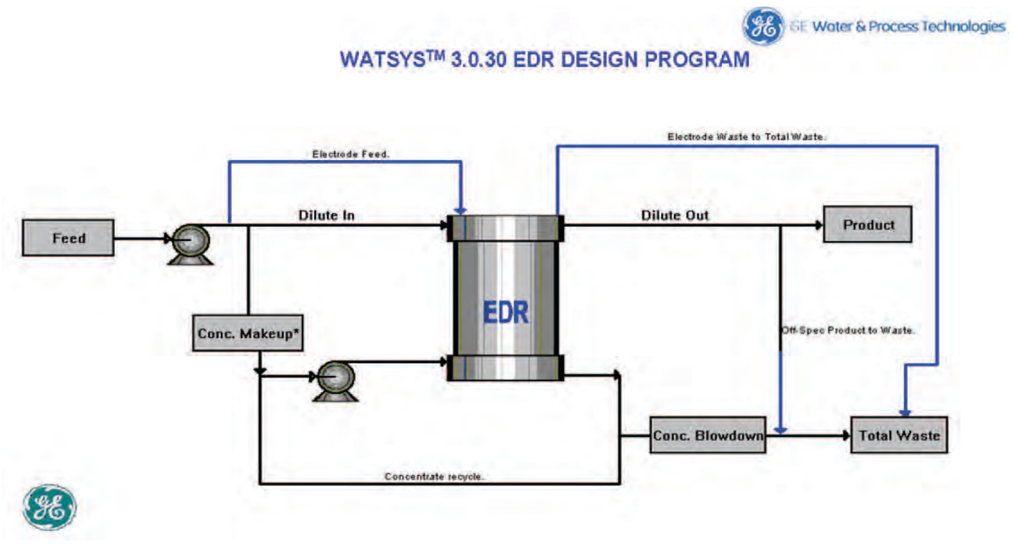
Feed Pump HP Limit exceeded

CBD to Product TDS Concentration Ratio (excluding Silica) 129:1 exceeds Limit of 125:1

Standard Volts Limit exceeded for Electrical Stage 1

Standard Volts Limit exceeded for Electrical Stage 2

Standard Volts Limit exceeded for Electrical Stage 3



Note:This is only a pictorial representation of the PFD and is for guidance purposes only.It does not indicate any problems in specific areas of the EDR system.

Antiscalant>	Max % saturation WATSYS None	Max % Saturation WATSYS 36% HCl		Max % saturation Argo MDC150	Max % saturation Argo MDC220	Max % saturation Argo MDC704	Max % saturation Argo MDC706	Max % saturation Argo MDC151	% of Saturation on using	% of Max Saturation using
CaSO4	150			350	300	400	600	350	NA	NA
BaSO4	800			10500	10500	11000	10500	10500	NA	NA
SrSO4	250			3500	3000	3000	3500	3500	NA	NA
CaF2	800			1300000	1300000	1300000	1300000	1300000	NA	NA
Ca5(PO4)3OH				1200	1100	1100	1100	1200	NA	NA
CaHPO4	400	229.6								
Ca3(PO4)2	400	263.7								
CaCO3 LI *	2.1	2.1		3.0	3.0	3.0	3.0	3.0		

Dosage in CBD	ppm(mg/l)	297.01	100% basis
Consumption	lb/day	222.07	100% basis
	kg/day	100.94	100% basis
	USGPD	62.70	as solution
	L/day	237.32	as solution

Please contact your GE representative if design with antiscalant exceeds 80% of max saturation (column K).
*Argo calculations for antiscalant use only; WATSYS for acid use.
Acid and antiscalant mass consumptions are on 100% basis.

Vanorman, Eric

From:	Girvin, Patrick (GE Power & Water) <Patrick.Girvin@ge.com>
Sent:	Tuesday, November 11, 2014 3:02 AM
To:	Vanorman, Eric
Subject:	RE: Wastewater Effluent Chloride Removal - RO
Attachments:	AECOM Wisconsin WW Plant.WAT.xlsx; 1303044-EDR-8X-3-PRE RevE.pdf; FS1242EN EDR 2020.pdf

Eric,
I put all this together a couple weeks ago, but I guess I never sent it over to you.

Here's the Watsys design program results for the EDR system. Chloride removal over 92%, but not quite 95% like you were looking for. The program usually underestimates, so we should expect slightly better values than in the program. The largest system that we supply is 1.5 MGD (8 lines of stacks). The system has three stages per line, so 24 stacks total per system. We can use multiple systems in order to meet your treatment needs. So if you are looking at 2030 total flow of 26.4 MGD, that would mean 18 systems.

Now I will point out that our facility in Barcelona is 53 MGD, and they have larger custom systems that were 32 lines each or 4x the flow capacity for 6 MGD. That would reduce the number of systems you would be looking at. The stacks and membranes are the bulk of the pricing, so we could put a number for either option. They should be similar pricing.

Each of these 8-line systems is approximately $1.75MM.

Operating costs can be estimated from the design. Power is estimated at 3.37 kWh/kgal. Acid consumption is also called out.

All piping is PVC since the pressure is low.
Membrane life is 10 years for anions, likely 15 for cations.

Look over the design run and see if that performance is acceptable to you, and then we can discuss.

-Patrick

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Tuesday, October 28, 2014 1:00 PM
To: Girvin, Patrick (GE Power & Water)
Subject: Wastewater Effluent Chloride Removal - RO

Hi Patrick:

Per my voicemails we are working with a Wisconsin municipality to reduce chloride in their wastewater effluent. We are looking at using an EDR membrane system to effectively remove chloride from a portion of the flow. This EDR treated wastewater effluent will then be combined with the balance of the wastewater effluent to meet a target effluent limit.

The EDR reject stream will also need to be minimized. Please provide a recommendation based on water quality for any further concentration of the waste stream.

See the attached Basis of Design Water Quality and Flow Data at the wastewater treatment plant. The water quality which will be seen by the chloride removal equipment is the effluent data as the equipment will be installed just prior to the disinfection step. The design Flow Rate shall be 26.4 MGD to meet the 2030 design condition. We are shooting for 95% chloride removal in the treated flow. Ideally the equipment can be partially off line or turned down as current average conditions only require 46.2% of the chloride treatment design capacity as shown. Flow rates required for treatment are even further reduced under high flow conditions at the plant.

Ultimately we will be looking for the following information:

- Equipment capital cost delivered to the site for main treatment and ancillary equipment. Provide a general break out of the various equipment components.
- Equipment list including pretreatment recommendations
- Equipment sizes (capacity and foot prints)
- Materials of construction
- Anticipated labor required for operation
- Electrical consumption
- Natural gas consumption
- Chemical usage
- Consumables (membranes/media/etc.) including cost and life expectancy
- Anticipated waste stream volume
- Maintenance costs/labor

Please don't hesitate to contact me with any questions or if you would like to discuss in more detail. We are working to arrive at a cost estimate for the complete system and hope that you can provide a timely response.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600   F 1.616.940.4396 Cisco 2084446
www.aecom.com

GE Water & Process Technologies

Fact Sheet

GE 2020 EDR Systems

Electrodialysis Reversal Technology

The GE 2020 Electrodialysis Reversal (EDR) product is a proven and reliable desalination technology that has been in service in a variety of industrial and public infrastructure applications.

EDR Features

- High Water Recovery, up to 94%
- Salt Removal of 50 to 95%
- Polarity Reversal self-cleaning with electricity
- Free chlorine tolerance
- Tolerance to moderate suspended solids
- Adjustable product water performance without blending
- Ability to disassemble stacks for inspection
- Silica tolerance

EDR Benefits

- Efficient use of scarce water resources
- Low pretreatment requirements and costs
- Low chemical consumption costs
- Long membrane life, typically 10+ years
- Strong ability to recover from less than ideal feed water quality

Standard Design and Scope of Supply

- MK-IV-2 EDR stack
- Cartridge filter
- Concentrate Recirculation pump with VFD
- GE Fanuc Micro PLC & 12” (30 cm) color Quick Panel HMI
- Full Owners Operation & Maintenance Manual, Factory Acceptance Test results and Stack Performance Test results

a product of
ecomagination℠

Instrumentation - Transmitters

Flow	Product Outlet, Concentrate Outlet
Pressure	Cartridge Filter Inlet & Outlet Concentrate, Recirculation Pump Outlet, Product Outlet
Conductivity	Inlet & Product Outlet

Operating Parameters

Water Recovery	Up to 94%
Salt Removal	50% to 95%
Silica Removal	none
Temperature	40 to 100°F (4 To 38°C)
Maximum Feed Pressure	50 psi
Input Voltage	480VAC/3/60Hz

Feed Water Requirements

Typical Feed TDS	100 to 3,000 ppm (mg/l)
Maximum Feed TDS	12,000 ppm (mg/l)
Silica (Reactive)	unlimited
pH	2 to 10
SDI (5 min. test)	10
Turbidity	< 0.5 NTU
Free Chlorine (continuous)	0.5 ppm (mg/l)
TOC	< 15 ppm (mg/l)

Find a contact near you by visiting www.ge.com/water and clicking on “Contact Us” .

COD	< 50 ppm (mg/l) as O_2
Iron	< 0.3 ppm (mg/l)
Manganese, Aluminum	< 0.1 ppm (mg/l)
H2S	< 0.1 ppm (mg/l)

Allowable Intermittent Levels:

SDI (5 min. test)	15
Turbidity	2.0 NTU
Free Chlorine	30 mg/l

Material of Construction

Welded Frame	Painted Carbon Steel
Dilute and Concentrate Piping	Sch. 80 PVC
Flanges	ANSI
Concentrate Pump	Single-stage Centrifugal
Rectifier	NEMA 3R
Control Panel	NEMA 4

Quality Assurance

Certification	UL
Facility	ISO 9001:2000

EDR 2020 2 & 4 Line Standard Systems

MODEL	2020-2L-2S	2020-2L-3S	2020-4L-2S	2020-4L-3S
Flow Rates				
Product Flow Nominal	280 gpm 63.6 m^3/h	260 gpm 59.1 m^3/h	560 gpm 127.2 m^3/h	520 gpm 118.2 m^3/h
Product Flow Range	165 to 325 gpm 37.5 to 73.8 m^3/h	165 to 270 gpm 37.5 to 61.3 m^3/h	325 to 655 gpm 73.8 to 148.8 m^3/h	325 to 545 gpm 73.8 to 123.8 m^3/h
Concentrate Outlet Flow	Depends on recovery and product			
Electrode Outlet Flow	2.2 gpm 8.3 lpm	2.5 gpm 9.5 lpm	4.3 gpm 16.3 lpm	5.0 gpm 19 lpm
General Information				
Number of Stacks	4	6	8	12
Number of Lines	2	2	4	4
Number of Stages	2	3	2	3
Type of Stack	MK-IV-2	MK-IV-2	MK-IV-2	MK-IV-2
Dimensions				
System Dimensions Width x Length	90” x 309” (2.3 x 7.9 m)	90” x 375” (2.3 x 9.5 m)	169” x 493” (4.3 x 12.5 m)	169” x 625” (4.3 x 15.9 m)
Inlet Piping	4” (10 cm)	4” (10 cm)	6” (15 cm)	6” (15 cm)
Product Outlet Piping	4” (10 cm)	4” (10 cm)	6” (15 cm)	6” (15 cm)
Off-Spec Outlet Piping	4” (10 cm)	4” (10 cm)	6” (15 cm)	6” (15 cm)
Electrode Outlet Piping	3” (8 cm)	3” (8 cm)	3” (8 cm)	3” (8 cm)
Concentrate Outlet Piping	1.5” (4 cm)	1.5” (4 cm)	2” (5 cm)	2” (5 CM)
Note: all piping sizes are provided for nominal flow rates at 85% recovery.				
Electrical				
Maximum Rectifier Output (Per Stack Basis)				
Stage 1	590VDC, 46A	590VDC, 26A	590VDC, 46A	590VDC, 26A
Stage 2	518VDC, 18A	518VDC, 14A	518VDC 18A	518VDC, 14A
Stage 3		420VDC, 7.5A		420VDC, 7.5A
Connection Requirement (Includes Feed pump, which may be supplied by others)	140 KVA	107 KVA	276 KVA	209 KVA
Typical Power consumption	2 – 4 kWh/1,000 gallons of product water			
Performance, number of stages and cell pairs, recovery and power consumption are dependent on inlet feed water quality and temperature. A Watsys projection must be completed by an authorized GE Water & Process Technologies design representative for proper system design & for any performance guarantee to be provided.				

EDR 2020 6 & 8 Line Standard Systems

MODEL	2020-6L-2S	2020-6L-3S	2020-8L-2S	2020-8L-3S
Flow Rates				
Product Flow Nominal	840 gpm 190.8 m^3/h	780 gpm 177.2 m^3/h	1120 gpm 254.4 m^3/h	1040 gpm 236.2 m^3/h
Product Flow Range	485 to 985 gpm 110.2 to 223.7 m^3/h	485 to 820 gpm 110.2 to 186.2 m^3/h	645 to 1315 gpm 146.5 to 298.7 m^3/h	645 to 1090 gpm 146.5 to 247.6 m^3/h
Concentrate Outlet Flow	Depends on recovery and product flow rate			
Electrode Outlet Flow	6.5 gpm 25 lpm	7.5 gpm 28 lpm	8.7 gpm 33 lpm	10 gpm 38 lpm
General Information				
Number of Stacks	12	18	16	24
Number of Lines	6	6	8	8
Number of Stages	2	3	2	3
Type of Stack	MK-IV-2	MK-IV-2	MK-IV-2	MK-IV-2
Dimensions				
System Dimensions Width x Length	270" x 493" (6.0 x 12.5 m)	270" x 625" (6.0 x 15.9 m)	270" x 493" (6.0 x 12.5 m)	270" x 625" (6.0 x 15.9 m)
Inlet Piping1	8" (20 cm)	8" (20 cm)	8" (20 cm)	8" (20 cm)
Product Outlet Piping	8" (20 cm)	8" (20 cm)	8" (20 cm)	8" (20 cm)
Off-Spec Outlet Piping	8" (20 cm)	8" (20 cm)	8" (20 cm)	8" (20 cm)
Electrode Outlet Piping	3" (8 cm)	3" (8 cm)	3" (8 cm)	3" (8 cm)
Concentrate Outlet Piping	3" (8 cm)	3" (8 cm)	3" (8 cm)	3" (8 cm)
Note: all piping sizes are provided for nominal flow rates at 85% recovery.				
Electrical				
Maximum Rectifier Output (Per Stack Basis)				
Stage 1	590VDC, 46A	590VDC, 26A	590VDC, 46A	590VDC, 26A
Stage 2	518VDC, 18A	518VDC, 14A	518VDC 18A	518VDC, 14A
Stage 3		420VDC, 7.5A		420VDC, 7.5A
Connection Requirement (Includes Feed pump, which may be supplied by others)	380 KVA	285 KVA	542 KVA	397 KVA
Typical Power consumption	2 – 4 kWh/1,000 gallons of product water			
Performance, number of stages and cell pairs, recovery and power consumption are dependent on inlet feed water quality and temperature. A Watsys projection must be completed by an authorized GE Water & Process Technologies design representative for proper system design & for any performance guarantee to be provided.				

NOTES:

1. CONNECTION TABLE

ITEM	DESCRIPTION	MATERIAL	TYPE	SIZE
A	FEED	PVC SCH80	FLANGE	8.0
B	DILUTE	PVC SCH80	FLANGE	8.0
C	DILUTE OFF SPEC	PVC SCH80	FLANGE	8.0
D	CIP FEED (CUSTOMER)	PVC SCH80	FLANGE	8.0
E	CONCENTRATE BLOWDOWN	PVC SCH80	FLANGE	3.0
F	CIP PARALLEL RETURN (CUSTOMER)	PVC SCH80	FLANGE	8.0

2. SHIPPING WEIGHT/ OPERATING WEIGHT :

PART NUMBER	DESCRIPTION	SHIPPING WEIGHT	OPERATING WEIGHT
3023473	ASSY,EDR,INLET MODULE,2 LINES	750 LB/[350 Kg]	900 LB/[400 Kg]
3023474	ASSY,EDR,OUTLET MODULE,2 LINES	800 LB/[365 Kg]	900 LB/[410 Kg]
3023478	ASSY,EDR,CATWALK,3 STACKS	1350 LB/[625 Kg]	1650 LB/[7[illegible]5 Kg]
3024072	ASSY,EDR-8-3-3X600-PRE,PUMPMODULE	6600 LB/[3000Kg]	12000 LB/[5500 Kg]
3103191	EDR-STACK,MKIV-2,600CP,1/1,CARB-EL-404	1000 LB/[450 Kg]	2000 LB/[900 Kg]

3. PLUMBING RUN \ EQUIPMENT TABLE:

FIND NO.	PART NUMBER	QTY.	DESCRIPTION	U/M
1	3023473	4	ASSY,EDR,INLET MODULE,2 LINES	EA
2	3023474	4	ASSY,EDR,OUTLET MODULE,2 LINES	EA
3	3023478	4	ASSY,EDR,CATWALK,3 STACKS	EA
4	3024018	8	PLMB,PVC,8.00,PDTX2,EDR	EA
5	3024062	4	PLMB,PVC,0.50,PDTX2,EDR	EA
6	3024072	1	ASSY,EDR-8-3-3X600-PRE,PUMP MODULE	EA
7	3024093	64	PLMB,REV/STACK,MODULAR,HOSE/PVC,2.00	EA
8	3024094	64	PLMB,STACK/STACK,MODULAR,HOSE/PVC,2.00	EA
9	3053817	1	DISCONNECT,100A,480VAC,N4,GE	EA
10	3055448	1	VFD,GE,AF650,65 FLA,N4X,380/480VAC	EA
11	3103191	24	EDR-STACK,MKIV-2,600CP,1/1,CARB-EL-404	EA
12	3115181	4	ASSY-SUPPORT,IC-PLMB,71.00X13.75,EDR	EA
13	3134553	1	ELEC-ASSY,DC PWR SUPPLY,EDR,2020-8L-3S	EA

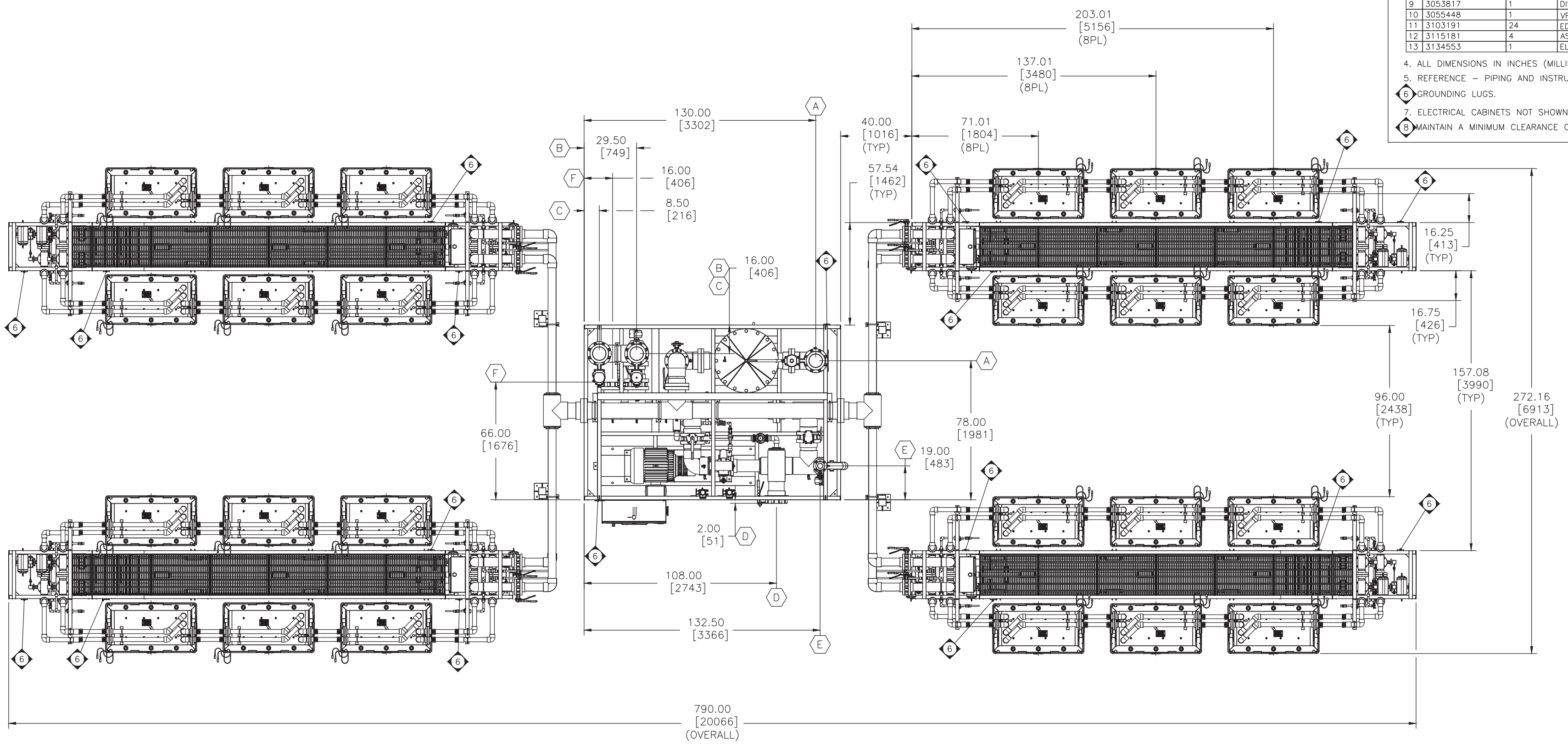
4. ALL DIMENSIONS IN INCHES (MILLIMETERS IN BRACKETS).

5. REFERENCE - PIPING AND INSTRUMENTATION DIAGRAM: 1302829

6. GROUNDING LUGS.

7. ELECTRICAL CABINETS NOT SHOWN, ITEMS 9,10 & 13.

8. MAINTAIN A MINIMUM CLEARANCE OF 8 FEET AROUND ALL EQUIPMENT.



REV	DESCRIPTION	ECO	DWN	APVD	DATE	CHKD
E	NEW EDR STACK CHANGED	15734	AK	BRB	31MAR14	JB
D	PLUMBING UPDATED TO USE HSB CONNECTION	15315	SA	JB	02JAN13	SKS
C	EDR STACK UPDATE	14397	AK	PH	06JUN11	AD
B	REVISED PER REDLINE	13590	PDT	JSS	18MAR09	BRB
A	INITIAL RELEASE	13017	–	–	–	–

TOLERANCES UNLESS NOTED
DECIMALS .X .XX ±0.50 .XXX
ANGLES ±0.5
FRAC ±1/2

DIMENSIONS IN INCHES
DO NOT SCALE
THIRD ANGLE

DRAWN BY	PDT	DATE 08JUN07
CHECKED BY	JSS	DATE 05NOV07
APPROVED BY	BRB	DATE 05NOV07
APPROVED BY	–	DATE –

GE
Water & Process Technologies
GLOBAL HEADQUARTERS : TREVOSE, PA USA +1-215-355-3300 WWW.GEWATER.COM

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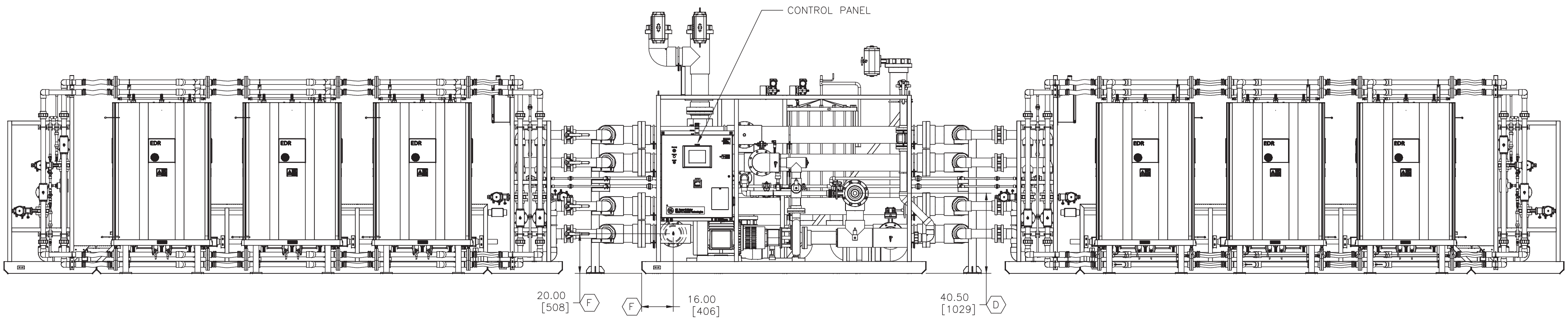
CLIENT/JOB
FILE AUTOCAD

TITLE GA SYS, EDR-2020-8L-3SX600CP-PRE
MATERIAL 3022152

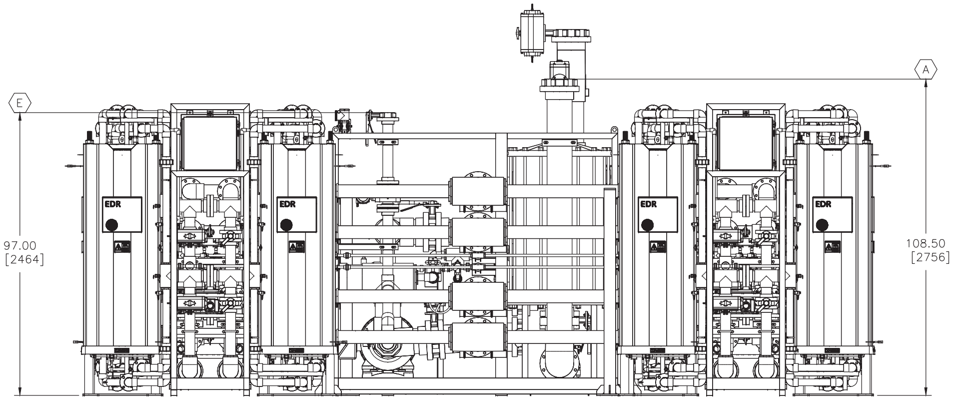
SIZE D
DRAWING NO. 1303044
REV E
PROJECT
SCALE 1:32
SHEET 1 OF 4

P/N 1161662-RHP01

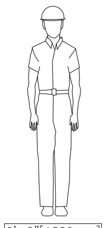
Electronic Filing: Received, Clerk's Office 05/30/2019 P.C. #6



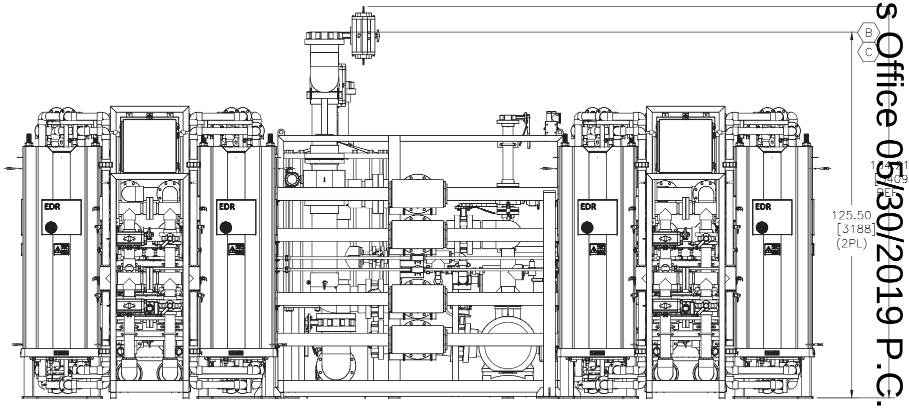
FRONT VIEW
SCALE : 7:16



RIGHT SIDE VIEW
SCALE : 3:64



6'-0"[1829mm]
(REF PERSON)



LEFT SIDE VIEW
SCALE : 3:64

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TOLERANCES UNLESS NOTED
DECIMALS
.X
.XX ±0.50
.XXX
ANGLES
±0.5
FRAC
±1/2
DIMENSIONS IN INCHES
DO NOT SCALE
THIRD ANGLE

DRAWN BY PDT	DATE 08JUN07
CHECKED BY JSS	DATE 05NOV07
APPROVED BY BRB	DATE 05NOV07
APPROVED BY –	DATE –

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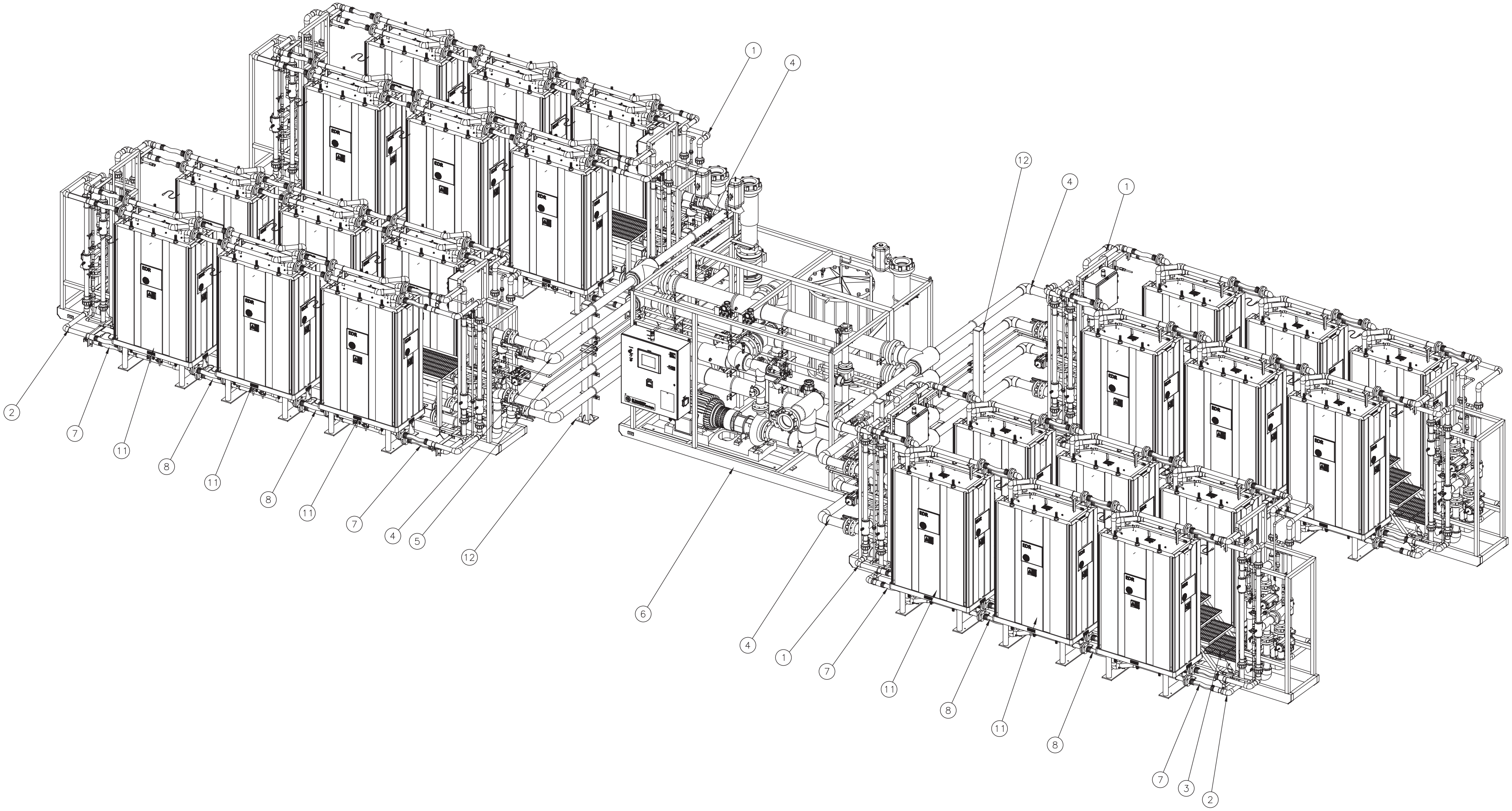
GA SYS,
EDR-2020-8L-3SX600CP-PRE
MATERIAL 3022152
SIZE D
DRAWING NO. 1303044
REV E
PROJECT
SCALE 7:16
SHEET 2 OF 4

P/N 1161662-RHP01



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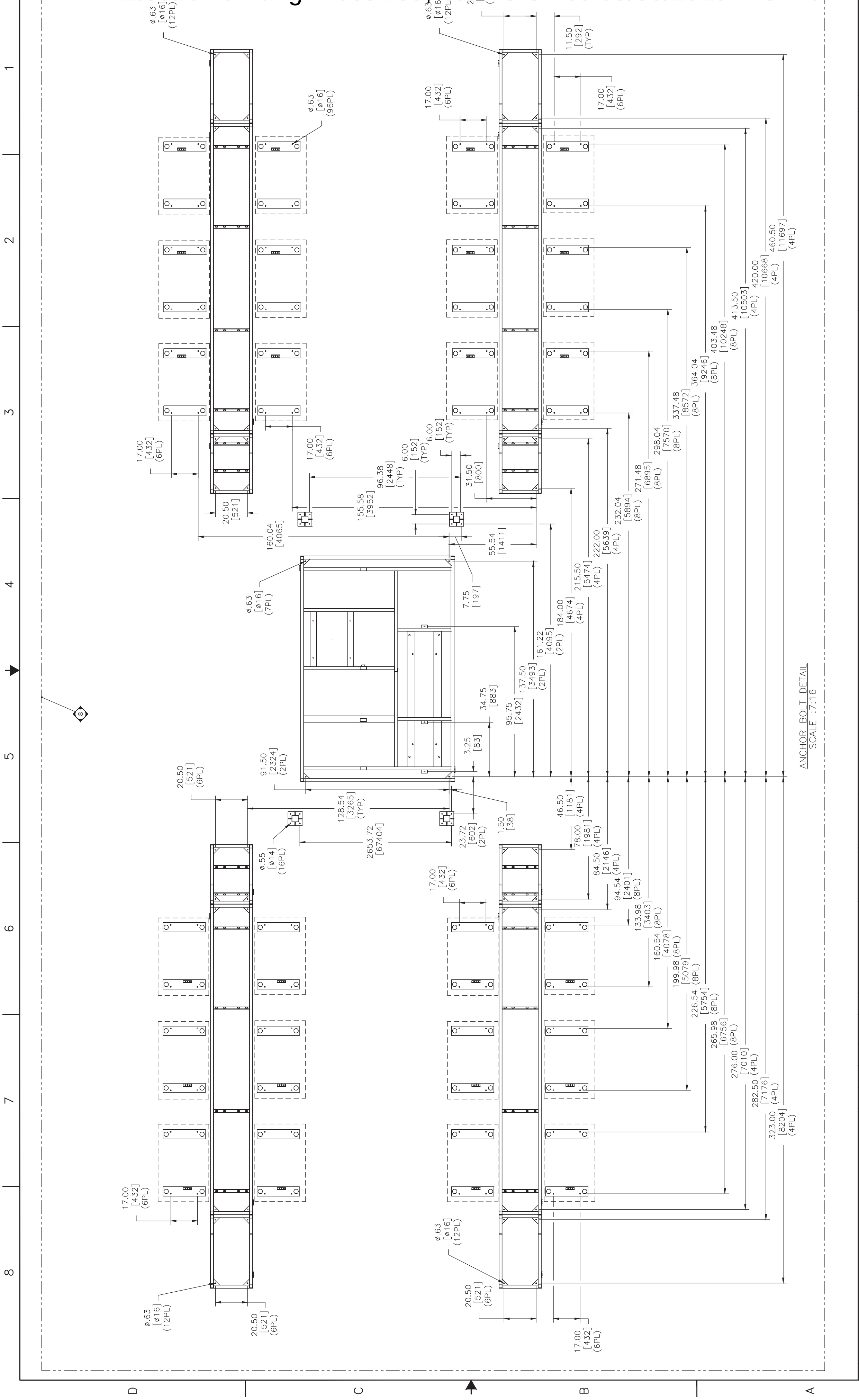
SCALE 7:16
SHEET 3 OF 4

P/N 1161662-RHP01

Electronic Filing: Received, Clerk's Office 05/30/2019 P.C. #6



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MATERIAL 3022152

SIZE	DRAWING NO.	REV
D	1303044	E

PROJECT

SCALE 7:16 SHEET 4 OF 4

P/N 1161662-RHP01

AECOM
5555 Glenwood Hills Pkwy, Ste. 300
Grand Rapids, Michigan 49512
www.aecom.com

616 942 9600 tel
616 940 4396 fax

Memorandum

To	File	Page	1
cc			
Subject	San Diego EDR System Telephone Conversation		
From	Eric Van Orman		
Date	December 3, 2014		

On December 3, 2014 I contacted Albert Sohikish an engineer with the City of San Diego who is familiar with the EDR process they have in operation. Following are some key points from that discussion:

1. The plant is currently reducing their use of the EDR units and in the process of transitioning to MF/RO units. The rational for this is the district has a goal of reusing reclaimed water as drinking water and the MF/RO is more conducive to this. They plan to ultimately reclaim water at three different facilities rated at 30, 40 and 50 MGD.
2. The San Diego facilities are and plan to place future membrane equipment after a tertiary filtration step at the plants.
3. They currently have a 60 to 65% TDS reduction through the EDR units. Albert indicated that they have 3 stage EDR units but subsequent conversations with Patrick Girvin of GE indicated there are only 2 stages.
4. Albert indicated that the EDR units are more energy efficient and use less chemicals than the MF/RO system. He did however indicate that they clean these units every 800 hours of operation or so and that 2 GE contract employees work full time to maintain the 6 MGD system. GE indicated that this cleaning cycle is likely overkill and advances in membranes have also improved the run times.
5. San Diego has had a good experience with the EDR systems. They did however indicate that equipment and membranes pricing increased significantly when Ionics was acquired by GE.

Follow-up questions and responses from Albert Sohikish and Patrick Girvin are attached.

Vanorman, Eric

From: Sohikish, Albert <ASohikish@sandiego.gov>
Sent: Wednesday, December 03, 2014 5:53 PM
To: Vanorman, Eric
Subject: RE: Follow-up questions on EDR system
Attachments: City SD EDR Product 4 Nov 2011.RTF; City SD Feed 4 Nov 2011.RTF

Hi Eric, please see my comments below. Let me know if you need additional information.

Thanks,
Albert

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Wednesday, December 03, 2014 1:25 PM
To: Sohikish, Albert
Subject: Follow-up questions on EDR system

Albert:

Thank you so much for taking the time this morning to discuss your EDR system. After reviewing my notes from our call I came up with a few more questions which I am hoping you can answer, and if not, hopefully point me in the direction of someone who may.

1. If I understood correctly you currently have anthracite deep bed granular media filters providing tertiary treatment ahead of the EDR units. For the MF/RO treatment do you also plan to have tertiary treatment upstream and if so will it be a similar process?
   Anthracite coal has been used as a roughing filter medium at two of our reclamation plants. The third reclamation plant is scheduled for 2025 and I do not know what type of filtration will be designed for this future treatment plant. Regardless of having EDR equipment or MF/RO, tertiary treatment process is required for the production of reclaimed water.

   Primarily we use EDR system to lower the total dissolved solids in reclaimed water. The MF/RO and more advanced system will be required to produce purified (drinking) water. As stated, we currently operating both EDR system and MF/RO at the North City Water Reclamation Plant which anthracite coal is being used for filtration.

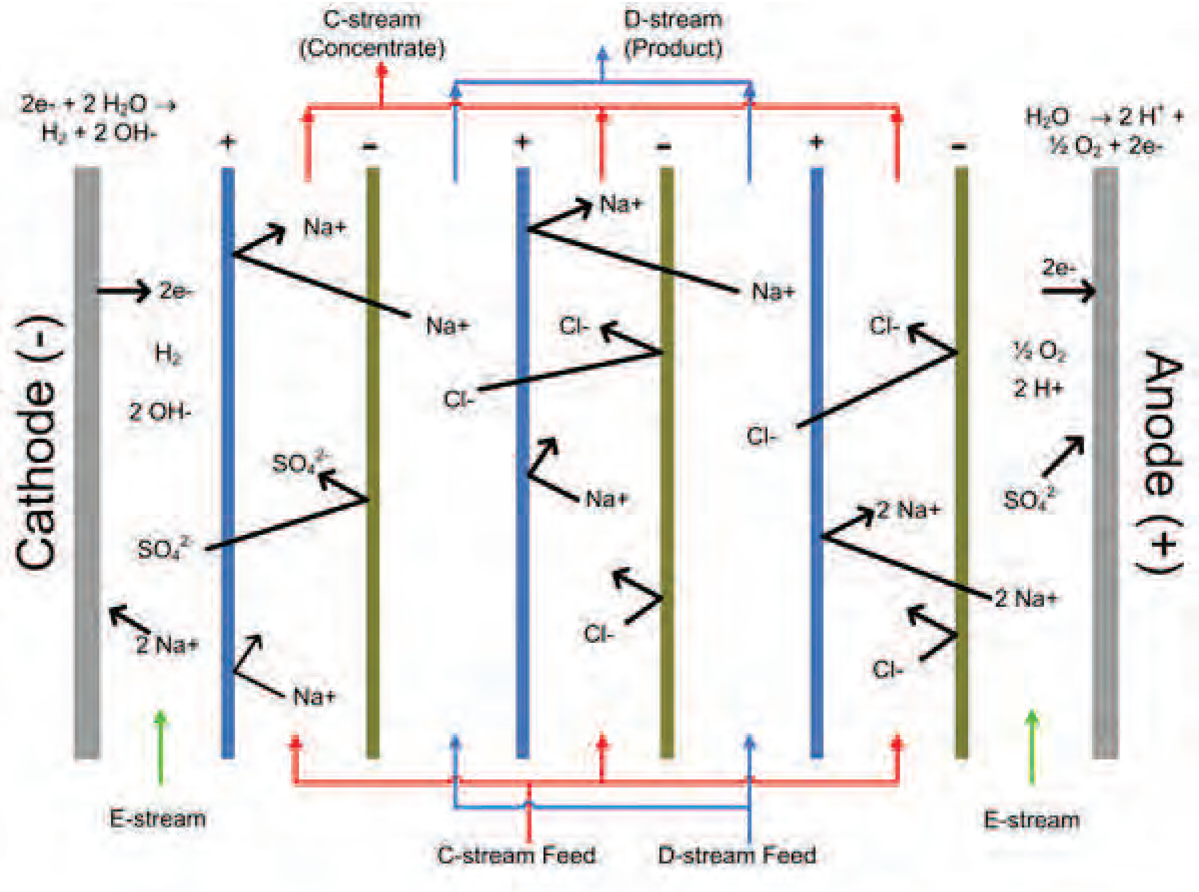
2. Have you needed to replace membranes yet? If so what was their life span?
   Yes, we have replace several of the membrane stacks so far and generally they last for about ten years. Though anions have a smaller life span than cations, so cation would have a longer life span than 10 years.

3. Do you know what type of fouling was typically limiting on the membranes? Biological, mineral, other?
   Cellulose acetate membranes can be degraded by microbiological activity. Proper maintenance of chlorine residuals can prevent microbiological attack of these membranes.

   Polyacrylamide membranes are resistant to microbiological degradation; however, they are susceptible to chemical oxidation. Therefore, chlorination is not an acceptable treatment. If inoculation occurs, microbiological fouling can become a problem. Nonoxidizing antimicrobials and biodispersants should be used if serious microbiological fouling potential exists.

4. What chemicals and dosages are typically used as part of the EDR process and for CIP?
   We use HCL for the ECIPs. 10 gallons per day per EDR unit while unit is online. We use sodium hypochlorite in the discharge side of the concentrate pump. 2-5 ppm. We do not use NaOCl for disinfection. The addition of NaOCl in the discharge side of concentrate pump is to lower stack inlet pressure and other adverse effects of coagulants added in the plant clarifiers such as hot spots.
   CIP is performed when needed. Average ranges from 500 to 700 hours.

5. It would be interesting to see any standard EDR influent and effluent values for the system which may be available.
   Attached are the results of water sample analysis for North City. Chloride reduction results vary according with the velocity of water thru the stacks. EDR 4,5 results have a better reduction ,but they make less water: 724 gpm vs 800 gpm in the land based stacks EDR 1,2,3,6.



Courtesy EET Corporation
www.eetcorp.com

Thanks again for discussing this with me. If you would rather give me a call to respond to these questions my number is below.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512

GE Power & Water
Water & Process Technologies

WATER ANALYSIS REPORT

N04324
NORTH CITY WATER RECLAMATION PLANT
SAN DIEGO WATER TREATMENT
4949 EASTGATE MALL RD
San Diego, CA

Sampled: 04-NOV-2011
Reported: 09-DEC-2011
Field Rep: Costa, Carlos
91002719

	FEED V1114237
Anion Sum, as $CaCO_3$	604
Cation Sum, as $CaCO_3$	661
pH	7.2
Specific Conductance, at 25°C, µmhos	1280
Alkalinity, "P" as $CaCO_3$, ppm	0
Alkalinity, "M" as $CaCO_3$, ppm	86
Sulfate, as SO_4, ppm	128
Chloride, as Cl, ppm	237
Hardness, Total, as $CaCO_3$, ppm	249
Barium, Total, as Ba, ppm	0.019
Strontium, Total, as Sr, ppm	0.45
Copper, Total, as Cu, ppm	< 0.002
Iron, Total, as Fe, ppm	0.069
Sodium, as Na, ppm	175
Potassium, as K, ppm	23
Nitrite, as NO_2, ppm	< 5

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	FEED V1114237
Nitrate, as NO_3, ppm	61
Phosphate, Total, as PO_4, ppm	6.8
Silica, Total, as SiO_2, ppm	15.0
Fluoride, as F, ppm	0.6
Boron, as B, ppm	0.38
Calcium, Total, as Ca, ppm	53
Magnesium, Total, as Mg, ppm	28
Silver, as Ag, ppm	< 0.01
Carbon, Total Organic, as C, ppm	50

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	EDR#1 PROD + POLAR V1115169	EDR#1 PROD - POLAR V1115170	EDR#2 POS PRODUCT V1115171	EDR#2 NEG PRODUCT V1115172
Anion Sum, as $CaCO_3$	214	210	229	235
Cation Sum, as $CaCO_3$	224	219	242	261
pH	7.0	7.0	7.0	7.1
Specific Conductance, at 25°C, µmhos	495	467	501	511
Alkalinity, "P" as $CaCO_3$, ppm	0	0	0	0
Alkalinity, "M" as $CaCO_3$, ppm	46	47	49	51
Sulfate, as SO_4, ppm	52	48	57	58
Chloride, as Cl, ppm	70	70	76	78
Hardness, Total, as $CaCO_3$, ppm	40	44	51	65
Barium, Total, as Ba, ppm	< 0.005	< 0.005	0.005	0.005
Strontium, Total, as Sr, ppm	0.071	0.077	0.090	0.12
Copper, Total, as Cu, ppm	< 0.002	< 0.002	< 0.002	< 0.002
Iron, Total, as Fe, ppm	0.047	0.046	0.047	0.051
Sodium, as Na, ppm	80	76	83	84
Potassium, as K, ppm	7.3	7.0	7.6	7.6
Nitrite, as NO_2, ppm	< 0.5	< 0.5	< 0.5	< 0.5

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	EDR#1 PROD + POLAR V1115169	EDR#1 PROD - POLAR V1115170	EDR#2 POS PRODUCT V1115171	EDR#2 NEG PRODUCT V1115172
Nitrate, as NO_3, ppm	17.1	16.5	15.7	15.3
Phosphate, Total, as PO_4, ppm	3.0	3.1	3.4	3.4
Silica, Total, as SiO_2, ppm	13.6	13.7	13.9	14.6
Fluoride, as F, ppm	0.4	0.4	0.4	0.4
Boron, as B, ppm	0.34	0.35	0.37	0.39
Calcium, Total, as Ca, ppm	8.1	8.7	10.2	13.3
Magnesium, Total, as Mg, ppm	4.9	5.3	6.1	7.7
Silver, as Ag, ppm	< 0.01	< 0.01	< 0.01	< 0.01
Carbon, Total Organic, as C, ppm	10.0	15.0	11.0	10.0

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	EDR#3 POS PRODUCT V1115173	EDR#3 NEG PRODUCT V1115174	EDR#4 PROD + POLAR V1115175	EDR#4 PROD - POLAR V1115176
Anion Sum, as $CaCO_3$	241	229	167	161
Cation Sum, as $CaCO_3$	247	230	169	178
pH	7.1	7.1	7.0	6.9
Specific Conductance, at 25°C, µmhos	523	487	367	371
Alkalinity, "P" as $CaCO_3$, ppm	0	0	0	0
Alkalinity, "M" as $CaCO_3$, ppm	51	50	31	30
Sulfate, as SO_4, ppm	59	55	67	66
Chloride, as Cl, ppm	80	76	41	39
Hardness, Total, as $CaCO_3$, ppm	44	41	24	25
Barium, Total, as Ba, ppm	< 0.005	< 0.005	< 0.005	< 0.005
Strontium, Total, as Sr, ppm	0.077	0.072	0.041	0.042
Copper, Total, as Cu, ppm	< 0.002	< 0.002	< 0.002	< 0.002
Iron, Total, as Fe, ppm	0.051	0.051	0.050	0.053
Sodium, as Na, ppm	88	82	63	67
Potassium, as K, ppm	8.5	7.4	5.5	5.3
Nitrite, as NO_2, ppm	< 0.5	< 0.5	< 0.5	< 0.5

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	EDR#3 POS PRODUCT V1115173	EDR#3 NEG PRODUCT V1115174	EDR#4 PROD + POLAR V1115175	EDR#4 PROD - POLAR V1115176
Nitrate, as NO_3, ppm	18.5	16.9	10.3	8.7
Phosphate, Total, as PO_4, ppm	3.6	3.4	2.7	2.8
Silica, Total, as SiO_2, ppm	14.2	14.1	13.9	14.6
Fluoride, as F, ppm	0.4	0.4	0.2	0.3
Boron, as B, ppm	0.36	0.36	0.35	0.37
Calcium, Total, as Ca, ppm	9.0	8.3	4.8	4.8
Magnesium, Total, as Mg, ppm	5.3	5.0	3.0	3.1
Silver, as Ag, ppm	< 0.01	< 0.01	< 0.01	< 0.01
Carbon, Total Organic, as C, ppm	12.0	5.0	1.2	4.0

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	EDR#5 PROD + POLAR V1115177	EDR#5 PROD - POLAR V1115178	EDR#6 POS PRODUCT V1115179	EDR#6 NEG PRODUCT V1115180
Anion Sum, as $CaCO_3$	172	166	241	244
Cation Sum, as $CaCO_3$	193	177	248	286
pH	6.9	6.9	7.2	7.2
Specific Conductance, at 25°C, µmhos	380	369	535	543
Alkalinity, "P" as $CaCO_3$, ppm	0	0	0	0
Alkalinity, "M" as $CaCO_3$, ppm	35	33	54	52
Sulfate, as SO_4, ppm	68	65	27	25
Chloride, as Cl, ppm	41	41	99	102
Hardness, Total, as $CaCO_3$, ppm	26	26	37	47
Barium, Total, as Ba, ppm	< 0.005	< 0.005	< 0.005	< 0.005
Strontium, Total, as Sr, ppm	0.044	0.044	0.062	0.080
Copper, Total, as Cu, ppm	< 0.002	< 0.002	< 0.002	< 0.002
Iron, Total, as Fe, ppm	0.056	0.051	0.041	0.044
Sodium, as Na, ppm	73	66	92	104
Potassium, as K, ppm	5.9	5.6	8.6	10.4
Nitrite, as NO_2, ppm	< 0.5	< 0.5	< 0.5	< 0.5

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Reported: 09-DEC-2011
Field Rep: Costa, Carlos
91002719

	EDR#5 PROD + POLAR V1115177	EDR#5 PROD - POLAR V1115178	EDR#6 POS PRODUCT V1115179	EDR#6 NEG PRODUCT V1115180
Nitrate, as NO_3, ppm	9.3	9.3	23	26
Phosphate, Total, as PO_4, ppm	3.1	2.8	2.5	2.7
Silica, Total, as SiO_2, ppm	15.3	14.4	14.1	16.1
Fluoride, as F, ppm	0.3	0.2	0.4	0.4
Boron, as B, ppm	0.39	0.37	0.36	0.40
Calcium, Total, as Ca, ppm	5.1	5.1	7.2	9.3
Magnesium, Total, as Mg, ppm	3.2	3.1	4.5	5.7
Silver, as Ag, ppm	< 0.01	< 0.01	< 0.01	< 0.01
Carbon, Total Organic, as C, ppm	3.0	5.0	20	15.0

Vanorman, Eric

From:	Girvin, Patrick (GE Power & Water) <Patrick.Girvin@ge.com>
Sent:	Wednesday, December 03, 2014 3:53 PM
To:	Vanorman, Eric
Subject:	RE: Wastewater Effluent Chloride Removal - RO

Eric,
Glad that Albert was helpful.

1. The EDR system at San Diego is only two stages (not three). They have about 1200 mg/L of TDS is the feed water, and they treat down to about 400 mg/L. Their effluent requirement is under 1,000 mg/L, so they end up blending 50:50 with feed water.
2. I agree with you that this is excessive, and we've talked to them about it, but they like having the staff on site working on the system. A couple things that would be different in a new system: new membranes and better operating practices. The new membranes are a WW specific membrane that has been designed to handle higher solids loading. It also allows us to do high pH cleans which will clean more of the organics and foulants in the water. This cleaning CIP can be performed automatically to enhance performance, and will minimize the manual cleans.

Let me take a look at the RO aspect.

-Patrick

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Wednesday, December 03, 2014 2:29 PM
To: Girvin, Patrick (GE Power & Water)
Subject: RE: Wastewater Effluent Chloride Removal - RO

Hi Patrick:

Thanks for the contact info! I had a nice chat with Albert this morning. It seems like they are happy with their EDR system. I did have a couple of questions that you may be able to clear up for me.

1. Albert stated that they are getting 60 to 65% removal of TDS through the units. My understanding is that these are three stage units similar to what is proposed for our Wisconsin site, but we're looking at 92% removal of chloride. Is this due to the difference between overall TDS and Cl or is it due to variations in the influent concentrations?
2. Albert indicated that they had a contract with GE in which 2 full time personnel are kept busy with cleaning (CIP) of the EDR systems. Based on my current understanding of EDR technology this seemed excessive. Is this a function of their pretreatment? Maybe you can help clarify this.

With regards to the RO analysis how quickly could you pull together some recommended sizing and equipment offerings? As part of this we would also be looking at the potential for 2nd stage MF/RO or softening followed MF/RO to help minimize the brine waste volume. We would also be interested in your thoughts on that.

If you would like to discuss further please don't hesitate to contact me.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water

D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600   F 1.616.940.4396 Cisco 2084446
www.aecom.com

From: Girvin, Patrick (GE Power & Water) [mailto:Patrick.Girvin@ge.com]
Sent: Wednesday, December 03, 2014 8:38 AM
To: Vanorman, Eric
Subject: RE: Wastewater Effluent Chloride Removal - RO

Albert Sohikish is the Engineer for San Diego that is most familiar with the project.
I can help put an RO analysis together.
For AutoCAD files, I will need to get an NDA in place. I'll start to work on that later this afternoon.

-Patrick

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Tuesday, December 02, 2014 2:42 PM
To: Girvin, Patrick (GE Power & Water)
Subject: RE: Wastewater Effluent Chloride Removal - RO

Hi Patrick:

Couple questions as we are reviewing the various options related to our chloride removal project:

1. Do you have a reference and contact number for the San Diego municipal wastewater facility? We would like to speak with them regarding their EDR system?
2. Is there somebody within GE with whom I may be able to discuss the potential for an RO system alternative at this Wisconsin facility?
3. Would it be possible to get your general arrangement *.pdf's drawings in AutoCAD format which could be used in some conceptual layouts?

Please let me know if you have any questions.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

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From: Girvin, Patrick (GE Power & Water) [mailto:Patrick.Girvin@ge.com]
Sent: Friday, November 14, 2014 12:18 PM
To: Vanorman, Eric
Subject: RE: Wastewater Effluent Chloride Removal - RO

LIME SOFTENING VENDOR INFO

Westech

WESTECH
an employee-owned company

Proposal For:
AECOM

Equipment:
Solids CONTACT CLARIFIER™ Mechanisms

Represented By:
Hamlett Environmental Technologies
905 Gulley
Howell, MI 48843
Contact: Scott Kafka
Phone: (517) 545-2500
Fax: (517) 545-3231
scottk@hamlettenvironmental.com

Furnished By:
WesTech Engineering, Inc.
Salt Lake City, Utah 84115
Contact: Tyler Drzycimski
Direct: 801.290.7019
Phone: 801.265.1000
Fax: 801.265.1080

WesTech Proposal: 1560029
Wednesday, January 28, 2015

ITEM "A" - Two (2) 30' Dia. x 16' SWD Solids CONTACT CLARIFIER™ Mechanisms WesTech Model No. SCS71

BASIS OF DESIGN (EACH)

Application:	Brine Softening
Design Flow Rate:	525 gpm
Peak Flow Rate:	1,050 gpm
Surface Loading Rate:	0.82 gpm/ft^2
Recirculation Rate:	4,200 gpm
Flocculation Well Detention Time:	30 min
Basin Detention Time:	165 minutes

EACH UNIT FURNISHED COMPLETE BY WESTECH WITH THE FOLLOWING COMPONENTS:

DRIVE

One (1) WesTech standard dual shaft drive unit. Rake drive unit designed for a minimum of 9,000 ft-lbs continuous rated torque, with steel housing, forged alloy steel precision bearing and integral spur gear, cycloidal or helical speed reducer, and 1/2 hp TEFC motor. Radial impeller drive unit utilizing helical speed reducers, support bearings and one (1) 2 hp min. TEFC VFD rated motor. All motors to be suitable for 480 V, 3 phase, 60 Hz supply power.

One (1) WesTech Torkmatic™ overload control for the rake drive with two (2) adjustable switches for alarm and motor cutout.

DRIVE SHAFT

One (1) 6" dia. carbon steel drive shaft to transmit torque from the drive unit to the rake arms. Shaft will include steel cone scraper to scrape the sludge sump twice per revolution.

RAKE ARMS

Two (2) structural carbon steel rake arms with segmented blades and adjustable 304 stainless steel squeegees which scrape the tank bottom twice per revolution.

IMPELLER

One (1) carbon steel recirculation impeller with swept back blades will be provided. Impeller will be designed to pump the previously specified recirculation rate at a maximum tip speed of 4.25 ft/sec.

DRAFT TUBE

One (1) 3/16" thick carbon steel draft tube will be provided.

REACTION WELL

One (1) carbon steel reaction well fabricated of 3/16" thick carbon steel plate.

INLET PIPE

One (1) 8" diameter x 1/4" thick inlet pipe will be provided from the draft tube to the wall pipe. Wall pipe and coupling to be by others, not by WesTech.

BRIDGE / WALKWAY / PLATFORM

One (1) mechanism support bridge supported by the tank wall on both ends. Bridge will be designed not to exceed a deflection of 1/360 of the span applying all dead loads and a live load of 50 lbs per square foot. One (1) 36" wide walkway with handrails will extend from one end of the bridge to the equipment platform. Walkway and equipment platform will be floored with 1-1/4" aluminum I-bar grating with 1-1/2" dia., double row, 42" high aluminum handrail with 4" high toe plates provided at the base of handrail. The center drive platform will provide a minimum of 24" clearance around the center drive components.

LAUNDER SYSTEM

Six (6) radial launders will be supplied. Launders will be made from 3/16" thick carbon steel plate. All radial launders to be of weir trough design. Each basin will include one (1) annular collection launder to collect water from the radial launders and transfer it to the main discharge outlet launder.

SAMPLE VALVES

Six (6) bronze sample valves will be supplied for the clarifier sample lines. Samples lines and sample sink will be provided.

BLOWDOWN VALVE

One (1) air actuated cast iron diaphragm valve with remote mounted 120 VAC electrically operated solenoid pilot valve will be supplied.

ANCHOR BOLTS AND FASTENERS

316 stainless steel anchor bolts and 316 stainless steel assembly fasteners will be provided.

SURFACE PREPARATION AND PAINTING

All submerged fabricated steel:

Abrasive blast to minimum angular profile of 2 mils, painted with
Primer: zinc rich primer, 2.5- 3.5 mils DFT.
Finish: high solids modified polyamine epoxy, 14.0 – 18.0 mils DFT.

All non-submerged fabricated steel:

Sandblasted to SSPC-SP6 / NACE 3 commercial blast, painted with
(1) coat of Tnemec N140-1255, 3 to 7 mils DFT, and
(1) coat of Tnemec 140-Color B5712 Pota Pox® Plus, 3 to 7 mils DFT.

Drive units:

Sandblasted to SSPC-SP6 / NACE 3 commercial blast, painted with
(1) coat Tnemec N140F-1255 3 to 9 mils DFT, and
(1) coat Tnemec 1074U-B5712 Dark Blue Aliphatic Acrylic Polyurethane enamel, 2 to 5 mils DFT.

CONTROL PANEL

One (1) Hoffman, NEMA 4X, 304 stainless steel control panel for complete start, stop and alarm functions for the clarifier. Included in the panel are also controls for operation of the impeller. The control panel will be provided with door mounted, operators and status lights. A 1/2 hp rated magnetic combination starter with internally reset thermal overloads and a 2 hp rated VFD with line reactor for the impeller is provided. Also, all necessary relays, fuse and fuse blocks, terminal blocks, and other miscellaneous hardware will be provided. A control power transformer will provide 120 VAC for internal controls. The transformer will have both primary legs and one secondary leg fused.

A top mounted, red light with horn and silence pushbutton provide indication of a high torque condition. A door mounted reset pushbutton clears all interlocks after the torque conditions have been removed.

The control panel is wired to accept a single 480VAC, 3 phase, 60 Hz power feed from the customer. A 3 pole, circuit breaker with padlockable disconnect handle is provided for short circuit protection. All wiring for field connections will be brought to a terminal strip. All interconnecting wiring to be by others.

BLOWDOWN PANEL

One (1) Hoffman, NEMA 4X, 304 stainless steel enclosure will be provided with controls for two Clarifiers. The control panel will include a door mounted selector switches. Internally, will be timers, fuses and fuse blocks, terminal blocks and miscellaneous hardware.

The control panel is wired to accept a single 120 VAC, single phase, 60 Hz power feed from the customer. A 10 amp, single pole, fuse is provided for short circuit protection. All interconnecting wiring and quick disconnects to be by others.

FIELD SERVICE

Total field service to include, three (3) trips and six (6) days for installation inspection, initial start-up, observation of torque testing, and training of plant personnel.

NOTE: ANY ITEM NOT LISTED ABOVE TO BE FURNISHED BY OTHERS.

ITEMS NOT BY WESTECH

Electrical wiring, conduit, or electrical equipment, piping, valves, or fittings, shimming material, lubricating oil or grease, shop or field painting, field welding, erection, assembly of component handrail, detail shop fabrication drawings, performance testing, bonds, unloading, storage, concrete work, or field service (except as specifically noted).

This proposal section has been reviewed for accuracy and approved for issue:

By: Tyler Drzycimski Date: January 28, 2015

BUDGET PRICING

ITEM	EQUIPMENT	PRICE (U.S.)
"A"	(2) Solids CONTACT CLARIFIER™ Mechanisms SCS71	$400,000

The above mentioned equipment was designed according to the information which we received. The dimensions may vary slightly depending on the plant's actual design parameters. Assumed values may have been used, therefore, all information shall be verified by the Engineer.

Unless otherwise indicated, prices listed are for equipment only. All optional items will be offered with the purchase of the scoped equipment only. No optional items will be sold separately.

Prices are for a period not to exceed 30 days from date of proposal.

Warranty: A written supplier's warranty will be provided for the equipment specified in this section. The warranty will be for a minimum period of (1) year from start-up or 18 months from time of equipment shipment, whichever comes first. Such warranty will cover all defects or failures of materials or workmanship which occurs as the result of normal operation and service except for normal wear parts (i.e. squeegees, skimmer wipers, etc.).

Terms: Terms for equipment are 15 percent payment of the purchase price with submittal drawings, 35 percent upon release for fabrication, and 50 percent net **30 days** from shipment. Retentions are not allowed.

Sales Tax: No sales taxes, use taxes, or duties have been included in our pricing.

Freight: Prices quoted are **F.O.B. shipping point** with freight allowed to a readily accessible location nearest to jobsite. All claims for damage or loss in shipment shall be initiated by purchaser.

Submittals: Submittals will be made approximately **6 to 8 weeks** after purchase order is received in our office.

Shipment: Estimated shipment time is **18 to 20 weeks** after approved submittal drawings are received in our office.

Field Service: Prices do not include field service unless noted in equipment description. Additional field service is available at $960.00 per day plus expenses.

Paint: If your equipment has paint included in the price, please take note of the following. Primer paints are designed to provide only a minimal protection from the time of application (usually for a period not to exceed 30 days). Therefore, it is imperative that the finish coat be applied within 30 days of shipment on all shop primed surfaces. Without the protection of the final coatings, primer degradation may occur after this period, which in turn may require renewed surface preparation and coating. If it is impractical or impossible to coat primed surfaces within the suggested time frame, WesTech strongly recommends the supply of bare metal, with surface preparation and coating performed in the field. All field surface preparation, field paint, touch-up and repair to shop painted surfaces are not by WesTech.

CONTACT CLARIFIER™

A true solids contact clarifier

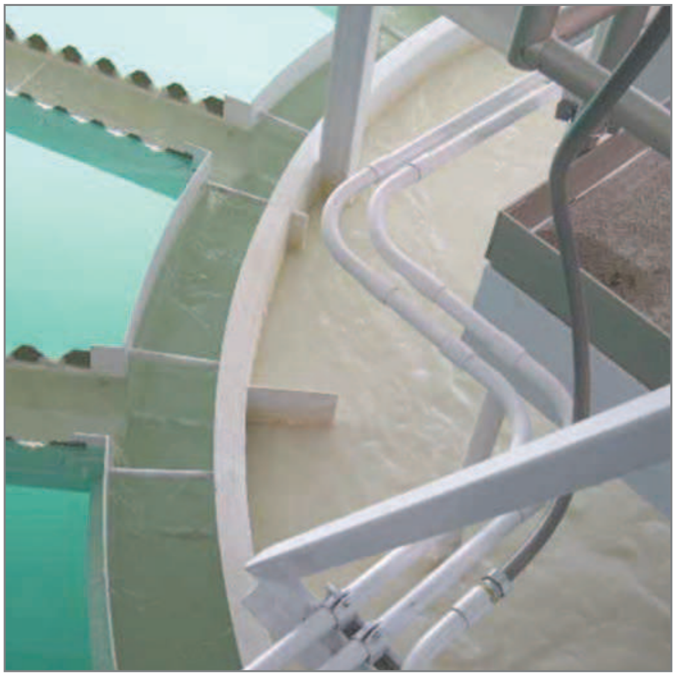
WesTech

The solids CONTACT CLARIFIER™ is a mixture of old art and new process technology. Patent art dates back to the 1880s and contemporary solids contact clarifier units have their origins in the 1940s and 1950s. The two most common applications for the solids CONTACT CLARIFIER are cold lime softening, where the unit is used to ***maximize the rate of chemical precipitation***, and surface water clarification, where the unit is used as an ***enhanced flocculation device.***

With thousands of process equipment installations – hundreds of which are solids CONTACT CLARIFIER units – and more than 40 years of engineering and equipment experience, WesTech offers a unique breadth of expertise through all phases of design, manufacture, installation, and operation. WesTech engineers understand key process design parameters – solids concentration, detention time, recirculation rates, sludge blanket depth, draft tube velocities, chemical addition, blowdown duration / frequency – and how they affect solids CONTACT CLARIFIER sizing and performance. Our installation and field experience in the industrial market benefits the municipal market with fresh insight into design and operations.

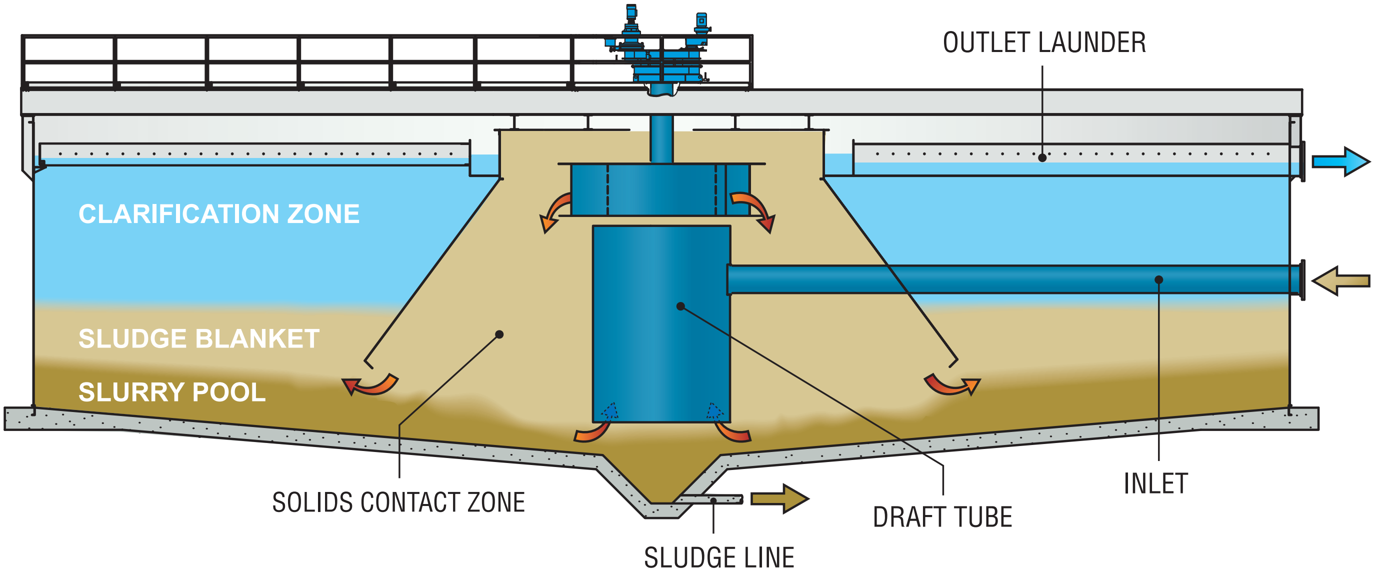
Industrial Surface Water Clarification

Surface Water Clarification



Cold Lime Softening

Slurry Settling Properties are Key



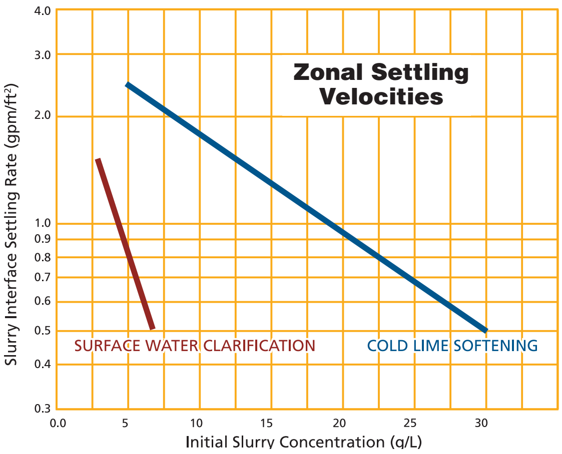
Zones in a True Solids CONTACT CLARIFIER

Solids Contact Zone - where chemical precipitation and /or enhanced flocculation occurs.

Sludge Blanket Zone - where further flocculation occurs.

Slurry Pool - where settled solids are transported to the draft tube entrance.

Clarification Zone - where liquid-solids separation occurs and clear supernatant is removed.



Cold lime softening and surface water clarification produce widely differing slurry properties. Understanding these slurry properties is crucial to understanding the importance of solids inventory and proper operational control.

Depending upon whether the plant flow rate is constant or variable, operational control of solids produced and retained within the CONTACT CLARIFIER is accomplished by utilizing different approaches:

Constant Flow Rate

- Controlling the slurry pool or sludge blanket elevation (when applicable) within a desirable range.
- Controlling the solids contact zone solids concentration (_%Vol@_Min) within a desirable range for effective treatment and performance.

Variable Flow Rate

- Controlling the solids inventory (tons of dry solids) within the CONTACT CLARIFIER below a desirable maximum level that can be retained within the unit at the peak rise rate.

Elements of a True Solids CONTACT

Launder System

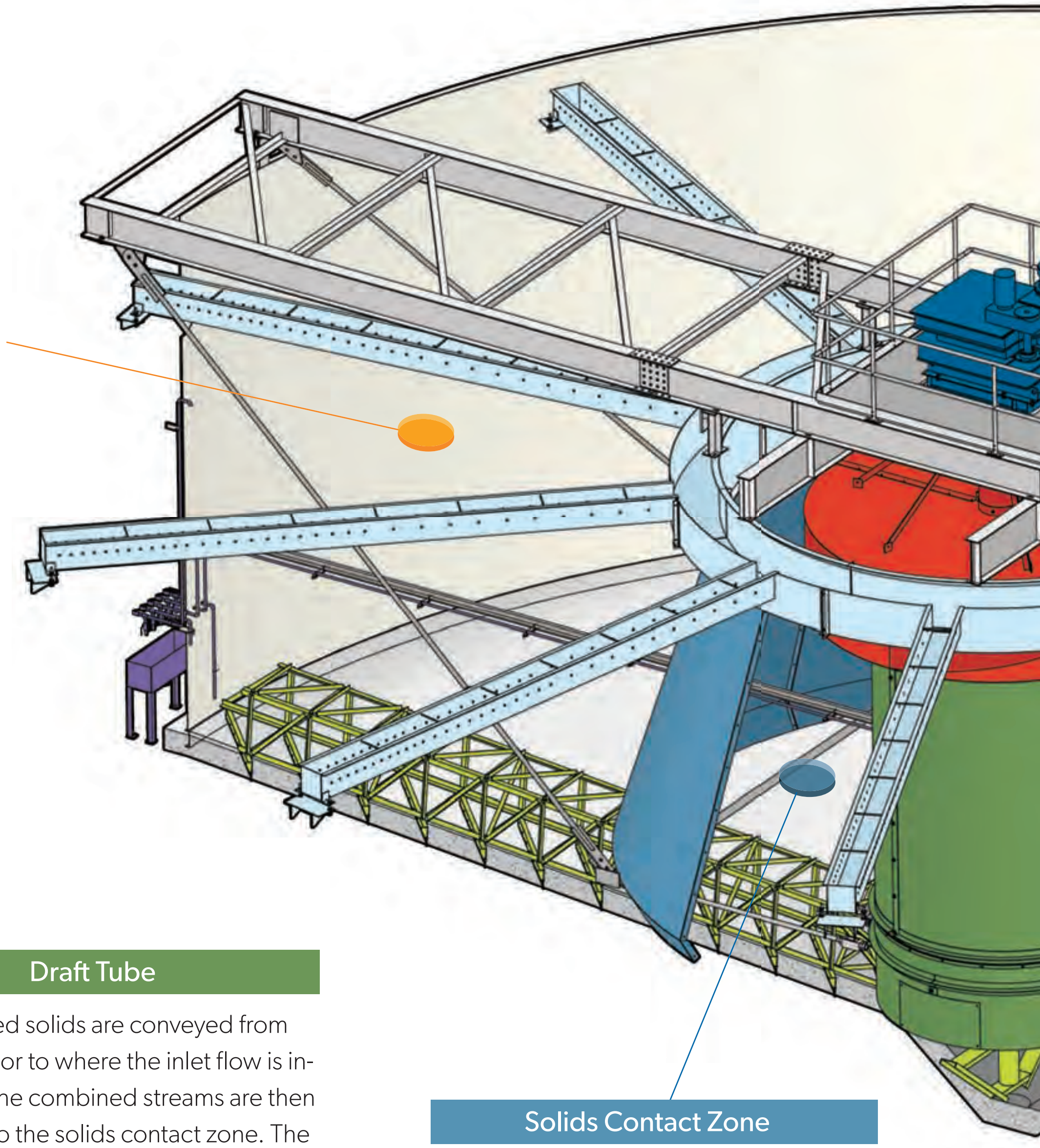
Provides uniform collection of clarified water over the entire clarification zone and transports it out of the basin. Launders can be radial or peripheral.

Clarification Zone

Where clarified water rises and solids settle. Often a sludge blanket is maintained low in this zone to improve clarity by providing low-energy flocculation.

Sample Lines

Strategically located to allow monitoring of solids inventory.



Draft Tube

Concentrated solids are conveyed from the basin floor to where the inlet flow is introduced. The combined streams are then pumped into the solids contact zone. The draft tube extends close to the basin floor, recirculating only the most concentrated solids and making the WesTech unit a true solids CONTACT CLARIFIER.

Solids Contact Zone

A slow mix zone where chemical precipitation and / or enhanced flocculation occurs. Velocities decrease due to the size and shape of the reaction well, resulting in tapered flocculation. Both conical and cylindrical-shape reaction wells are available.

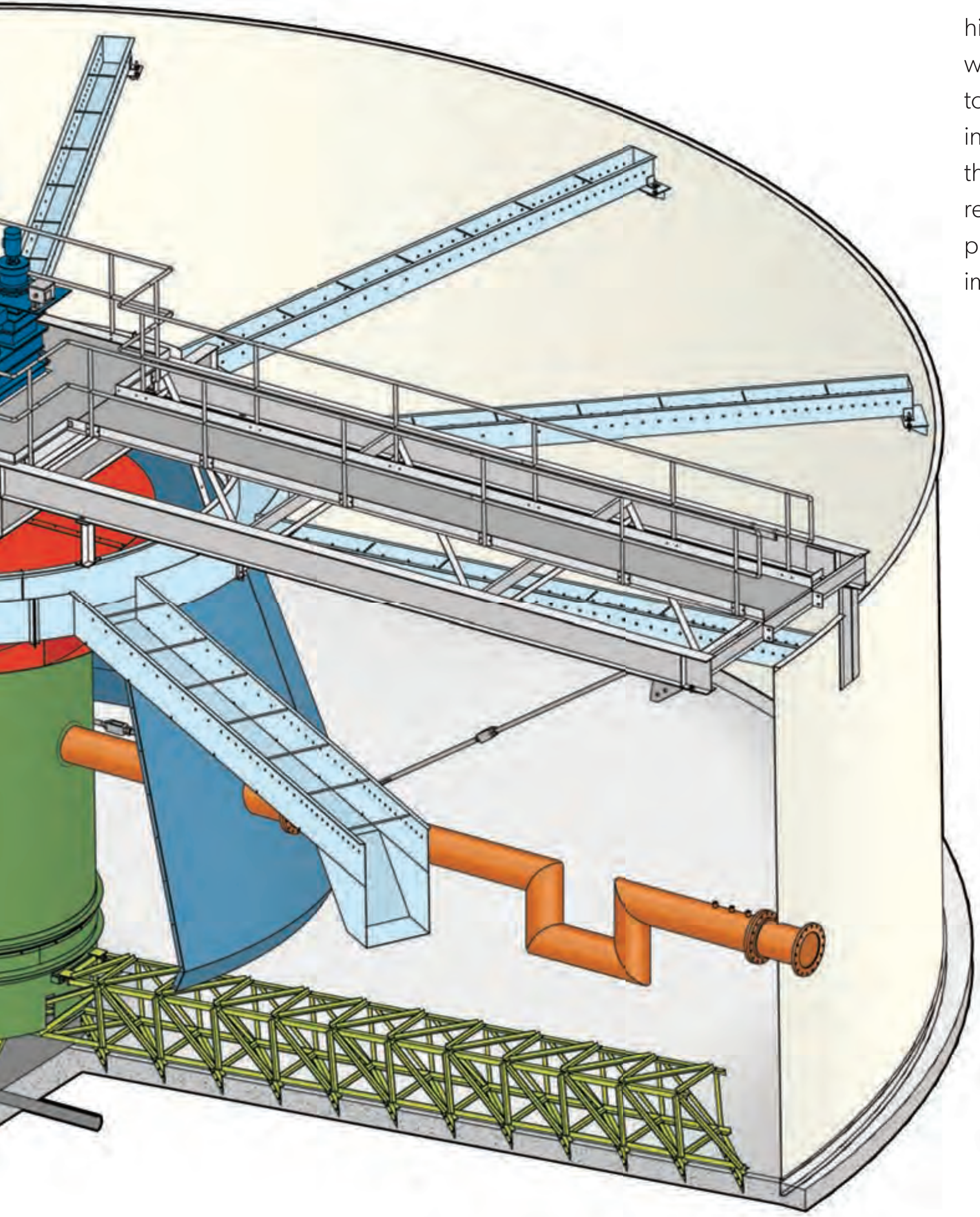
CLARIFIER

Concentric Dual Drive

Our highly efficient, robust, maintenance-friendly drive rotates the sludge scrapers at a slow constant speed while allowing the centrifugal impeller to operate at variable speeds.

Centrifugal Impeller Pump

The heart of a true solids CONTACT CLARIFIER is WesTech's uniquely efficient, high-volume, low-head, low-shear pump which lifts concentrated settled solids to mix with the low-solids concentration inlet flow and disperses the mixture into the upper solids contact zone. WesTech's recirculation impeller has lower horsepower draw and less shear than any other impeller on the market.



Inlet Pipe

Conveys the raw water directly into the draft tube and often provides provisions for injecting and mixing treatment chemicals into the process stream.

Sludge Scrapers

Transport settled solids along the basin floor to the draft tube entrance and to the sludge sump.

Sensible Design Approach

Centrifugal Impeller Pump and Draft Tube

The key components of WesTech's CONTACT CLARIFIER are the result of a sensible design approach. From the low-shear impeller to properly located sample taps and sludge sump sizing, WesTech's decades of engineering, manufacturing, installation, and operating experience bring you value-added performance.

Laboratory Jar Testing

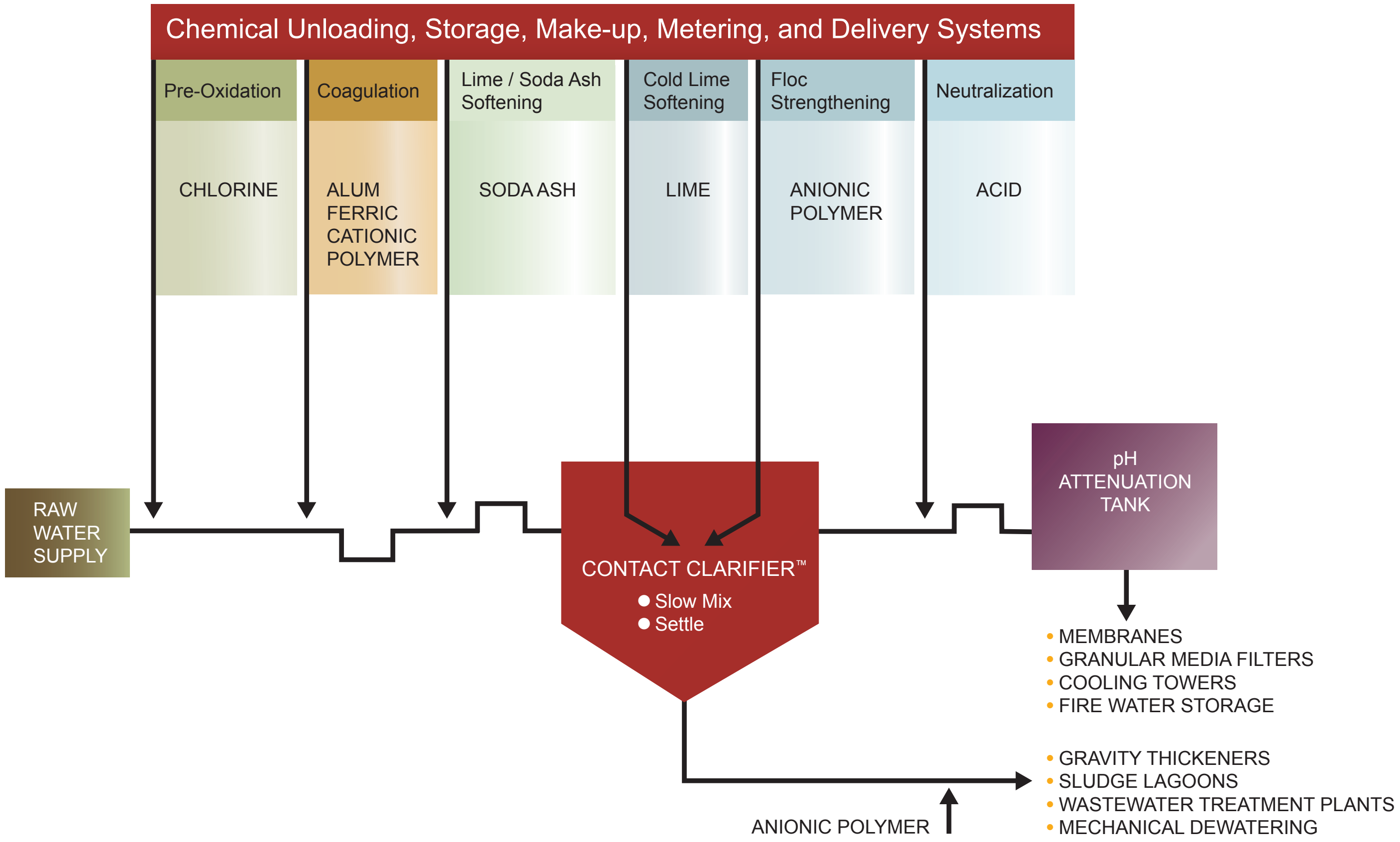
Radial Flow Launders

WesTech offers laboratory and pilot plant services to determine recommended process equipment design and performance. WesTech has several 8′ dia. x 16′ high CONTACT CLARIFIER pilot plants which have process similitude, allowing operation and performance to be scaled up directly to full-size units.

Heavy-Duty Concentric Dual Shaft Drive

Pilot Plant

Systems Integration



Lime / Soda Ash Storage

Coagulant / Polymer / Acid Feed System with Dilution Water

Chemical Mixing and In-line Dispersion Units

The solids CONTACT CLARIFIER is the heart of a chemical treatment and clarification system. However, successful performance is highly dependent upon the effective integration of chemical make-up, mixing, metering, and delivery sub systems.

Turnkey Applications

Represented by:

WesTech

Tel: 801.265.1000
westech-inc.com
info@westech-inc.com
Salt Lake City, Utah, USA

EVAPORATOR VENDOR INFO

GEA

Vanorman, Eric

From: Leonescu, Craig <craig.leonescu@gea.com>
Sent: Monday, December 15, 2014 9:19 AM
To: Vanorman, Eric
Cc: Sumpter, Ben; Pugh, Lucy B.
Subject: RE: Budget Estimate for Wastewater Evaporator
Attachments: P02e-MVR.pdf; P03e-Evaporation_Technology_1.pdf; Capture.JPG

Best regards

Craig Leonescu
Senior Sales/Process Engineer

GEA Process Engineering Inc.
GEA Process Engineering
Office 410 997 6611, Fax +1 410 997 5021
Mobile 443 831 2258
craig.leonescu@gea.com
www.gea.com

We live our values.
Excellence • Passion • Integrity • Responsibility • GEA-versity

9165 Rumsey Road, Columbia, Maryland, 21045, USA

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 12, 2014 4:36 PM
To: Leonescu, Craig
Cc: Sumpter, Ben; Pugh, Lucy B.
Subject: RE: Budget Estimate for Wastewater Evaporator

Hi Craig:

Thanks for the information! On the initial read through I had a couple of questions:

- Any specific requirements for the cooling water? Could plant effluent be used? Typically this is cooling tower water. The water needs to be treated for Bio-Growth as well as scaling. Cold Condensate can be used as long as it is treated.
- I assume the cooling water system is a once through system. Is this correct? If it is coming from a cooling tower, the water will flow through the condenser and back to a cooling tower to be cooled. The cooling tower will of course evaporate a portion of the water. You will need make-up water for this as well as for the blow-down stream.

- We will ultimately need to get at the operations cost. I assume that a unit would essentially be operated at full load and then shut down for a period. So the total cost would be a percentage of continuous full load. Is this correct? Your operating cost would entail the number of hours you are running multiplied by your KW of electricity, by your steam consumption (PPH) and then you can use your costs for a KW-Hr and for $ per 1,000 lbs of steam.
    - For electrical is the 4,600 Kw the bulk of the electrical consumption or should an additional factor be added to this. Please keep in mind the 4,600 KW is per 525 gpm train, so you would have 2 X this. The 4,600 KW represents the consumed power at the motor shaft. Your actual consumed power would be a bit higher as you have to account for the motor efficiency (say 0.97) and the power factor. Again, this 4,600 KW per train is a preliminary number and we would need to verify final boiling point elevation as this can have an impact on the power consumed.
    - What chemicals may be required as part of the operation including cleaning cycles? As discussed you may need a lot of NaOH in your upstream process to shift the bi-carbonate to carbonate and drop out Calcium Carbonate (This you indicated you would take care of). Aside from this, some acid may be required for some periodic cleaning, I will check to see if there are any other chemicals that could potentially be required.
    - Under utilities you list soft water. What is this used for and in what quantities. The soft water is typically used for your mechanical seals on your process pumps and vacuum pumps (you may have vacuum pumps on the crystallizer as we may need to run at lower temperatures). This can also be clean cold condensate. A mechanical seal may require anywhere from 1/3 to 1 gpm per pump.
- What would need to occur in order for the system to be shut down and restarted? Typically you will chase out the product will make-up water so that the evaporator is back on water. Then you would shut-down the MVR's and the steam. If the plant is going to be down for an extended period, you may want to drain the system completely. If it needs to be cleaned than you can dose some acid into it and recirculate it, flush out with water and either restart or shut down. Restarting from when the plant is down; You would recirculate water, then product (or you may be able to just start-up on product), then you would put steam on the plant, once you get to the proper operating temperature and pressure, you would start the fans. Then it is just a matter of achieving steady state conditions.
- Do you have any brochures or information giving general information regarding your systems or showing a typical layout? Please see attached
- Ultimately we would like to see similar information and pricing for the crystallizer as well so that we can work that into our analysis. What type of time frame do you need this information in?

If you have any questions regarding the above please don't hesitate to contact me.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446 M 1.616.558.4490
eric.vanorman@aecom.com

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From: Leonescu, Craig [mailto:craig.leonescu@gea.com]
Sent: Friday, December 12, 2014 3:58 PM
To: Vanorman, Eric
Cc: Sumpter, Ben
Subject: Budget Estimate for Wastewater Evaporator

Dear Eric,

As promised, we have put together a budget estimate for your review. The design is based on a feed rate of 1,050 GPM (90% Recovery). We have based the design on physical property data that we have including boiling point elevation data. I have broken this up into two (2) equal trains. Please see the information as follows (Per Train):

1. Design (Per Train): One Effect (2 Stage) MVR Heated Falling Film Evaporator. The MVR will consist of Two (2) Turbofans in series.
2. Mass Balance (Per Train)
    a. Feed Rate=525 GPM (265,798 PPH), 50-80 F
    b. Evaporation Rate=243,648 PPH
    c. Discharge Rate=22,150 PPH, +/- 80 C
    d. Process Condensate=249,060 PPH, 108 F (Depending upon the Product Feed Temperature, I used 50 F in this case)
3. Major Utilities (Per train)
    a. Steam
        i. Design Continuous=5,500 PPH (Based on 50 F Feed Temperature)
        ii. Start-Up Steam=7,500 PPH
    b. Electric
        i. 4160 V/3/60: Turbofans Total Consumed=4,600 KW, Installed=7,000 HP
        ii. 460/3/60: Pumps: TBD
    c. Cooling Water=400 GPM 85 F Supply/100 F Return
4. Scope of Supply (Per Train):
    a. 2 Ea. Falling Film Evaporator Chests w/ Vapor Separators. Ti Grade 12 Tubes, Hastelloy Tubesheets and Product Contact Areas, Duplex Shells
    b. 2 Ea. Plate and Frame Preheaters
    c. 1 Ea. Deaeration Vessel
    d. 1 Ea. Surface Condenser
    e. 2 Ea. Turbofans, with Inlet Guide Vane. Including Lube Oil System, instrumentation. Duplex casing, Duplex/Super Duplex Impeller.
    f. 2 Ea. Turbofan Motors and Soft Starts
    g. 3 Ea. Condensate Collectors
    h. 1 Lot of Vapor Ducting
    i. 1 Lot of Spray Devices
    j. 1 Lot of Process Pumps
    k. 1 Lot of Field Instruments, Control and On/Off Valving
    l. 1 Lot of Engineering
        i. PFD
        ii. P&ID
        iii. General Arrangement (Including Recommended Platform locations)
        iv. Hole & Load Drawing with equipment weights.
        v. Connection Point List
        vi. Equipment List
        vii. Manual Valve Specifications
        viii. Tag List
        ix. Piping Guideline Model
        x. Lifting Drawings
        xi. Functional Description
        xii. Equipment Outline Drawings
        xiii. O&M Manual and Spare Parts Lists
5. Exclusions:
    a. Building, Foundations, Structural Steel, Platforms, Stairways, Ladders, HVAC, Lighting, Sewers

- b. Piping & Fittings, Hangers
- c. Piping Stress Analysis and Hanger Location.
- d. Manual Valving
- e. Complete Installation of Equipment and Piping (Installation Supervision can be supplied on a T&M Basis)
- f. Cranes, Rigging
- g. Control System and HMI (This can be added if requested)
- h. MCC, including VFD's
- i. Power and Control Wiring, Pneumatics
- j. Utilities (Electric, Steam, Water, Cooling Water, Air, Chemicals, Soft Water) and associated piping, valving, instrumentation.
- k. Permits
- l. Freight (Ex Works, points of mfg.), VAT, Duties
- m. Commissioning Assistance (This can be supplied on a T&M Basis)

6. L X W X H (Per Train): 90' X 55' X 85' High

7. Budget Pricing (Per Train)=US $11,500,000.00 per Train, $23,000,000.00 Total

Please let me know if you have any questions. We can also add a crystallizer and dewatering system to provide a "Full" ZLD system. The crystallizer would be heated with steam most likely.

Have a good weekend.

Best regards

Craig Leonescu
Senior Sales/Process Engineer

GEA Process Engineering Inc.
GEA Process Engineering
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Mobile 443 831 2258
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www.gea.com

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9165 Rumsey Road, Columbia, Maryland, 21045, USA

Six Fan MVR Heated Evaporator

Evaporation Technology

GEA Wiegand GmbH

Evaporation Technology

Evaporation plants are used as a thermal separation technology, for the concentration or separation of liquid solutions, suspensions and emulsions.

A liquid concentrate that can still be pumped is generally the desired final product. Evaporation may however also aim at separating the volatile constituents, or distillate, as would be the case in a solvent separation system. During these processes, it is usual that product qualities are maintained and preserved.

These, together with many other requirements result in a wide variety of evaporator types, operating modes and arrangements.

GEA Wiegand has substantially contributed to the development of evaporation technology. The first Wiegand evaporator, built in 1908, was a patented multiple-effect circulation evaporator. This concentrated liquids in a gentle and efficient manner in a way unparalleled in its time. It was easy to control and had a compact arrangement.

Further technical developments led to the first Wiegand falling film evaporator, built in 1952, which combined these considerably improved, essential characteristics with new process possibilities, especially in the field of evaporating heat-sensitive products. At the same time, the thermal efficiency of evaporation plants was considerably improved.

Thanks to its advantages, the falling film evaporator has virtually replaced other evaporator types in many fields. Forced circulation and circulation evaporators still have some significance, whereas special types such as spiral tube, counterflow or stirrer evaporators are only used in special circumstances.

Research and Development

Due to ongoing research and development work spanning many decades, and the experience of several thousand installed references, GEA Wiegand continues to provide the broadest technical expertise and the respected ability to offer the best solution for almost any product, evaporation rate, operating condition or application.

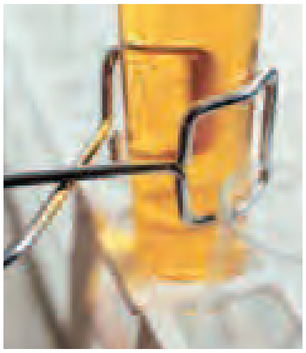
GEA Wiegand has its own Research and Development Centre, where numerous laboratory and pilot plants are available for detailed analyses and testing in the field of evaporation and distillation. At the R&D Centre, important physical characteristics such as boiling point elevation, surface tension, solubility and maximum achievable concentration are determined. Certain pilot plants are available as mobile units and can therefore be installed at a customer's site. Data is captured and plant operating behaviour modelled by means of the latest computer programs.

The tests are performed in different types of tubular and plate evaporators and distillation columns. To date, more than 3,000 product categories have been tested through our plants. The alphabetical list of products tested ranges from acetone/alcohol mixtures to zinc dichloride.

Contents

Reference Products from GEA Wiegand Evaporation Plants

The following list shows groups of products that are successfully concentrated in more than 4.000 GEA Wiegand evaporation plants. Additional products are detailed in our reference lists.



Chemical and Pharmaceutical Industries

Caustic solutions	Caustic soda solution, caustic potash solution
Organic acids	Ascorbic acid, citric acid
Inorganic acids	Phosphoric acid, nitric acid
Saline solutions	Ammonium nitrate, ammonium sulphate, sodium sulphate
Amines	Urea, diethyl amine
Alcohol	Methanol, ethanol, glycerine, glycol, isopropanol
Organic products	Aromatic compounds, acetone, caprolactam water, synthetic glue, aromas
Pharmaceutical solutions	Enzymes, antibiotics, drug extracts, sugar substitutes, sorbitol, sorbose and gluconate
Suspensions	Kaolin, calcium carbonate
Waste water	Process waste water, wash and rinsing water, oil emulsions, etc.

Food and Beverage Industry

Dairy products	Whole and skimmed milk, condensed milk, whey and whey derivates, buttermilk proteins, lactose solutions, lactic acid
Protein solution	Soya whey, nutrient yeast and fodder yeast, whole egg
Fruit juices	Orange and other citrus juices, pomaceous juice, red berry juice, tropical fruit juices
Vegetable juices	Beetroot juice, tomato juice, carrot juice
Starch products	Glucose, dextrose, fructose, isomerose, maltose, starch syrup, dextrine
Sugar	Liquid sugar, white refined sugar, sweetwater, inulin
Extracts	Coffee and tea extracts, hop extract, malt extract, yeast extract, pectin, meat and bone extract
Hydrolisate	Whey hydrolisate, soup seasoning, protein hydrolisate
Beer	De-alcoholized beer, wort

Organic Natural Products Industry

Fermentation broth	Glutamate, lysine, betain
Glue and gelatine	Technical gelatine, edible gelatine, leather glue and bone glue
Emulsions	Miscella
Extracts	Tanning extract
Stillage	Whisky, corn, yeast, potato stillages, vinasses
Steep water	Corn steep water, sorghum steep water
Stick water	Slaughterhouse waste water, fish stick water, fruit peel press water, beet chips, fibre press water, fibreboard press water
Organic waste water	Wash water, wheat and potato starch effluents, manure
Blood	Whole blood, blood plasma

Evaporator Types

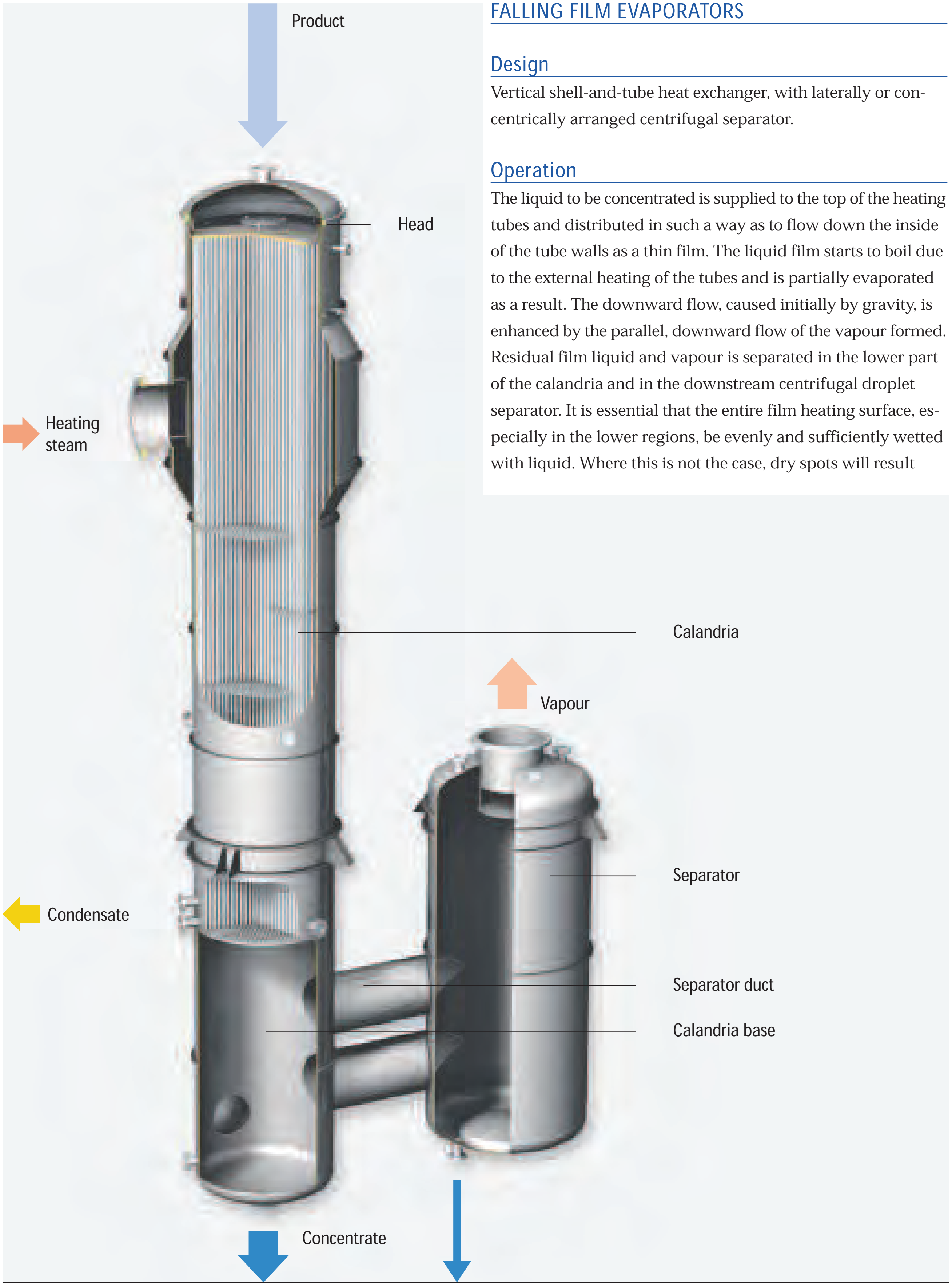
FALLING FILM EVAPORATORS

Design

Vertical shell-and-tube heat exchanger, with laterally or concentrically arranged centrifugal separator.

Operation

The liquid to be concentrated is supplied to the top of the heating tubes and distributed in such a way as to flow down the inside of the tube walls as a thin film. The liquid film starts to boil due to the external heating of the tubes and is partially evaporated as a result. The downward flow, caused initially by gravity, is enhanced by the parallel, downward flow of the vapour formed. Residual film liquid and vapour is separated in the lower part of the calandria and in the downstream centrifugal droplet separator. It is essential that the entire film heating surface, especially in the lower regions, be evenly and sufficiently wetted with liquid. Where this is not the case, dry spots will result



Two examples of suitable distribution systems, above: Perforated bowl, below: Tubelet

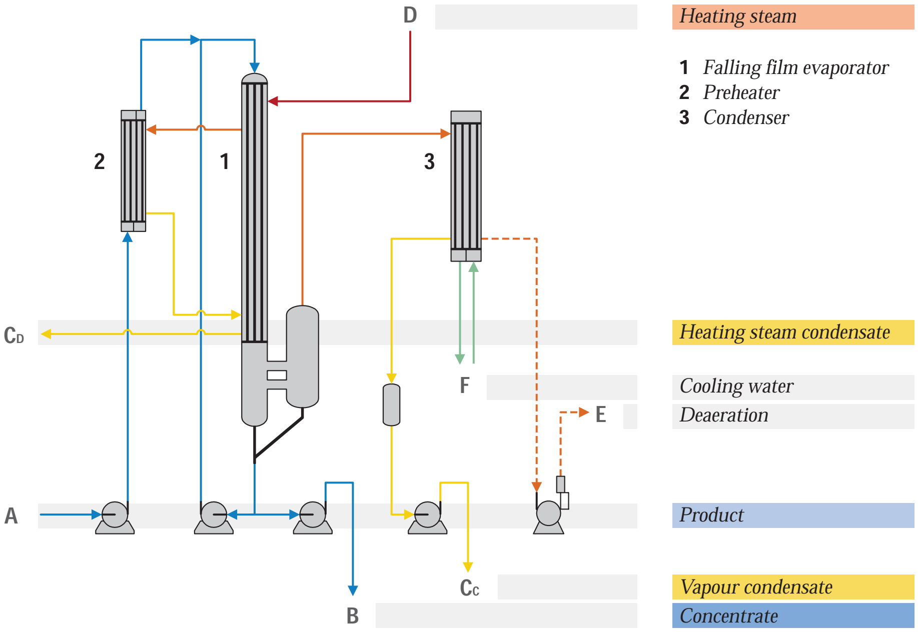
that will lead to incrustation and the build-up of deposits. For complete wetting it is important that a suitable distribution system is selected for the head of the evaporator. Wetting rates are increased by using longer heating tubes, dividing the evaporator into several compartments or by recirculating the product.

Particular features

- **Best product quality** – due to gentle evaporation, mostly under vacuum, and extremely short residence times in the evaporator.
- **High energy efficiency** – due to multiple-effect arrangement or heating by thermal or mechanical vapour recompressor, based upon the lowest theoretical temperature difference.
- **Simple process control and automation** – due to their small liquid content falling film evaporators react quickly to changes in energy supply, vacuum, feed quantities, concentrations, etc. This is an important prerequisite for a uniform final concentrate.
- **Flexible operation** – quick start-up and easy switchover from operation to cleaning, uncomplicated changes of product.

Fields of application

- Capacity ranges of up to 150 t/hr, relatively small floor space requirement.
- Particularly suited for temperature-sensitive products.
- For liquids which contain small quantities of solids and have a low to moderate tendency to form incrustations.

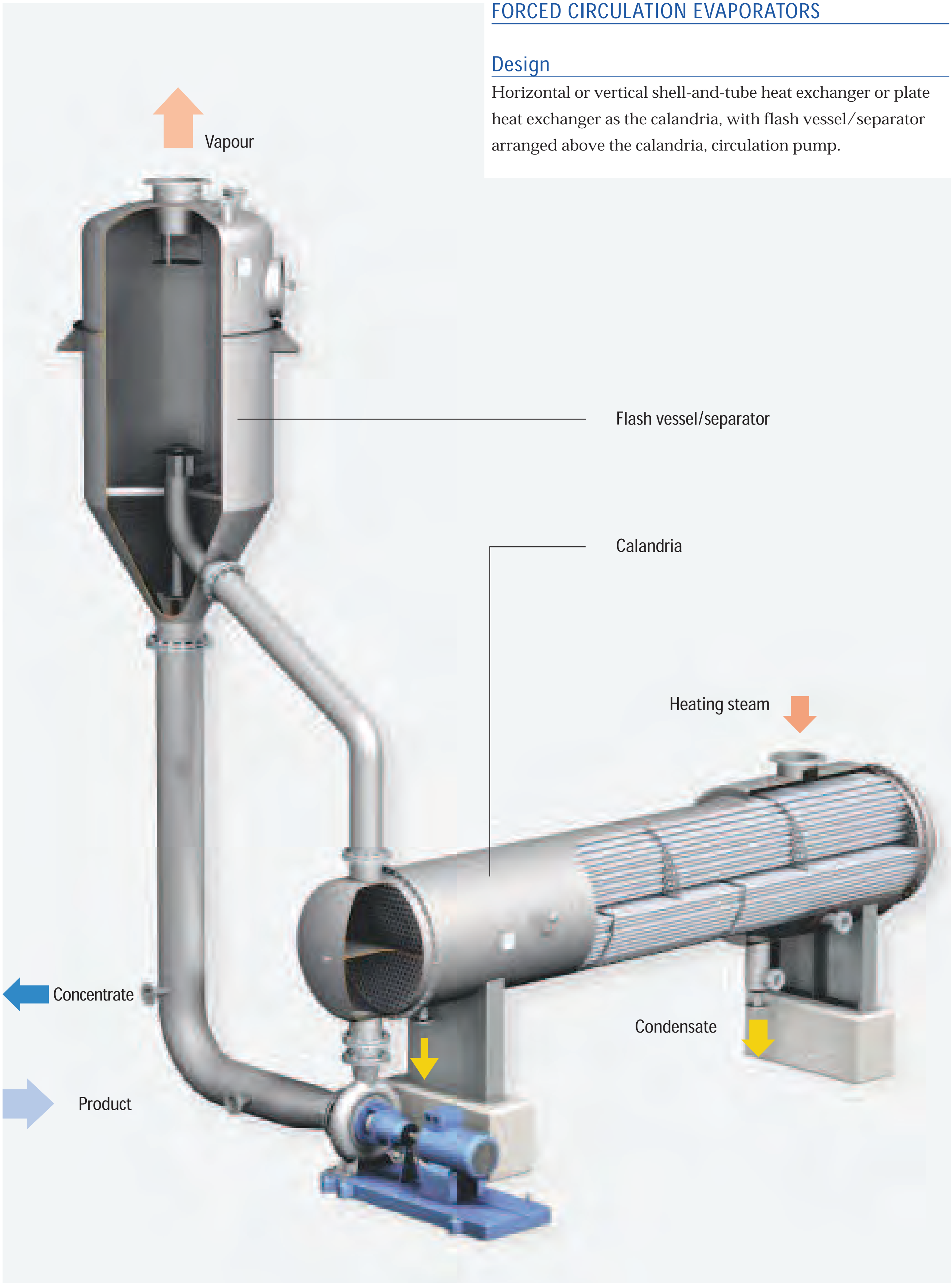


Evaporator Types

FORCED CIRCULATION EVAPORATORS

Design

Horizontal or vertical shell-and-tube heat exchanger or plate heat exchanger as the calandria, with flash vessel/separator arranged above the calandria, circulation pump.



Operation

The liquid is circulated through the calandria by means of a circulation pump, where it is superheated at an elevated pressure, higher than its normal boiling pressure. Upon entering the separator, the pressure in the liquid is rapidly reduced resulting in some of the liquid being flashed, or rapidly boiled off. Since liquid circulation is maintained, the flow velocity in the tubes and the liquid temperature can be controlled to suit the product requirements independently of the pre-selected temperature difference.

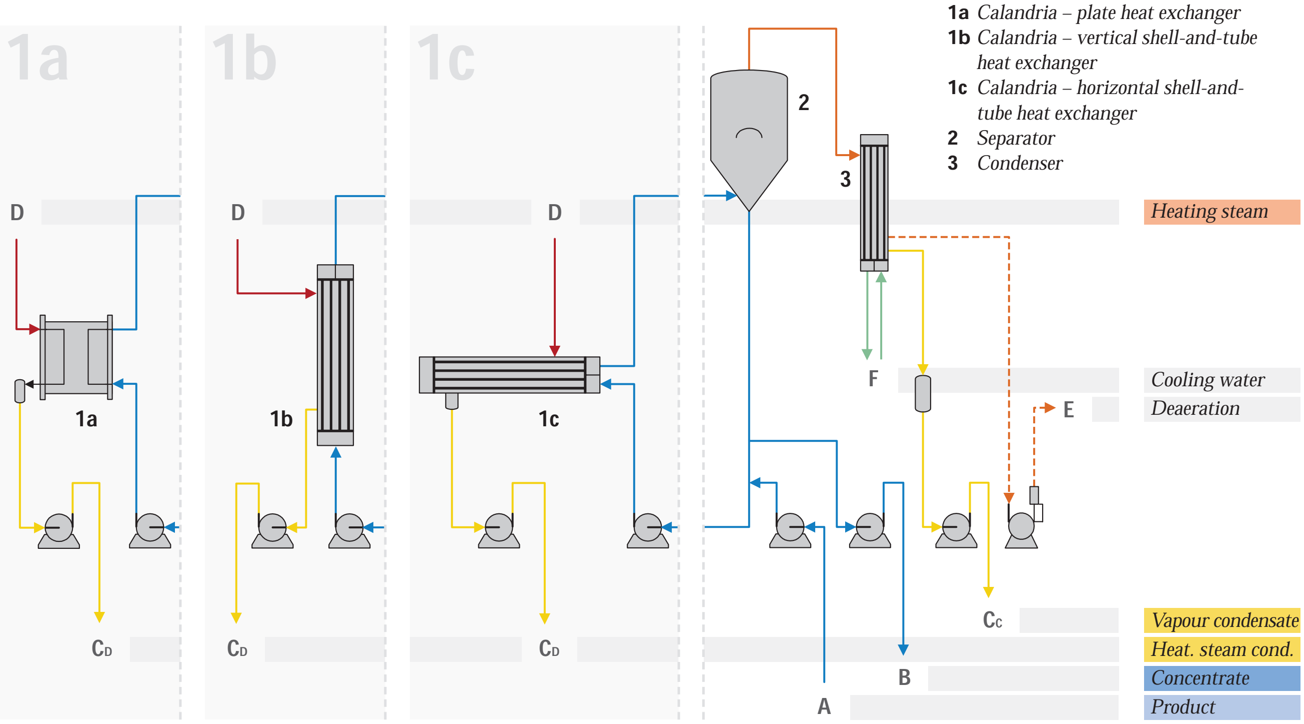
Particular features

- **Long operating periods** – boiling/evaporation does not take place on the heating surfaces, but in the separator. Fouling due to incrustation and precipitation in the calandria is therefore minimised.
- **Optimised heat exchange surface** – flow velocity in the tubes determined by the circulation pump.

Fields of application

- Liquids with a high tendency for fouling, highly viscous liquids, as the high concentration step in multiple-effect evaporation plants.
- Forced circulation evaporators are optimally suited as crystallising evaporators for saline solutions.

2-effect falling film, forced circulation evaporation plant in counterflow arrangement with downstream system for the purification of vapour condensate by distillation of waste water containing salts and organic compounds. Evaporation rate: 9,000 kg/hr concentrated to 65 % TS

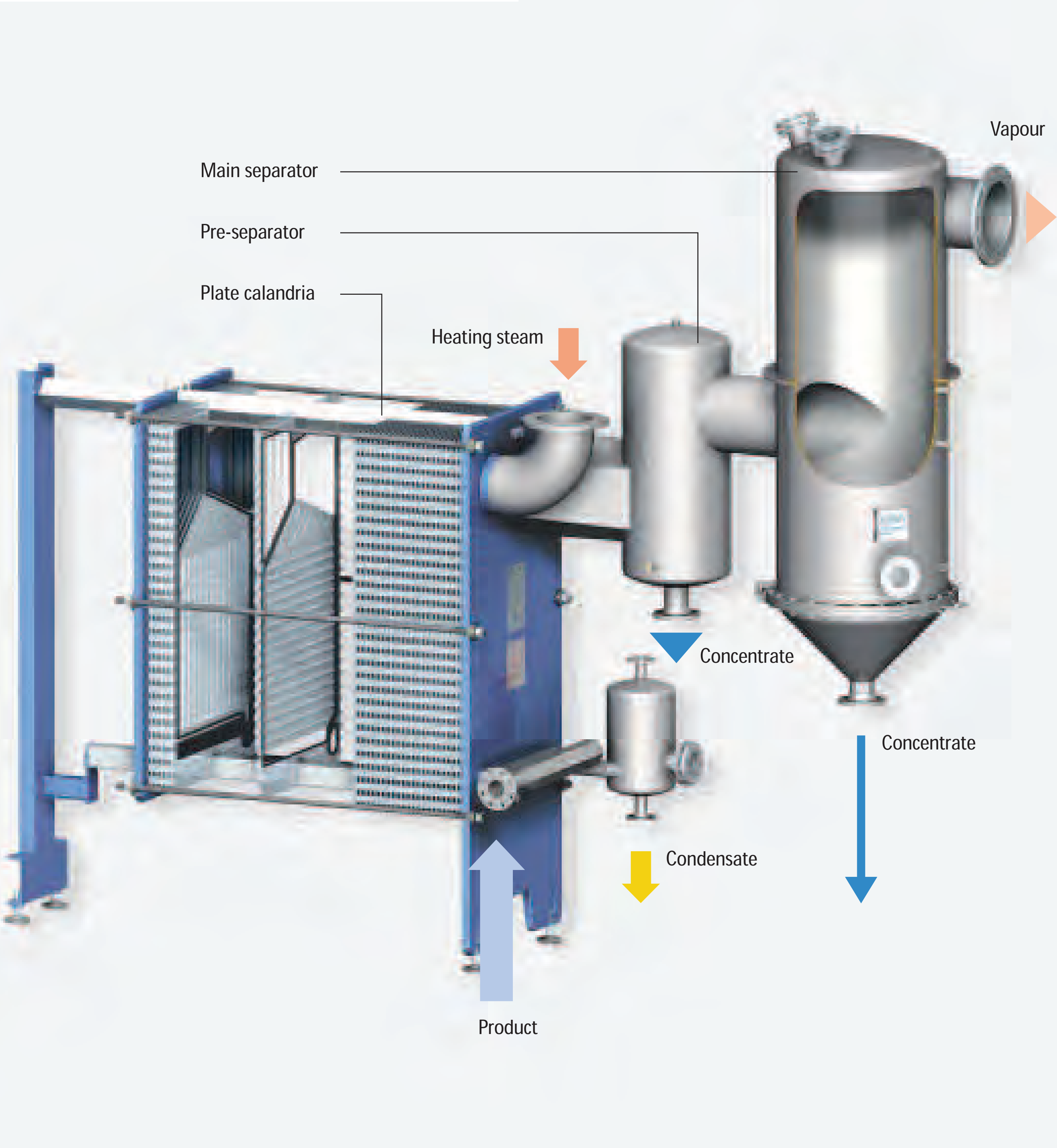


Evaporator Types

PLATE EVAPORATORS

Design

Plate heat exchanger, separator.
A plate-and-frame configuration employs special plates, with alternate product and heating channels. The plates are sealed by gaskets located within specially designed slots that do not require adhesives. These gaskets can be inserted and removed without special tools.



Operation

Product and heating media are transferred in counterflow through their relevant passages. Defined plate distances in conjunction with special plate shapes generate strong turbulence, resulting in optimum heat transfer.

Intensive heat transfer causes the product to boil while the vapour formed drives the residual liquid, as a rising film, into the vapour duct of the plate package. Residual liquid and vapours are separated in the downstream centrifugal separator. The wide inlet duct and the upward movement ensure optimum distribution over the total cross-section of the heat exchanger.

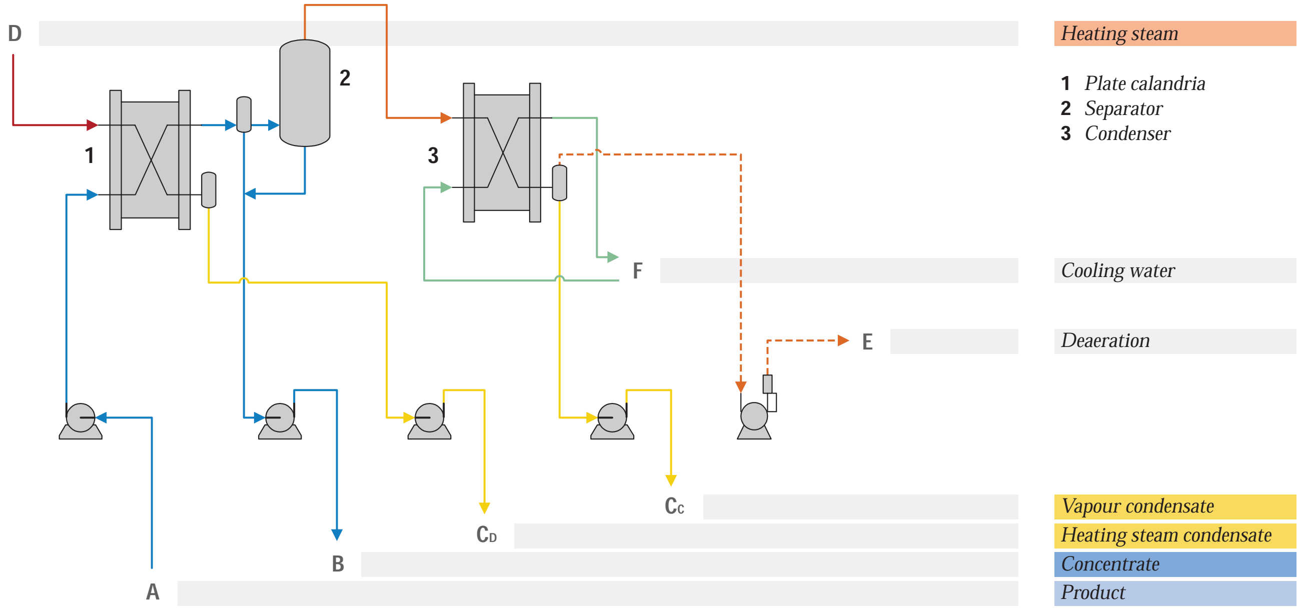
Particular features

- **Use of different heating media** – due to plate geometries, the system can be heated with both hot water as well as with steam.
- **High product quality** – due to especially gentle and uniform evaporation during single-pass operation.
- **Little space required** – due to compact design, short connecting lines and small overall height of max. 3 - 4 m.
- **Easy installation requiring little time** – due to pre-assembled, transportable construction units.
- **Flexible evaporation rates** – by adding or removing plates.
- **Ease of maintenance and cleaning** – as plate packages can be easily opened.

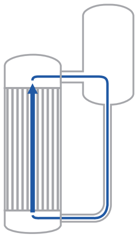
Fields of application

- For low to medium evaporation rates.
- For liquids containing only small amounts of undissolved solids and with no tendency to fouling.
- For temperature-sensitive products, for highly viscous products or extreme evaporation conditions, a product circulation design is chosen.

Multiple-effect plate evaporation plant for fructose.
Evaporation rate: 16 t/hr



Evaporator Types



CIRCULATION EVAPORATORS

Design

Vertical shell-and-tube heat exchanger of short tube length, with lateral separator arranged at the top.

Operation

The liquid to be concentrated is supplied to the bottom and rises to the top of the heating tubes in accordance with the “mammoth pump” or rising film principle. Due to the external heating of the tubes the liquid film on the inside walls of the tubes starts to boil releasing vapour. The liquid is carried to the top of the tubes as a result of the upward movement of the vapours.

The liquid is separated from the vapours in the downstream separator and flows through a circulation pipe back into the evaporator, ensuring stable and uniform circulation. The larger the temperature difference between the heating chamber and the boiling chamber, the greater the intensity of evaporation and, consequently, the liquid circulation and heat transfer rates.

Where the boiling chamber of the circulation evaporator is divided into several separate chambers, each one equipped with its own liquid circulation system, the heating surface required for high final concentrations can be considerably reduced compared to an undivided system.

The final concentration is only reached in the last chamber. In other chambers, the heat transfer is considerably higher due to the lower viscosities and boiling point elevations.

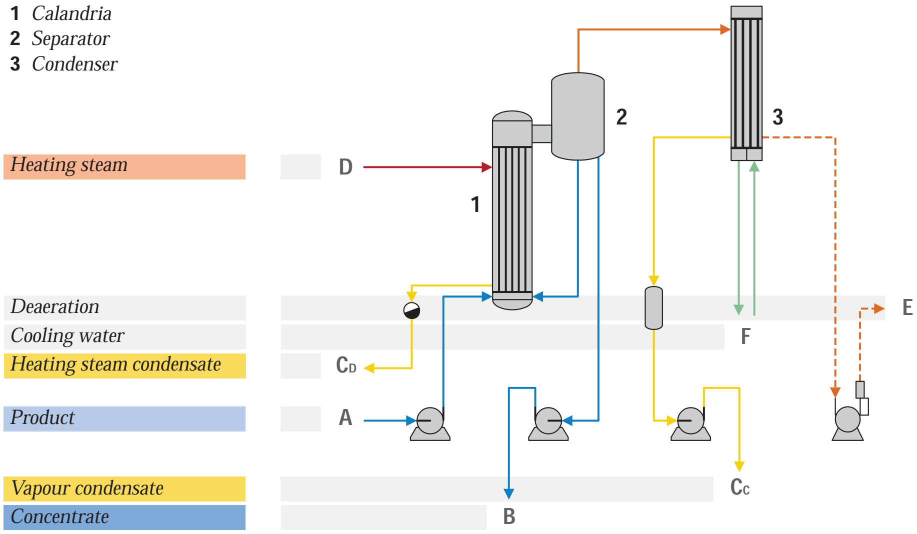
Particular features

- **Quick start-up and large specific capacity** – the liquid content of the evaporator is very low due to the relatively short length and small diameter of the heating tubes (1 - 3 m).

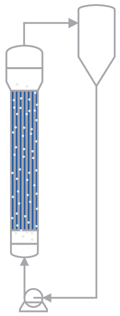
Fields of application

- For the evaporation of products insensitive to high temperatures, where large evaporation ratios are required.
- For products which have a high tendency to foul and for non-Newtonian products, where the apparent viscosity may be reduced by the high velocities.
- The circulation evaporator with divided boiling chamber and top-mounted separator can be used as a high concentrator.

3-effect circulation evaporation plant for glycerine water. Evaporation rate: 3,600 kg/hr



Special Evaporator Types



FLUIDISIED BED EVAPORATORS

Design

Vertical fluidised bed heat exchanger (on the tube side solid particles such as glass or ceramic beads, or stainless steel wire particles are entrained in the liquid), flash/vessel separator and circulation pump.

Operation

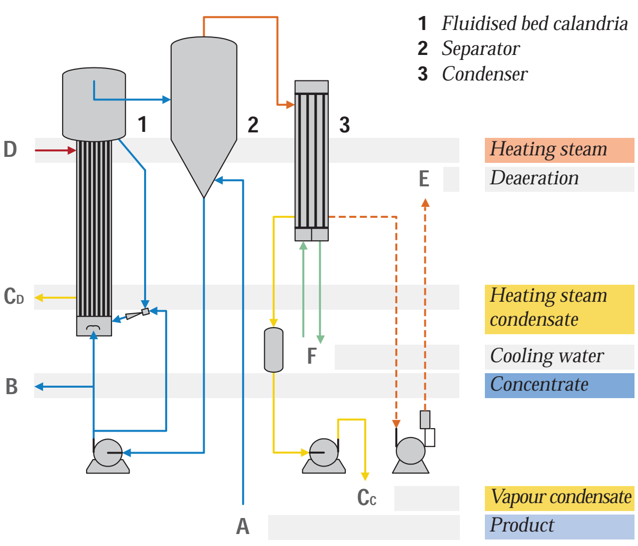
Same principle as for the forced circulation evaporator.
The upward movement of the liquid entrains the solid particles, which provide a scouring/cleaning action. Together with the liquid they are transferred through the calandria tubes.
At the head of the calandria, the particles are separated from the liquid and are recycled to the calandria inlet chamber.
The superheated liquid is flashed to boiling temperature in the downstream separator and is partially evaporated.

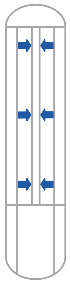
Particular features

- **Long operating periods** – continuous cleaning of the heating surface by the entrained beads and improved heat transfer.

Fields of application

- For products that have high fouling tendencies, where fouling cannot be sufficiently prevented or retarded in standard, forced circulation evaporators.
- For liquids of low to medium, viscosity.





FALLING FILM, SHORT PATH EVAPORATORS

Design

Vertical shell-and-tube heat exchanger equipped with concentrically arranged condenser tubes within the heating tubes and integrated separator in the lower part of the unit.

Operation

The liquid is evenly distributed over the heating tubes by means of a distribution system and flows as a thin film down the inside walls. The external heating of the tubes causes the liquid film to boil. The vapours formed are condensed as distillate on the external walls of the condensate tubes and flow downwards. Distillate and bottom product are separately kept and discharged from the lower part of the evaporator.

Particular features

- **Particularly gentle product treatment** – due to very low pressure/temperature processing, short product residence times and single pass operation. Distillation possible at vacuum pressures ranging from 1 mbar to below 0.001 mbar. Due to the integrated condenser tubes, there is no vapour flow pressure loss.
- **Optimised design** – no mechanical wear and tear, as the system has no rotating internal parts.
- **Low investment cost.**
- **Also suitable for high evaporation rates.**

Fields of application

- Particularly temperature sensitive, non-aqueous solutions.

Special Evaporator Types

RISING FILM EVAPORATORS

Design

Vertical shell-and-tube heat exchanger with top-mounted vapour separator.

Operation

The liquid to be concentrated is supplied to the bottom and rises to the top in accordance with to the "mammoth pump" principle, or rising film principle.
Due to external heating, the liquid film starts to boil on the inside walls of the tubes and is partially evaporated during this process. As a result of the upward movement of the steam bubbles, the liquid is transferred to the top. During the ascent more and more vapours form. The film starts to move along the wall, i.e. the liquid "rises". The vapours and liquid are then separated in the top-mounted separator.

Particular features

- **High temperature difference between heating chamber and boiling chamber** – in order to ensure a sufficient liquid transfer in tubes of a length of 5 - 7 m and to cause the film to rise.
- **High turbulence in the liquid** – due to the upward movement against gravity. For this reason, rising film evaporators are also suited for products of high viscosity and those with the tendency to foul on the heating surface.
- **Stable high-performance operation** – based on product recirculation within a wide range of conditions.

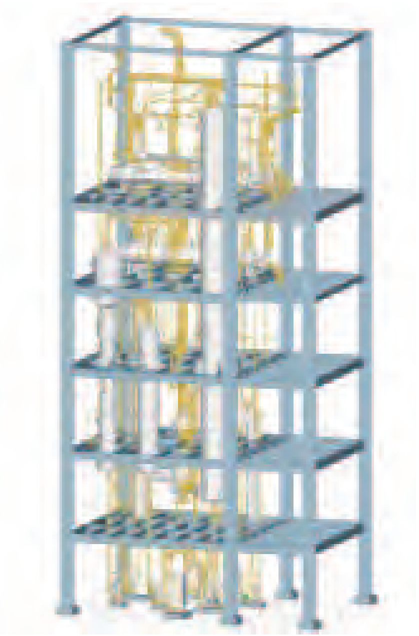
Fields of application

- For large evaporation ratios, for high viscosities and products having a tendency to foul.
- Can be used as a high concentrator in single pass operation based on extremely short residence times.

COUNTERFLOW-TRICKLE EVAPORATORS

Design

Shell-and-tube heat exchanger, lower part of calandria larger than that of e.g. the rising film evaporator, top-mounted separator equipped with integrated liquid distribution system.



Falling film counterflow trickle evaporation plant with rectification unit for olive oil refining

Operation

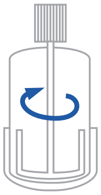
As in falling film evaporators, the liquid is supplied to the top of the evaporator and is distributed over the evaporator tubes, but the vapours flow to the top in counterflow to the liquid.

Particular features

- **Partial distillation** – amounts of volatile constituents contained in the product to be concentrated can be stripped. This process can be enhanced by the supply of an entraining stream, such as steam or inert gas, to the lower part of the calandria.

Fields of application

- This type of evaporator, designed for special cases, is used to enhance the mass transfer between liquid and vapour. If a gas stream is passed in counterflow to the liquid, chemical reactions can be triggered.



STIRRER EVAPORATORS

Design

External, jacket heated vessel equipped with stirrer.

Stirrer evaporator arranged as a high concentrator for yeast extract. Evaporation rate 300 kg/hr

Operation

The liquid is supplied to the vessel in batches, is caused to boil while being continuously stirred and is evaporated to the required final concentration.

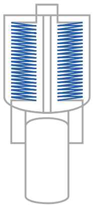
If the evaporated liquid is continuously replaced by thin product, and if the liquid content is in this way kept constant, the plant can be also operated in semi-batch mode.

Particular features

- **Low evaporation rate** – due to small heat exchange surface. For this reason, large temperature differences between the heating jacket and the boiling chamber are required. The product properties permitting, the heating surface can be enlarged by means of additional immersion heating coils.

Fields of application

- For highly viscous, pasty or pulpy products, whose properties are not negatively influenced by a residence time of several hours, or if particular product properties are required by long residence times.
- It can also be used as a high concentrator downstream from a continuously operating pre-evaporator.



SPIRAL TUBE EVAPORATORS

Design

Heat exchanger equipped with spiral heating tubes and bottom-mounted centrifugal separator.

Operation

The liquid to be evaporated flows as a boiling film from the top to the bottom in parallel flow to the vapour. The expanding vapours produce a shear, or pushing effect on the liquid film. The curvature of the path of flow induces a secondary flow, which interferes with the movement along the tube axis. This additional turbulence considerably improves the heat transfer, especially in the case of high viscosities.

Particular features

- **Small apparatus dimensions** – due to the spiral shape, longer tube lengths and consequently larger heating surfaces relative to the overall height of the unit can be obtained.
- **Large evaporation ratios** – due to large temperature differences and single pass operation.

Fields of application

- For high concentrations and viscosities, e.g. for the concentration of gelatine.

Quantities and Concentration Ratios in Evaporation Plants

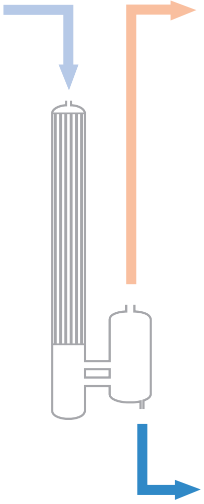
A

Part of the solvent (C), is evaporated from the **product flow** (A). The residual amount (B), is the evaporated product (concentrate):

$$A = B + C$$

c_A

Initial concentration c_A
of the product flow A kg/hr



C

The **evaporated quantity C,** can therefore be defined as the difference between the quantity of thin solution and concentrate:

$$C = A - B$$

Vapour flow C [kg/hr]: Evaporated water, solvent

B

Evaporated product, concentrate

c_B

Final concentration c_B
of concentrate flow B kg/hr

e

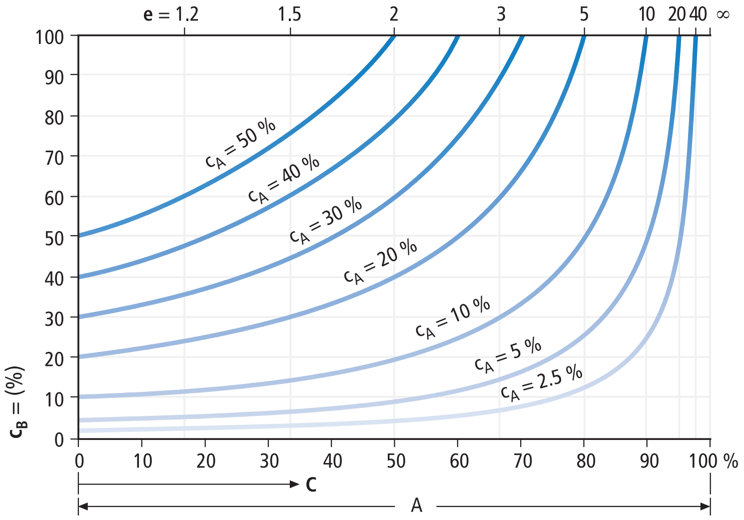
The evaporation ratio is a measure for the concentration process:

$$e = \frac{A}{B} = \frac{c_B}{c_A}$$

The evaporation ratio can also be defined as the ratio of the initial and final concentrations (% weight dry substance).

If the solvent is evaporated from thin solution A at an even rate, the concentration rises slowly at first, but rises increasingly rapidly to the theoretical maximum. At this point, no more solvent would be left in the solution. The lower the initial concentration c_A, the steeper the increase of the concentration curve. This relationship is essential for the control of evaporation plants, and in cases of high evaporation ratios, for the separation of the evaporation process into pre-evaporation and high concentration steps.

To calculate continuous evaporation processes, mass flow rates rather than volumetric quantities are used. The unit kg/hr is used for A, B and C. The ratios indicated above do not change.



If the concentrations or the evaporation ratio is known, the quantities can be calculated using the formulae in the table below:

Given	Required	Formula
Quantity A to be evaporated	C	$C = A \cdot \frac{e-1}{e}$
	B	$B = A \cdot \frac{1}{e}$

Left: Increase of final concentration during the evaporation from solutions at different initial concentrations

Energy Efficiency of Evaporation Plants

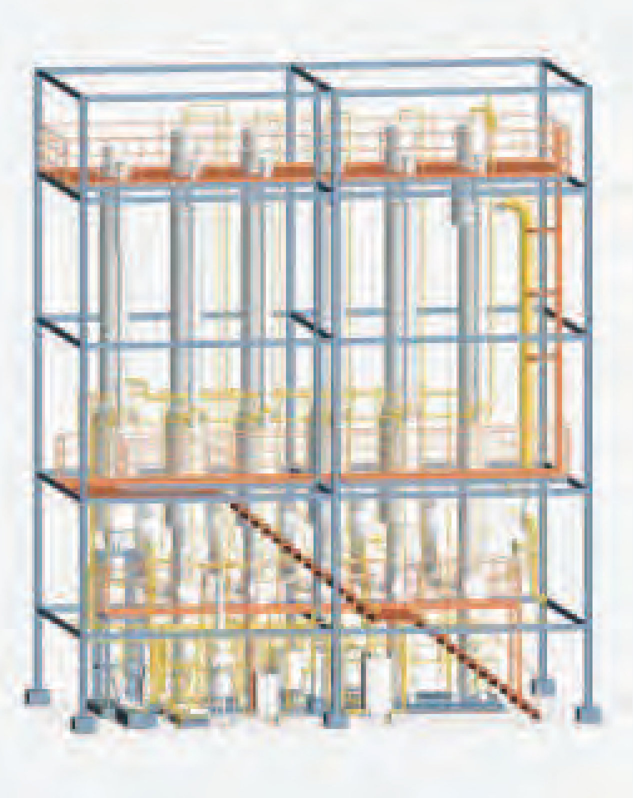
The operating costs of an evaporation plant are largely determined by the energy consumption.
Under steady-state conditions there must be a balance between the energy entering and leaving the system.

The energy consumption of the system can be tailored to meet the customer's individual requirements by intelligent thermal configurations of the evaporation plant.

There are three basic possibilities to save energy:

- Multiple-effect evaporation
- Thermal vapour recompression
- Mechanical vapour recompression

Application of one of these techniques will considerably decrease the energy consumption. Often it is feasible to combine two of these possibilities to minimise capital and operating costs. In highly sophisticated evaporation plants all three techniques may be applied.



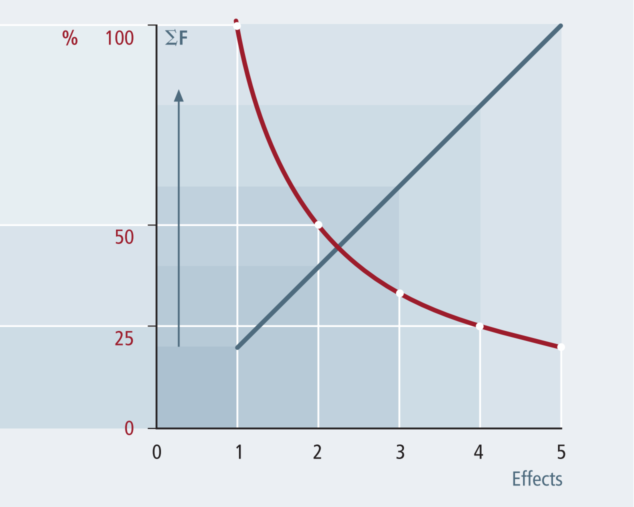
5-effect falling film evaporation plant for apple juice concentrate, directly heated, with aroma recovery. Evaporation rate: 12,000 kg/hr

Multiple-effect evaporation

If we consider the heat balance of a single-effect evaporator we find that the heat content (enthalpy) of the evaporated vapour is approximately equal to the heat input on the heating side. In the common case of water evaporation, about 1 kg/hr of vapour will be produced by 1 kg/hr of live steam, as the specific evaporation heat values on the heating and product sides are about the same.
If the amount of vapour produced by primary energy is used as heating steam in a second effect, the energy consumption of the overall system is reduced by about 50 %. This principle can be continued over further effects to save even more energy.

	Live steam	Vapour	Specif. steam consumption
1-effect-plant	1 kg/h	1 kg/h	100 %
3-effect-plant	1 kg/h	3 kg/h	33 %

The maximum allowable heating temperature of the first effect and the lowest boiling temperature of the final effect form an overall temperature difference which can be divided among the individual effects. Consequently, the temperature difference per effect decreases with an increasing number of effects. For this reason, the heating surfaces of the individual effects must be dimensioned accordingly larger to achieve the required evaporation rate, but with a lower temperature difference (Δ t).
A first approximation shows that the total heating surface of all effects increases proportionally to the number of effects. Consequently, the investment costs rise considerably whereas the amount of energy saved becomes increasingly lower.



Decrease of the specific steam consumption in % and increase of the approximate total heating surface ΣF in relation to the number of effects

Energy Efficiency of Evaporation Plants

Thermal vapour recompression

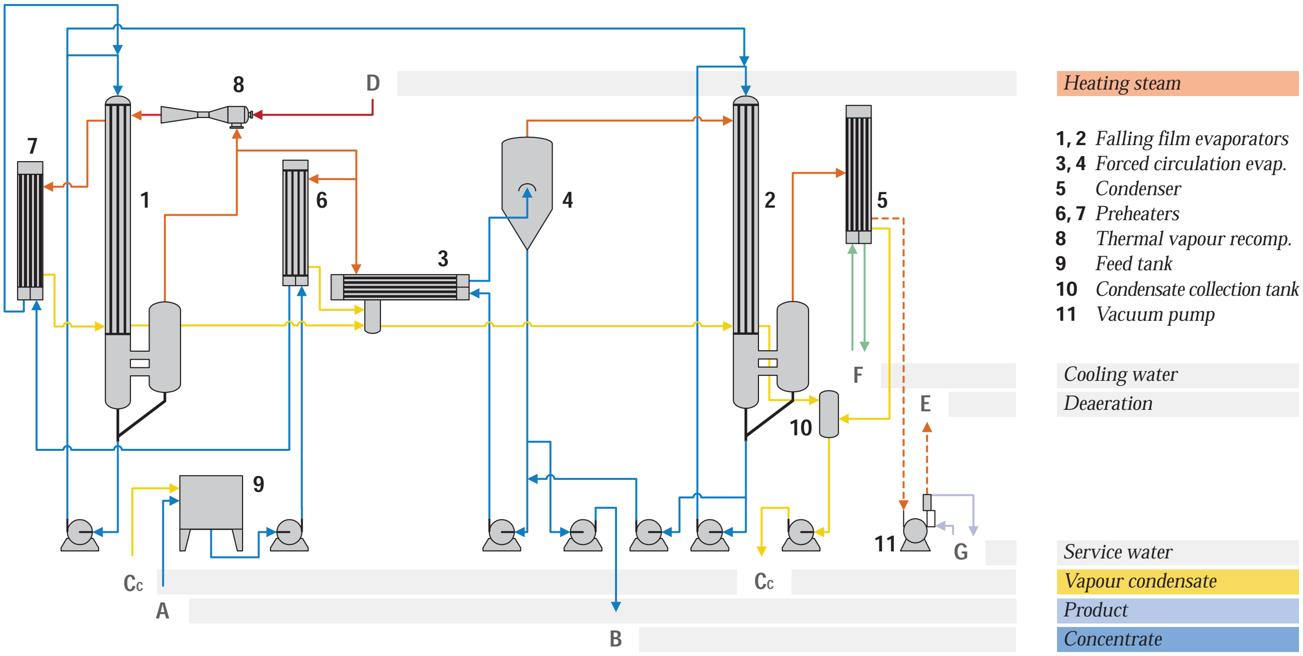
During thermal vapour recompression, vapour from a boiling chamber is recompressed to the higher pressure of a heating chamber in accordance with the heat pump principle. The saturated steam temperature corresponding to the heating chamber pressure is higher so that the vapour can be reused for heating.

To this end, steam jet vapour recompressors are used. They operate according to the steam jet pump principle. They have no moving parts and are therefore not subject to wear and tear. This ensures maximum operational reliability.

The use of a thermal vapour recompressor gives the same steam/energy saving as an additional evaporation effect.

A certain steam quantity, the so-called motive steam, is required for operation of a thermal vapour recompressor. This motive steam portion is transferred as excess vapour to the next effect or to the condenser. The energy of the excess vapours approximates the energy of the motive steam quantity used.

3-effect falling film forced circulation evaporation plant heated by thermal vapour recompressor for waste water from sodium glutamate production. Evaporation rate: 50 t/hr



Mechanical vapour recompression

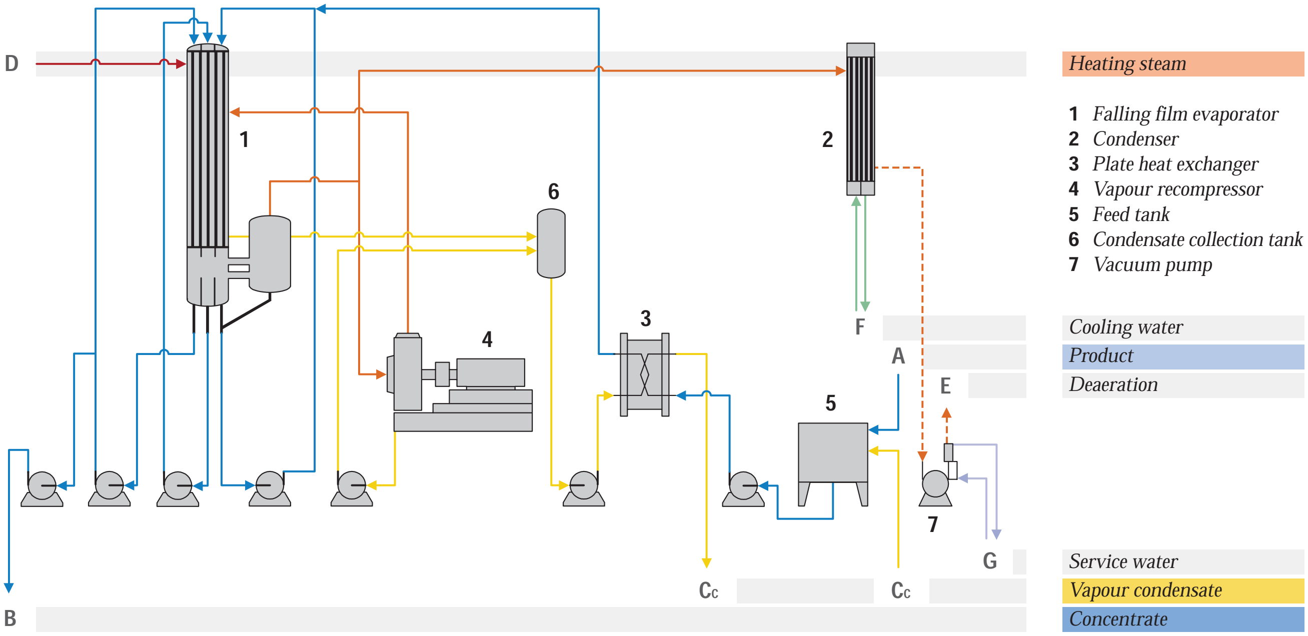
Evaporation plants heated by mechanical vapour recompressors require particularly low amounts of energy.

Whereas steam jet compressors only compress part of the vapour, mechanical vapour recompressors recycle all of the vapour leaving the evaporator. The vapour is recompressed to the pressure of the corresponding heating steam temperature of the evaporator, using a mere fraction of electrical energy relative to the enthalpy recovered in the vapour. The operating principle is similar to that of a heat pump. The energy of the vapour condensate is frequently utilized for the preheating of the product feed. The amounts of heat to be dissipated are considerably reduced, with the evaporator itself re-utilizing the energy normally dissipated through the condenser cooling water. Depending on the operating conditions of the plant, a small quantity of additional steam, or the condensation of a small quantity of excess vapour may be required to maintain the overall evaporator heat balance and to ensure stable operating conditions.

Due to their simplicity and maintenance friendly design, single stage centrifugal fans are used in evaporation plants. These units are supplied as high pressure fans or turbo-compressors. They operate at high flow velocities and are therefore suited for large and very large flow rates at vapour compression ratios of 1:1.2 to 1:2. Rational speeds typically are 3,000 up to 18,000 rpm. For high pressure increases, multiple-stage compressors can be used.

(See our special brochure “Evaporation Technology using Mechanical Vapour Recompression”).

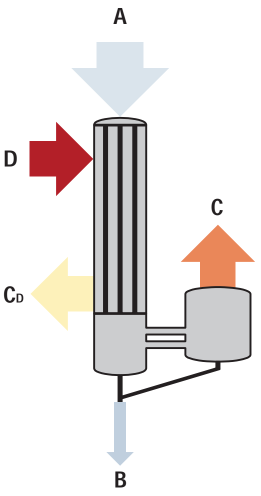
1-effect falling film evaporation plant heated by mechanical vapour recompression for wheat starch effluent. Evaporation rate: 17,000 kg/hr



Energy Efficiency of Evaporation Plants

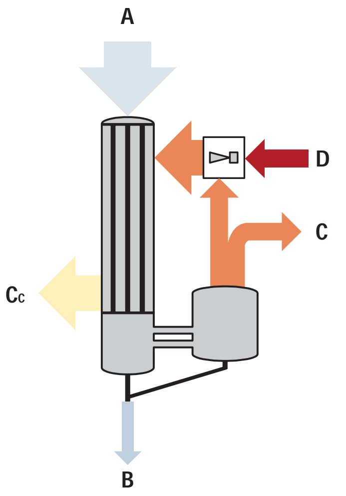
Mass/energy flow diagrams of an evaporator with different types of heating

Directly heated



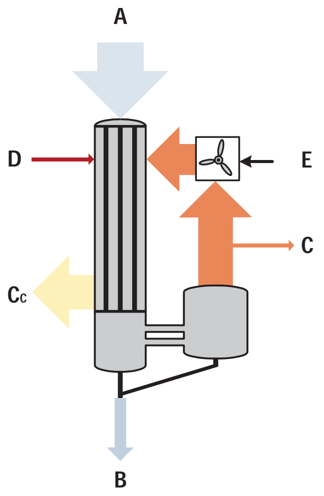
If we consider the heat balance of a single-effect evaporator we find that the heat content (enthalpy) of the evaporated vapour (C) is approximately equal to the heat input (D) on the heating side. In the common case of water evaporation, about 1 kg/hr of vapour will be produced by 1 kg/hr of live steam, as the specific evaporation heat values on the heating and product sides are about the same.

Thermal vapour recompression



A certain quantity of live steam, the so-called motive steam, is required for the operation of a thermal vapour recompressor. This motive steam quantity must be transferred to the next effect or to the condenser as surplus residual vapour. The surplus energy contained in the residual vapour approximately corresponds to the amount of energy supplied in the motive steam.

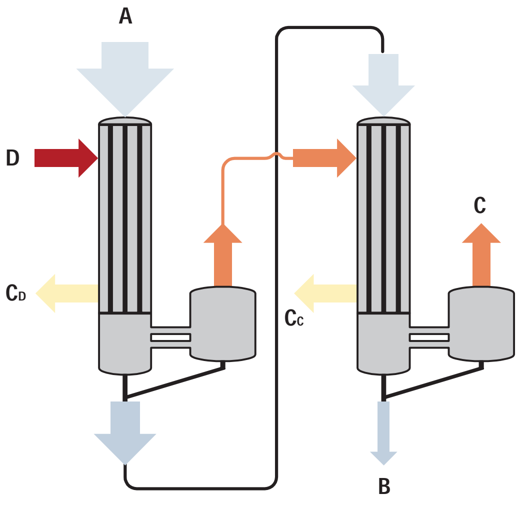
Mechanical vapour recompression



The operation of evaporation plants heated by mechanical vapour recompressors requires a particularly low amount of energy. The operating principle of a mechanical vapour recompressor is similar to that of a heat pump. Almost the entire vapour quantity is compressed and recycled by means of electrical energy. Only minimum quantities of live steam are required, generally just during start-up. The quantities of residual "waste" heat to be dissipated are considerably reduced.

2-effect design

If the amount of vapour produced by primary energy is used as heating steam in a second effect, the energy consumption of the overall system is reduced by about 50 %. This principle is repeated over further effects to save even more energy.



A	*Product*
B	*Concentrate*
C	*Condensate*
C_C	*Vapour condensate*
C_D	*Heating steam condensate*
D	*Heating steam*
E	*Electrical energy*

Criteria for the Design Selection, Arrangement and Operating Modes of Evaporation Plants

When designing evaporation plants, various and often contradictory requirements must be taken into consideration. These determine the type of design, arrangement and the resulting process and cost data.

GEA Wiegand evaporation plants are characterised by their high quality, efficiency and design refinements. Careful attention is paid to the above mentioned criteria in view of the individual requirements. In addition, a strong emphasis is placed on reliability and ease of operation.

The most important requirements are as follows:

- **Capacity and operating data** such as quantities, concentrations, temperatures, annual operating hours, change of product, control, automation.
- **Product properties** such as temperature sensitivity, viscosity and flow properties, tendency to foaming, fouling and precipitation, boiling properties.
- **Utility Requirements** such as steam, cooling water, electricity, cleaning agents, parts exposed to wear and tear.
- **Selection of materials** and surface finish.
- **Capital costs** for interest and repayments.
- **Personnel costs** for operation and maintenance.
- **Site conditions** such as space availability, climate for outdoor installations, connections for energy and product, service platforms.
- **Legislative framework** regarding health and safety, prevention of accidents, sound propagation, environmental protection and others, depending on the specific project.

Evaporation Plant Components

The core of any evaporation plant is the calandria. For the operation of the plant, several additional components are required.
The most important of these are condensers, preheaters, pumps, fittings, vents, vacuum systems and cleaning systems.

If substances are to be separated, the plants are also equipped with rectification columns, membrane filtration units, scrubbing and aroma recovery systems.

To guarantee trouble-free operation of the plant, state-of-the-art measuring, control and computer monitoring systems are used.

Attention to detail, safety and protective equipment and thermal and sound insulation ensure safe operation of the plant.

GEA Wiegand designs, builds and supplies turnkey evaporation plants. Our experience and expert knowledge of the performance of each individual component enables us to select the right equipment for each application so that the requirements of the entire evaporation plant will be met.

Evaporation Plant Components

Preheaters and heaters

In most cases the product to be evaporated must be preheated to boiling temperature before it enters the calandria. As a rule straight tube preheaters or plate heat exchangers are used for this duty.

Evaporators

The selection of the suitable type of evaporator is dependent on the particular case of each application and the product properties.

Separators

Each evaporator is equipped with a unit for separating vapours from liquids. Depending on the field of application different types of separators are chosen, e.g. centrifugal separators, gravitational separators or separators equipped with internals. Essential design criteria are separating efficiency, pressure loss and frequency of cleaning.

Condensers

Where possible, the heat content of the vapours produced during evaporation is used for heating downstream effects and preheaters, or the vapours are recompressed and re-utilized as the heating medium. The residual vapours from the last effect of an evaporation plant which cannot be used in this way must be condensed. Evaporation plants can be equipped with surface, contact or air-cooled condensers.

Deaeration/vacuum systems

Vacuum pumps are required for maintaining the vacuum in the evaporation plant. They discharge leakage air and non-condensing gases from the process, including dissolved gases which are introduced in the liquid feed. For this application, jet pumps and liquid ring pumps can be used depending on the size and the operating mode of the evaporation plant.

Pumps

Pumps must be chosen in view of a wide range of design conditions and applications. The main criteria for the selection of pumps are product properties, suction head conditions, flow-rates and the pressure ratios in the evaporation plant.
For low-viscosity products, centrifugal pumps are mostly used. Highly-viscous products require the use of positive displacement pumps. For liquids containing solids or crystallised products, other pump types such as propeller pumps are used. The type, size, speed, mechanical seals and material are determined by the particular case of application and the relevant conditions of use.

Cleaning systems

Depending on the product, scaling and fouling might occur after a certain operating time. Scale and fouling deposits can be removed by chemical cleaning in most cases. To this end, the evaporation plant is equipped with the necessary components, cleaning agent tanks, additional pumps and fittings. This equipment, ensuring ease of cleaning without disassembly, is commonly referred to as "Cleaning in Place" or CIP. Cleaning agents are chosen according to the type of deposit. The cleaning agents penetrate the incrustation, dissolve or disintegrate it and completely clean and, where necessary, sterilise the evaporator surfaces.

Vapour scrubbers

A vapour scrubber is required where the plant is not heated with live steam but with discharge stream such as dryer exhaust vapours. The vapours must be cleaned before they are transferred into the heating chamber of the evaporation plant in order to avoid contamination and fouling.

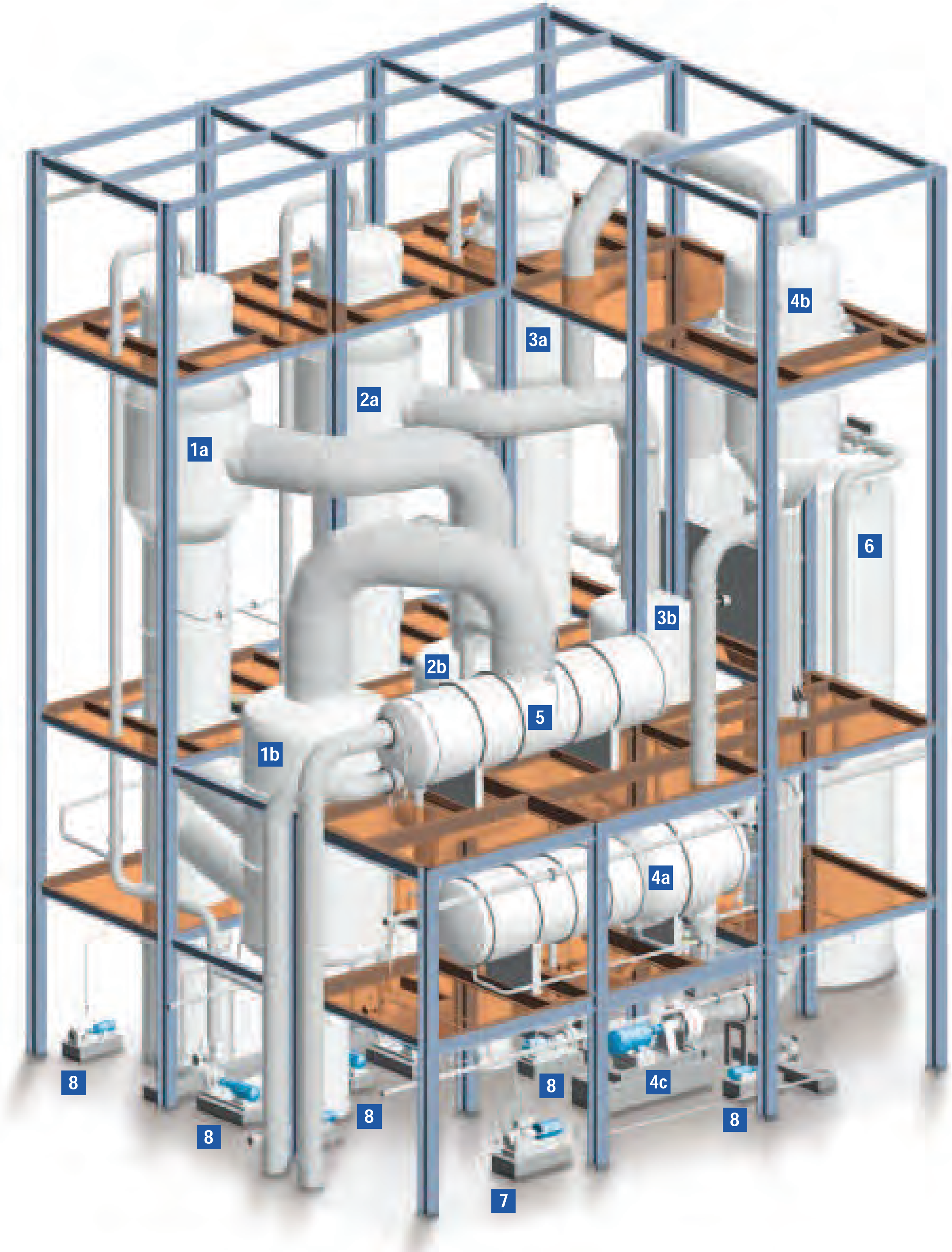
Condensate polishing systems

In spite of optimised droplet separation, the condensate quality might not correspond to the required purity especially if the product contains volatile constituents. Depending on the case of application the condensate can be further purified by means of a rectification column or a membrane filtration system.

Materials

The materials of the evaporation plant are determined by the requirements of the product and the customer's request. Depending on the corrosion behaviour under the relevant design conditions, a wide variety of materials is used. Stainless steels are most commonly used. For special requirements, Hastelloy, titanium, nickel, copper, graphite, rubberised steel or synthetic materials can also be used. As required the design and manufacture will comply with international standard directives and codes.

Depiction of a 4-effect evaporation plant for corn stillage, consisting of a 3-effect falling film evaporator and a single-effect forced circulation evaporator. The plant is directly heated with dryer exhaust vapours. The vapours are cleaned in a vapour scrubber.
Evaporation rate: 130 t/hr



1a, b	*Falling film evaporator with centrifugal separator*	**5**	*Surface condenser*
2a, b	*Falling film evaporator with centrifugal separator*	**6**	*Vapour scrubber*
3a, b	*Falling film evaporator with centrifugal separator*	**7**	*Vacuum pump*
4a, b, c	*Forced circulation evaporator with flash vessel/ gravitational separator and circulation pump*	**8**	*Product and condensate pumps*

Measuring and Control Equipment

The major goal of the evaporation process is to achieve a constant final concentration of the product. It is therefore important to maintain all parameters, such as steam pressure, product feed and vacuum, which might influence the evaporation plant or alter the mass and heat balances.
In accordance with the technical and customer's requirements, GEA Wiegand evaporation plants are equipped with the relevant measuring and control systems. We supply conventional control systems as well as process control systems.

1. Manual control

The plant is operated by means of manually operated valves. Concentrate samples must be checked at certain intervals. This type of control is suitable for simple plants and for products where slight variations in quality are acceptable.

2. Semi-automated control system

The most important parameters such as steam pressure, product feed quantity, vacuum, final concentrate density and liquid level are kept constant by means of hardware controllers and are recorded by a data recorder. Pump motors and valves are manually operated from a control panel.

3. Semi-automated control system based on PLC control

The plant is operated by means of software controllers from a programmable logic controller (PLC) with operating inputs and a data monitoring system provided by a PC. The controllers, motors and valves are manually operated from the PC. Smaller program sequences such as "cleaning mode" are possible. All key measured values are recorded and displayed on the monitor. Control and operating systems are chosen on the basis of GEA Wiegand specifications or customer specifications.

4. Automated control system based on PLC control

As an extended version, the PLC system is used as automation system for the program sequences of "start-up", "switch-over to product", "production", "cleaning" and "shut-down".

The processes can be centrally operated and monitored on the screen by means of a bus system. Set points and other key parameters are entered into the fields shown on a graphic display. The plant is self-monitored and is automatically switched to a safe mode in the event of operating trouble. The use of a multiple operator station system increases the availability.

5. Process control system

The plant is controlled by one or several automation systems, which can also be integrated into existing process structures. The process control system is particularly suited for multiple product and batch processes.

Manufacture, Transport, Erection, Commissioning and After-sales Service

The GEA Wiegand manufacturing workshop is situated in Beckum, Westphalia. Covering an area of more than 6,500 m^2, large parts of our plants are manufactured and prepared for transport.

In some cases small plants are completely assembled at the manufacturing workshop and are dispatched as compact or skid mounted units, ready for site connection. Most plants, however, are assembled on site due to their size.

Depending on the arrangement evaporation plants can be extremely complex, and therefore the first commissioning requires certain experience. Experienced specialists are therefore assigned to this task, who are also available to train the customer's personnel.

Each plant permanently achieves its optimal performance if it is expertly maintained. This service requires specialists who, if required, immediately trace and eliminate faults so that production losses caused by periods of standstill can be minimised. Our trained service personnel are therefore available to you. Thanks to their up-to-date training they are in a position to carry out maintenance and repairs quickly and thoroughly. Users benefit from our spare parts service, based on our plant reference numbers and a description of the item, spares can be ordered online or quotations requested for the required parts.

Overview on our Range of Products

Evaporation plants
to concentrate any type of fluid food, process water, organic and inorganic solutions and industrial waste water; with additional equipment for heating, cooling, degassing, crystallization and rectification.

Membrane filtration – GEA Filtration
to concentrate and process fluid food, process water and industrial waste water, to separate contaminations in order to improve quality and recover valuable substances.

Distillation / rectification plants
to separate multi-component mixtures, to recover organic solvents; to clean, recover and dehydrate bio-alcohol of different qualities.

Alcohol production lines
for potable alcohol and dehydrated alcohol of absolute purity; integrated stillage processing systems.

Condensation plants
with surface or mixing condensers, to condense vapour and steam/gas mixtures under vacuum.

Vacuum/steam jet cooling plants
to produce cold water, cool liquids, even of aggressive and abrasive nature.

Jet pumps
to convey and mix gases, liquids, and granular solids; for direct heating of liquids; as heat pumps; and in special design for the most diverse fields of application.

Steam jet vacuum pumps
also product vapour driven; also in combination with mechanical vacuum pumps (hybrid systems); extensive application in the chemical, pharmaceutical and food industries, in oil refineries and for steel degassing.

Heat recovery plants
to utilize residual heat from exhaust gases, steam/air mixtures, condensate and product.

Vacuum degassing plants
to remove dissolved gases from water and other liquids.

Heating and cooling plants
mobile and stationary plants for the operation of hot water heated reactors, contact driers.

Gas scubbers
to clean and dedust exhaust air, separate aerosols, cool and condition gases, condensate vapours and absorb gaseous pollutants.

Project studies, engineering for our plants.

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Process Engineering
Division

GEA Wiegand
GmbH

GEA Evaporation Technologies

Evaporation Technology using Mechanical Vapour Recompression

Leading Technologies. Individual Solutions.

Contents

Thermal separation processes such as evaporation and distillation are energy intensive. In the course of their development, the aim of reducing energy costs first led to multiple-effect plants, then to thermal vapour recompression, and finally, to the use of mechanical vapour recompression systems.

In a conventional evaporator, the vapour stream produced is condensed, meaning that its energy content is lost to a large extent. In comparison, mechanical vapour recompression permits the continuous recycling of this energy stream by recompressing the vapour to a higher pressure and therefore, a higher energy content.

Mechanical vapour recompression reduces the consumption of primary energy and, consequently, the environmental load.

Main fields of application are currently the Food and Beverages industry (evaporation of milk, whey, sugar solutions), Chemical industry (evaporation of aqueous solutions), the Salt Works industry (evaporation of saline solutions) and Environmental Technology (concentration of waste water).

In each case, the decision on whether a vapour recompression system should be installed must be made on the basis of an efficiency study.

Mechanical Vapour Recompression and Evaporation

- **Importance**
- **Background**
- **Economic efficiency**

Plants for evaporation, distillation, evaporative crystallisation and evaporative drying are energy intensive. Operating costs of these plants are therefore primarily determined by the energy costs.

The reduction and optimisation of the specific energy consumption is therefore of prime importance.

There are three main techniques for minimising specific energy consumption, which can be applied either singly, or in combinations:

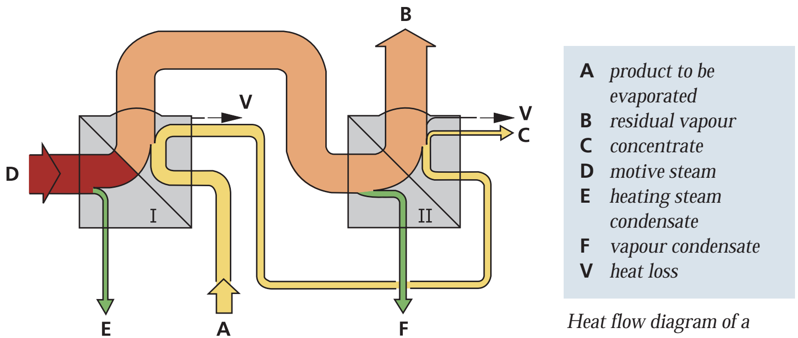
1. multiple effect arrangement
2. thermal vapour recompression
3. **mechanical vapour recompression**

1. Multiple Effect Arrangement

In a multiple effect evaporation plant, the vapour produced in the first effect by the live steam is not *lost* to the condenser, but is reutilized as the heating medium of the second effect. This effectively reduces the steam consumption by about 50%.

As this principle is repeated, further steam reductions follow.

The maximum heating temperature of the first effect, and the lowest boiling temperature achieved in the final effect creates a total temperature difference that is spread across the individual effects. As a result, the temperature difference per effect decreases as the number of effects increases. Their heating surfaces must consequently be larger in order to reach the specified evaporation rate. A first approximation shows that the heating surface to be used for all effects increases proportionally with the number of effects, and that in this way the investment costs considerably increase, whereas steam savings progressively decrease.



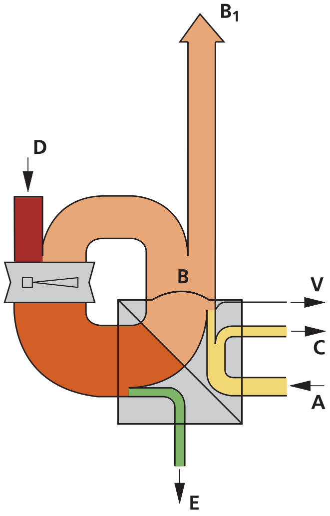
Heat flow diagram of a double-effect, directly heated evaporator

2. Thermal Vapour Recompression

During thermal vapour recompression, vapour from a boiling chamber is recompressed to the higher pressure of a heating chamber according to the heat pump principle; i.e. energy is added to the vapour. The saturated steam temperature corresponding to the heating chamber pressure is consequently higher, enabling the vapour to be reused for heating.

For this purpose, steam jet vapour recompressors are used. They operate according to the jet pump principle. They have no moving parts, ensuring a simple and effective design that provides the highest possible operational reliability.
The use of a thermal vapour recompressor has the same steam/energy saving effect as an additional evaporation effect.

A certain quantity of live steam, the so-called *motive steam*, is required for the operation of a thermal vapour recompressor. This motive steam quantity must be transferred to the next effect or to the condenser as surplus residual vapour. The surplus energy contained in the residual vapour approximately corresponds to the amount of energy supplied in the motive steam.



A	*product to be evaporated*
B	*vapour*
B$_1$	*residual vapour*
C	*concentrate*
D	*motive steam*
E	*heating steam condensate*
V	*heat loss*

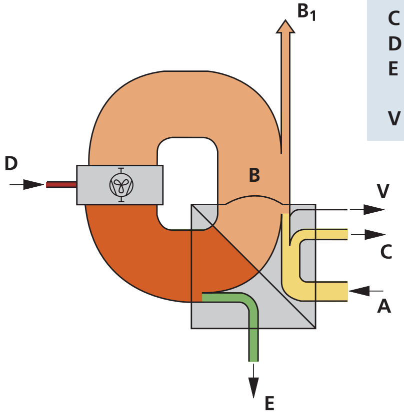
Heat flow diagram of an evaporator heated by thermal vapour recompression

3. Mechanical Vapour Recompression

During mechanical vapour recompression, the vapour of an evaporator is recompressed to a higher pressure by means of a mechanically driven compressor. The recompressor therefore also operates as heat pump, adding energy to the vapour.

Contrary to the compression heat pump with circulating process liquid (i.e. a closed system, refrigeration cycle) the vapour recompressor can be considered as a special case of the compression heat pump because it operates as an open system.
After compression of the vapour and subsequent condensation of the heating steam, the condensate leaves the cycle. The heating steam (hot side) is separated from the vapour (cold side) by the heat exchange surface of the evaporator.
The comparison between the open compression heat pump and the closed compression heat pump shows that the evaporator surface in the open system basically replaces the function of the expansion valve of the process liquid in the closed system.

By using a comparably small amount of energy, i.e. the mechanical energy of the compressor impeller in the case of the compression heat pump, energy is added to the process heat and continuously recycled. In this case, primary steam is not required as the heating medium.



A	*product to be evaporated*
B	*vapour*
B$_1$	*residual vapour*
C	*concentrate*
D	*electrical energy*
E	*heating steam condensate*
V	*heat loss*

Heat flow diagram of an evaporator heated by mechanical vapour recompression

The condensation heat to be dissipated in multiple effect and thermal vapour recompression systems, is still significantly high. In a multiple-effect plant, with *n* number of effects, the condensation heat is approximately 1/n of the primary energy input. Furthermore, a steam jet compressor will only recompress part of the vapour stream, and the energy of the motive steam must be dissipated as residual heat through the cooling water. However, the use of the open compression heat pump principle can significantly reduce, and even eliminate, the amount of heat to be dissipated through the condenser.

A small amount of additional energy or condensation of excess vapour may be required to achieve the final heat balance, thereby allowing constant pressure ratios and stable operating conditions.

Reasons for using mechanical vapour recompression

- low specific energy consumption
- gentle evaporation of the product due to low temperature differences
- short residence times of the product, as a single-effect system is most often used
- high availability of the plants due to the simplicity of the process
- excellent partial load behaviour
- low specific operating costs

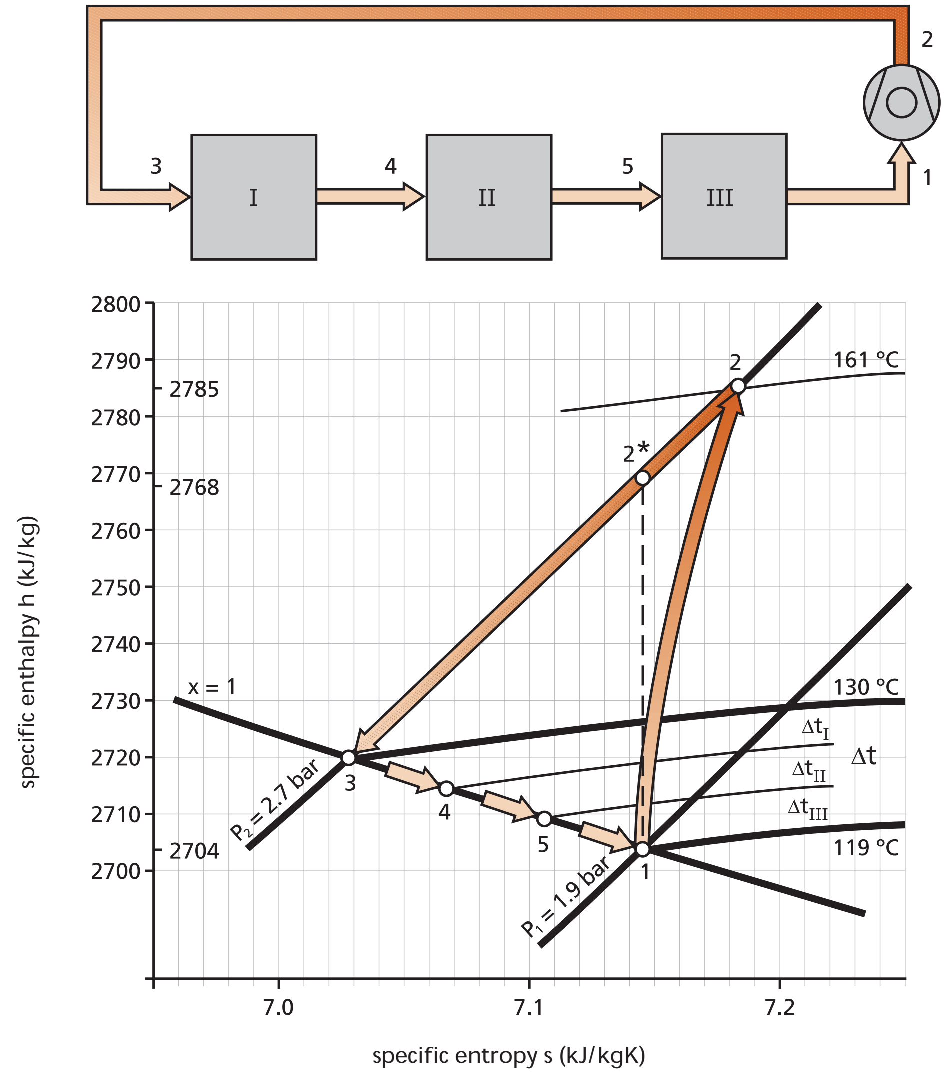
Principles of Mechanical Vapour Recompression

Single-stage centrifugal compressors and high pressure fans are generally used for mechanical vapour recompression systems for cost reasons. The explanations below are therefore limited to these designs.

Centrifugal compressors are volumetrically governed machines; i.e. the volumetric flow rate remains almost constant, regardless of the suction pressure. Mass flow does however change in proportion to the absolute suction pressure.

The compression cycle of the single-stage centrifugal compressor is depicted in the h,s diagram. The power that is required by the single-stage centrifugal compressor is

$$N = \dot{m} \cdot \Delta h_s / \eta_s$$



Change of state of water vapour in the Mollier h,s diagram in the case of single-stage compression

In the example: compression of saturated water vapour from the evaporator effect from suction state p_1 = 1.9 bar and t_1 = 119 °C to p_2 = 2.7 bar and t_2 = 161°C (compression ratio $\Pi = 1.4$).

The compression cycle follows the polytropic curve 1 – 2, with specific enthalpy of the vapour increasing by the amount of Δh_p. For the specific enthalpy h_2 of the vapour, the value to be obtained by definition from the equation for the internal (isentropic) efficiency of the compressor

$$\eta_s \approx \frac{\Delta h_s}{\Delta h_p} = \frac{h_2{}^* - h_1}{h_2 - h_1} \approx 0.8$$

is h_2 =2785 kJ/kg ($\eta_s \approx 0.8$ applies to single-stage centrifugal compressors in the case of water vapour). t_2 = 161 °C relative to h_2 and p_2. This vapour can now be used for heating of evaporator effect I. It first loses its superheat and is cooled to the saturation temperature t_3 (130 °C) of p_2 (2.7 bar). At this temperature, it passes to the calandria of the evaporator effect.

Based on $\Delta h_p \cong \Delta h_s / \eta_s$
$N = \dot{m} \cdot \Delta h_p / 3600$ (kW)

$\dot{m}$	the drawn-in vapour stream in kg/hr
Δh_p	the specific polytropic (effective) compression work in kJ/kg
Δh_s	the specific isentropic compression work in kJ/kg
η_s	the isentropic (internal) efficiency of the compressor

The specific polytropic compression work Δh_p depends *inter alia*, on the polytropic exponent κ and the molar mass M of the drawn-in gas, as well as the suction temperature and the required pressure increase. For the actual coupling power of the prime mover (electric motor, gas engine, turbine etc.) a further allowance for mechanical losses is taken into account.

Single-stage centrifugal compressors with impellers made of standard materials are capable of achieving a water vapour pressure increase by a factor of 1.8 , or, if higher-quality materials such as titanium are used, by a factor of up to 2.5.

The final pressure p_2 is then 1.8 , or max. 2.5 , times the suction pressure p_1, which corresponds to an absolute increase in saturated steam temperature of about 12-18 K, up to a max. 30 K depending on the suction pressure.

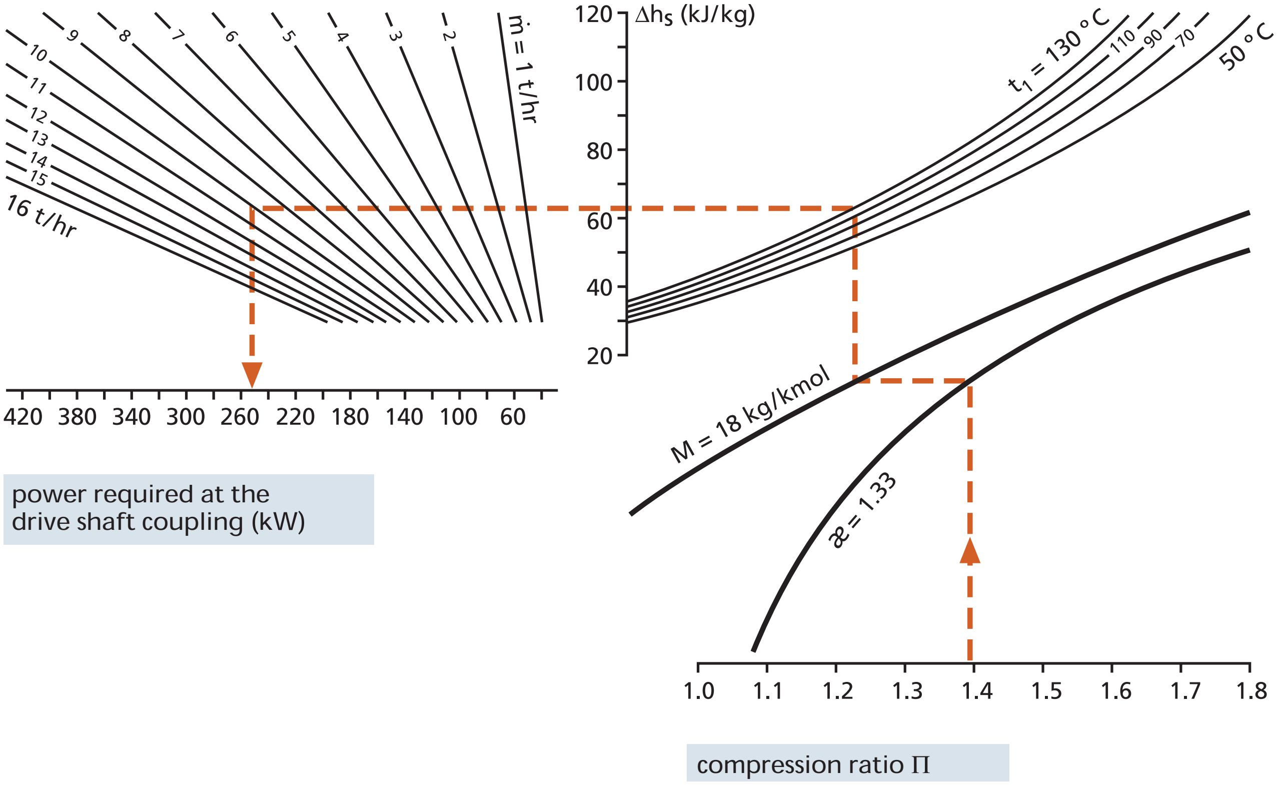
In evaporation technology, it is common practice to designate pressures by the corresponding water boiling temperatures. In this way, the temperature differences available can be directly indicated.

Example:

suction pressure $p_1 = 1$ bar corresponds to 100 °C
final pressure $p_2 = 1.7$ bar corresponds to 115.2 °C

$$\text{pressure ratio } \Pi = \frac{p_2}{p_1} = 1.7$$

saturated steam temperature increase: 15.2 K



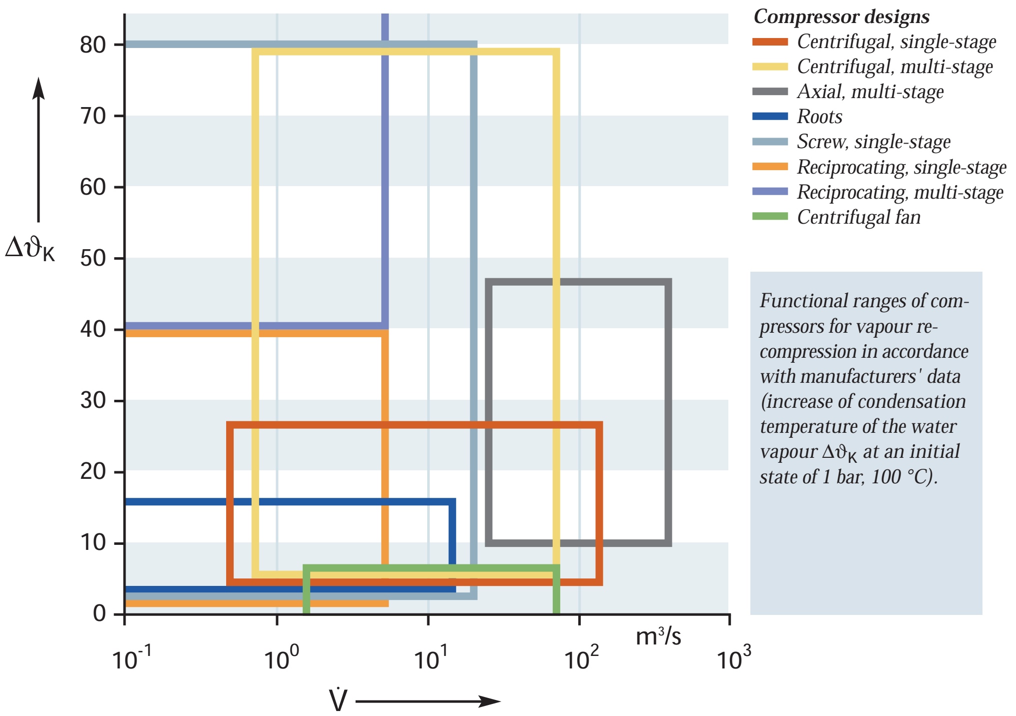
Determination of the coupling power (kW) for the prime mover. Nomogram for isentropic compression work Δh_s of the single-stage centrifugal compressor for saturated steam (molar mass M = 18 kg/kmol, polytropic exponent κ = 1.33) in relation to the compression ratio Π and the suction temperature.

Mechanical Vapour Recompressors – Design and Functional Ranges

Machines for the compression of gases operate in accordance with positive displacement or dynamic principles.

With positive displacement machines, moving machine parts separate the suction chamber and the pressure chamber, and the gas pressure is increased as the volume of the operating chamber decreases. In the case of a reciprocating compressor, this is done by the movement of the piston within the cylinder.

In dynamically operating machines, the gas is supplied with energy by the impeller blades rotating at high circumferential speeds. The gas is first accelerated and is then decelerated through a diffuser situated downstream from the impeller. In this way, the high velocity is converted into pressure energy. Depending on the direction in which the fluid passes through the impeller, the relevant machine is either called an axial-flow, mixed-flow or centrifugal compressor.



Functional ranges of compressors for vapour recompression in accordance with manufacturers' data (increase of condensation temperature of the water vapour $\Delta\vartheta_K$ at an initial state of 1 bar, 100 °C).

The type of compressor best suited depends on the operating conditions relevant to the application. Key parameters are the required pressure rise and the flow rate of the vapour to be compressed.

Π is the pressure ratio of final pressure p_2 to suction pressure p_1 and is defined as compression ratio.

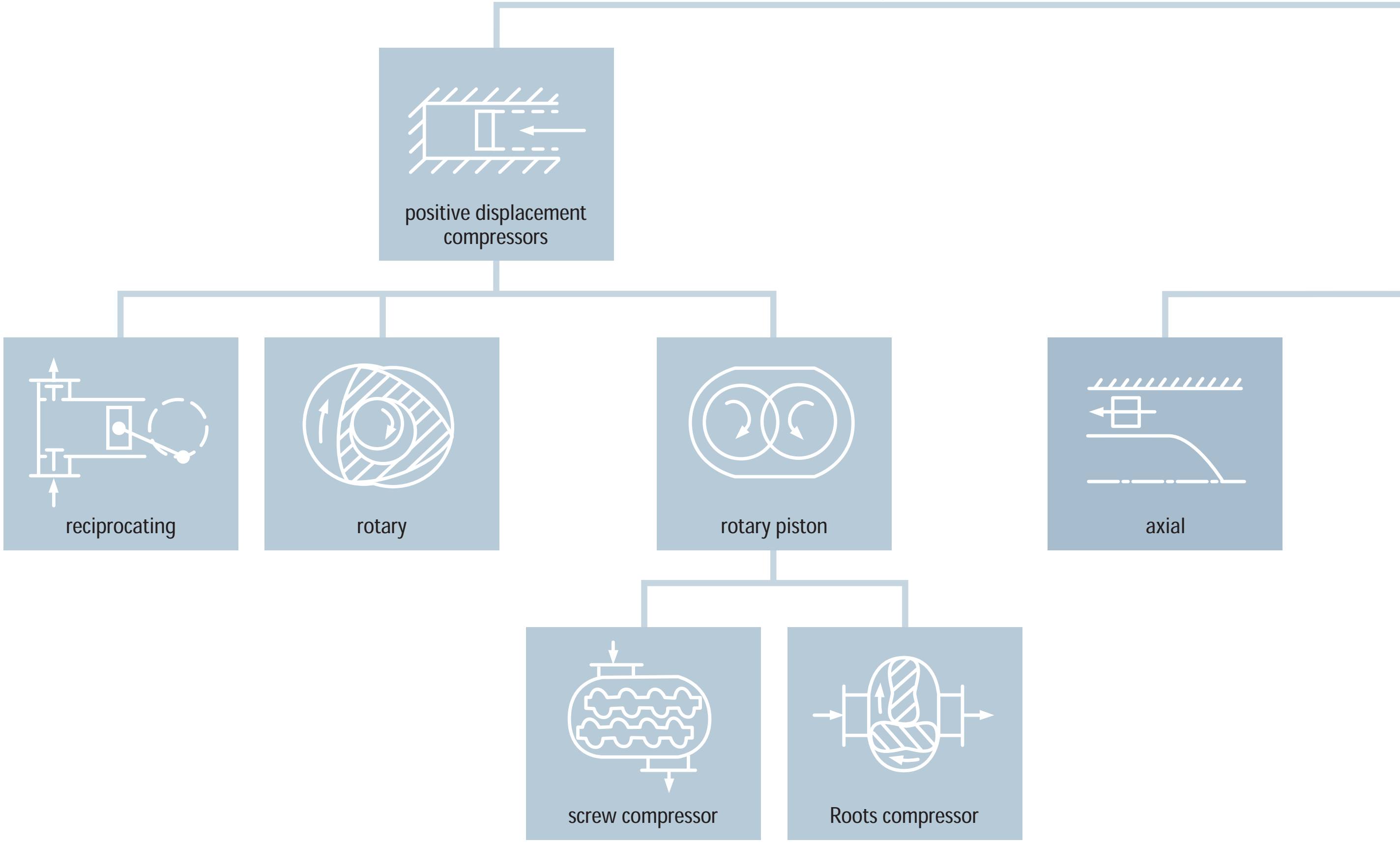
As evaporation plants are frequently operated in the vacuum range at medium heating surface loads and with small temperature differences, centrifugal recompressors are often used.

These are mainly:

- high pressure centrifugal fans
- single-stage centrifugal compressors

These machines are capable of a wide range of flow rates (e.g. 3,000 to 500,000 m³/hr), at pressure ratios of 1.1 to 2.5.

Mechanically driven compressors



Reciprocating compressors operate in similar fashion to the principle of the internal combustion engine. The crankshaft moves the piston in a straight oscillating motion via the connecting rod and the piston rod running on the crosshead. The gas in the working chambers above and below the piston is displaced through valves actuated by the gas pressure. In order to avoid thermal stress at the sealing faces, the cylinder shell and the gland pocket may be heated with steam.

$\dot{V}_{min} = 0.01\ m^3/s$
$\dot{V}_{max} = 6\ m^3/s$

Rotary compressors are of little importance for the compression of water vapour. They are frequently used for the compression of cooling agents.

The working elements of the **screw compressor** are the primary rotor and the secondary rotor. Compartments are formed by the rotors between their intermeshing screw profiles and the casing. As the rotors turn, the compartments become progressively smaller. *The installed pressure ratio* Π_{in} is determined by the position of the outlet port and rotor dimensions.

$\dot{V}_{min} = 0.06\ m^3/s$
$\dot{V}_{max} = 22\ m^3/s$

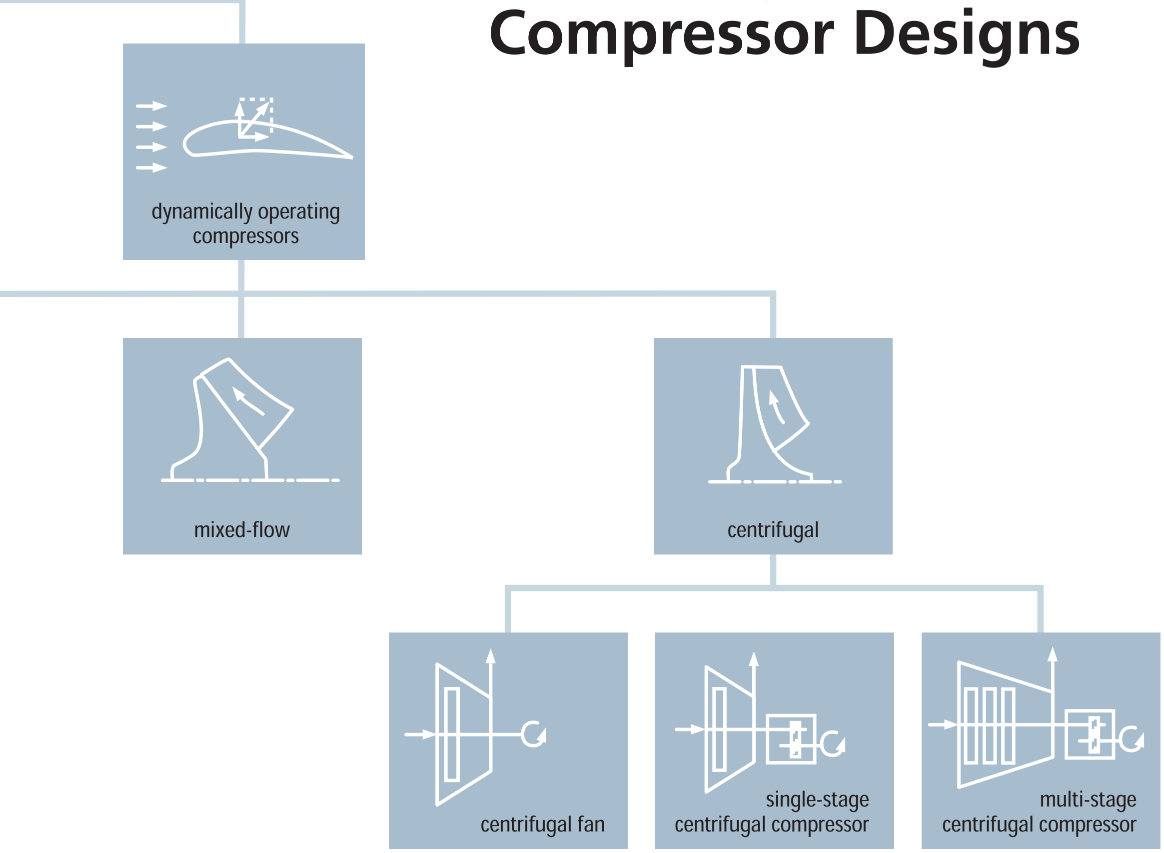
The two symmetrical, figure of eight shaped rotary lobes and the blower casing of the **Roots compressor** form compartments. As the lobes turn, the gas flows into these compartments and is transferred from the suction side to the pressure side. There is no internal compression in the rotating blades. The gas is compressed in the compartment on the pressure side by the positive displacement principle. A small gap remains between the lobes during rotation, and they do not actually touch.

$\dot{V}_{min} = 0.05\ m^3/s$
$\dot{V}_{max} = 25\ m^3/s$

Axial compressors are used for very large volumetric flow rates. They are nearly always designed as multi-stage systems. In a single axial stage, only a fraction of the pressure increase of a single centrifugal stage can be achieved. The efficiency of multi-stage axial compressors is however higher than that of multi-stage centrifugal compressors. Compared with the centrifugal compressor, a much smaller sized axial compressor can be used for the same type of compression work.

$\dot{V}_{min} = 25\ m^3/s$
$\dot{V}_{max} = 400\ m^3/s$

Operating Principles and Compressor Designs



Mixed-flow compressors are of little importance for the compression of water vapour.

Centrifugal fans can be used for low pressure ratios of up to $\Pi=1.25$. In the same way as a centrifugal compressor, the gas enters the eye of the impeller along its axis, exiting radially by means of centrifugal forces. The fan impeller and housing is of welded plate construction with reinforcing rib stiffeners as required. Gearboxes are generally not required, as the drive system gives the required speed of the impeller.

$\dot{V}_{min} = 1 \text{ m}^3/\text{s}$
$\dot{V}_{max} = 140 \text{ m}^3/\text{s}$

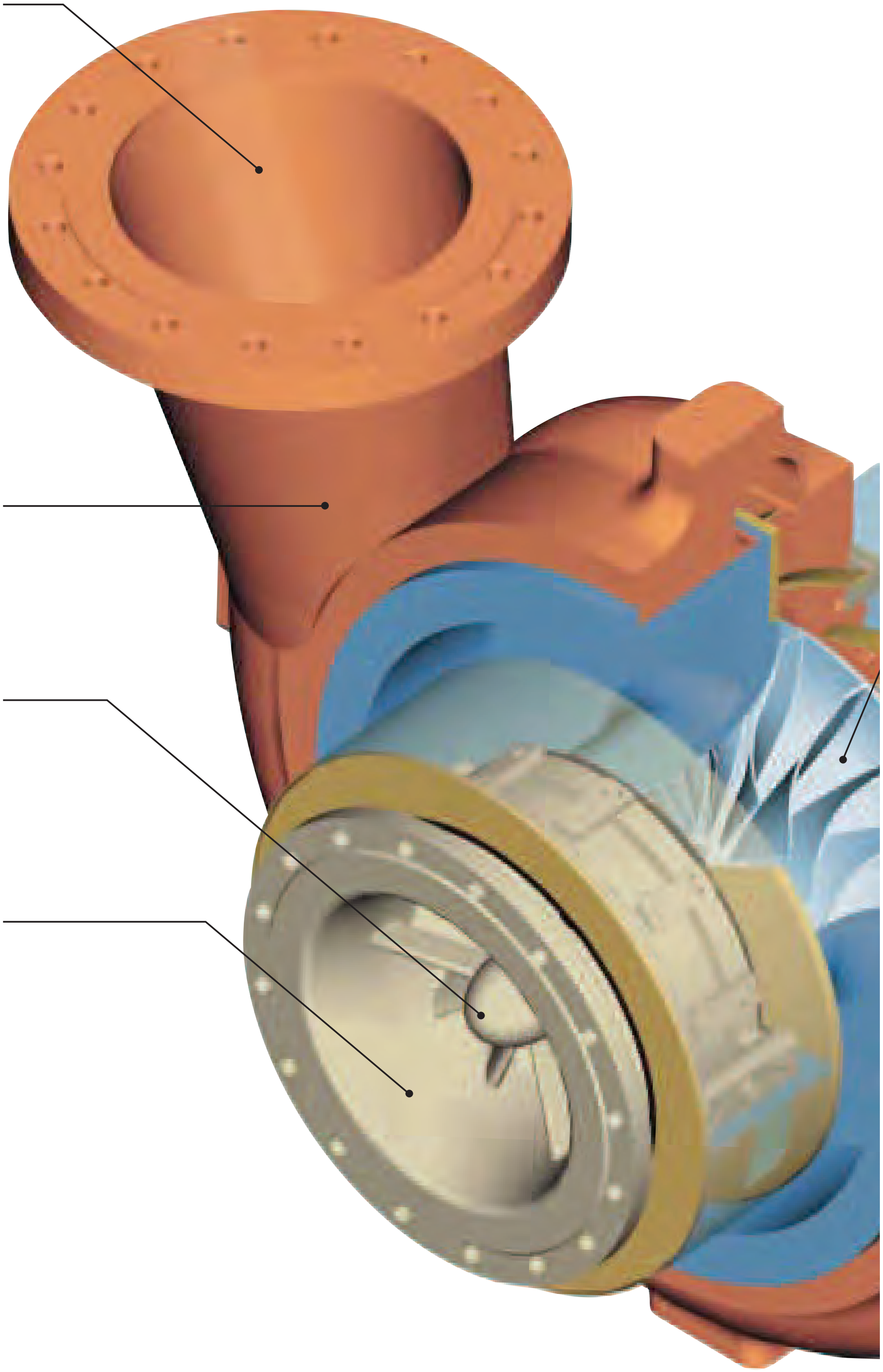
Single-stage, centrifugal compressors
The main feature of this type of compressor is the overhung impeller and the compact arrangement of compressor and gearbox. Motor, gearbox and compressor are mostly mounted on a common base-frame. Cast materials are used for the compressor casing. The impellers, which are highly stressed by the high tip speeds of > 400 m/s, are made of high-quality materials such as chrome-nickel steels or titanium alloys.

$\Pi_{max} = 2.5$
$\dot{V}_{min} = 0.5 \text{ m}^3/\text{s}$
$\dot{V}_{max} = 150 \text{ m}^3/\text{s}$

Multi-stage, centrifugal compressors
This type of compressor is used for large volumetric flow rates and high saturated steam temperature increases. The multi-stage centrifugal compressor is formed by the arrangement of several stages on a single shaft. After leaving one stage, the gas flows through a diffuser and interstage channel before entering the next impeller stage. The impeller shaft runs on bearings in the casing and is driven by a separate helical gear. For increasing the efficiency and for avoiding unacceptably high temperatures in the casing, water can be injected into the interstage channels.
In order to reach pressure ratios exceeding $\Pi = 10$, single-stage machines can also be connected in series. If the impellers were driven from a central drive with several pinions, the relevant unit would be called a two-, three-, or four-impeller compressor.

$\Pi_{max} = 10$ (in a casing)
$\dot{V}_{min} = 0.8 \text{ m}^3/\text{s}$
$\dot{V}_{max} = 70 \text{ m}^3/\text{s}$

Design Details of the Single-stage, Centrifugal Compressor

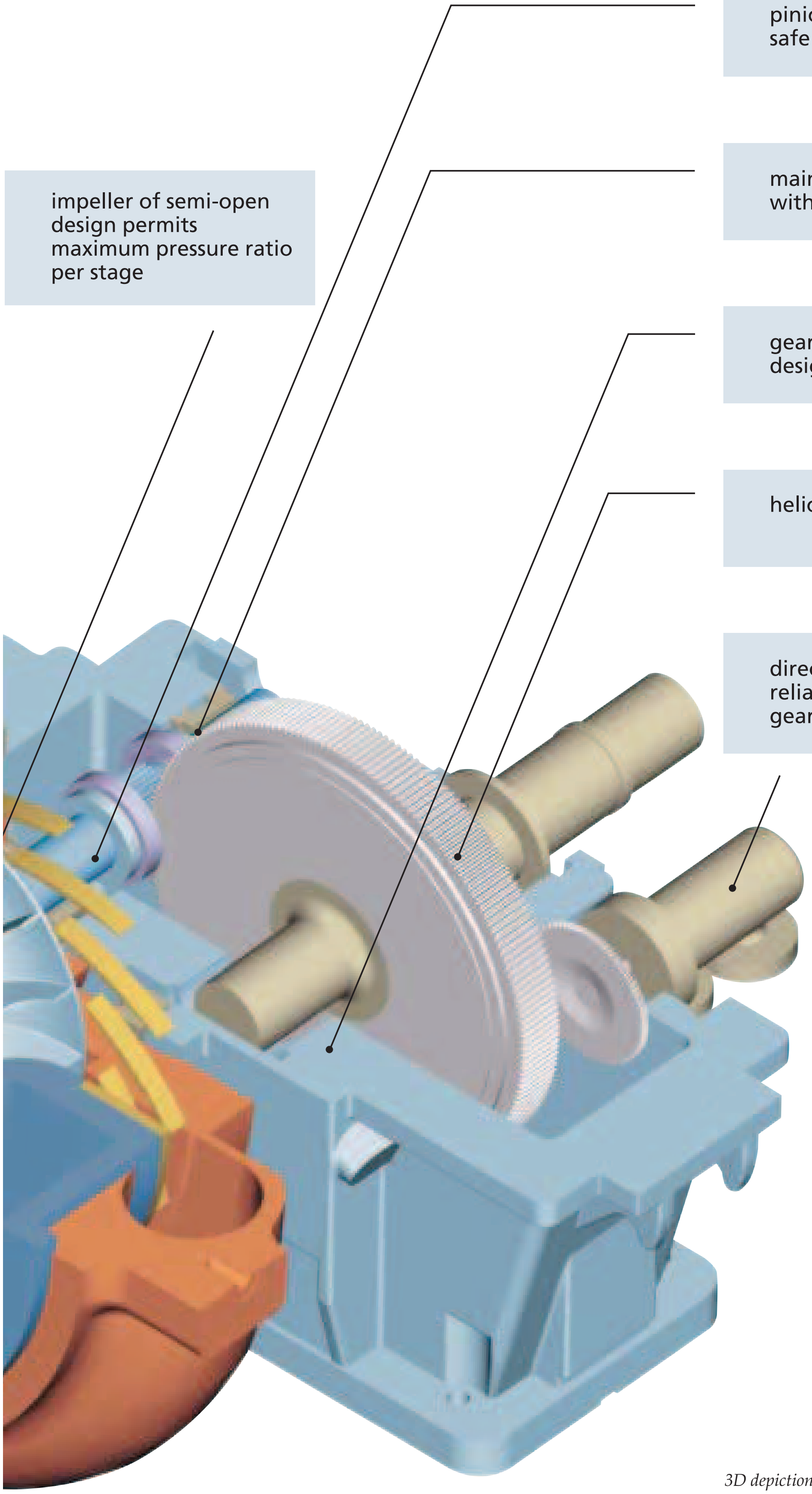


gas outlet

one-piece spiral casing permits final pressures of up to 60 bar

inlet guide vane for continuous adjustment achieves maximum partial load efficiencies

gas inlet



impeller of semi-open design permits maximum pressure ratio per stage

pinion shafts of highest quality ensure safe operation

maintenance-free pinion shaft bearings with optimum dampening properties

gearbox housing of solid, compact design

helical gear wheel

directly-driven main oil pump giving reliable lubrication to bearings and gears

3D depiction of a centrifugal compressor (illustration: Atlas Copco)

The impeller

The impeller is of the overhung design at the free end of the shaft (pinion shaft in the case of a compressor, main shaft in the case of a fan).

Depending on the compressor design, semi-open or closed impellers are used.

The blade geometry might be

- radial, or
- backward curved.

Radial bladed impellers are capable of achieving higher pressures due to the higher tip speeds that can be achieved as a result of their greater strength. Impellers with backward curved blades have lower permissible tip speeds, but their working range is wider and more stable.

For lower pressure increases, i.e. relatively low tip speeds, closed impellers are used due to their steep characteristic curve.

The impeller can be precision milled or of welded design. Frequently duplex steel of material EN 1.4462 is used. This material is corrosion resistant and has the required strength. Other CrNi steels and special materials such as titanium are also used.

Spiral casing

After leaving the impeller the accelerated gas stream flows into the spiral casing and tube diffuser. During this process, the high kinetic energy is converted into static pressure by deceleration of the flow.

While centrifugal compressor casings are mostly made of CrNi steel castings, fan casings are normally of welded design. To minimise corrosion, CrNiMo steel, typically material EN 1.4571, is used for the fan.

Casing thickness and external reinforcing is sized in such a way that the permissible deformation, which is of particular importance during vacuum operation, is not exceeded.

Gearbox

The helical gears of modern compressors are integrated within the compressor. For this reason, a coupling between gear and compressor shaft is not required. Thrust collars are situated on the high-speed pinion shaft. These thrust collars transmit the residual axial thrust to the low-speed main shaft (wheel shaft).

Centrifugal fans, which run at low speeds compared to compressors, do not require a gearbox. The impeller shaft is directly connected to the motor shaft by means of a coupling.

Bearing and lubrication system

The bearings of centrifugal compressors must ensure stable, vibration-free running conditions due to the high speeds, of up to 20,000 rpm, that can be encountered by a pinion shaft.

Radial tilting-pad bearings are therefore used for the high-speed pinion shaft. The wheel shaft of the gear runs on multi-faced, hydrodynamic journal bearings. The thrust bearing is designed as a combination radial/axial unit to contain the remaining axial thrust.

The bearings are lubricated with pressurised oil. For this purpose, a standardized lubrication system consisting of an oil tank, main oil pump, auxiliary oil pump, oil filter and oil cooler is installed.

Centrifugal fans are frequently equipped with less expensive roller bearings. For characteristic speed values (mean bearing diameter x speed) of up to 600,000 mm/min, simple forced oil lubrication is sufficient. At higher values, the same kind of lubrication system as for centrifugal compressors is used.

For fans running at characteristic speed values of more than 800,000 mm/min, hydrodynamic journal bearings are used.

Compressor Drives

Different types of prime mover can be used for driving vapour recompressors.

In each case, the drive is selected on the basis of its efficiency and the type of drive power available.

Electric motors are commonly used as drives. They offer considerable advantages due to the standardization of sizes and types of protection, their low power/weight, power/volume, price/performance ratios and minimum maintenance requirements.

Prime movers

Electric motors

Three-phase asynchronous motors

Three-phase asynchronous motors operate, according to the number of pairs of poles, at synchronous speeds of 3000, 1500, 1000 or 750 rpm (50 Hz, idle speed) or, if frequency converters are used, at variable speeds. Two types of motor are available: low voltage, and high voltage motors. Low voltage motors generally operate at capacities of up to 630 kW or 1,250 kW for supply voltages of 400 V or 690 V respectively. High voltage motors and converters can be used for capacities of up to approx. 6,000 kW. The efficiency of asynchronous motors is constant over a wide load range.

Direct current motors

Variable speed, direct-current motors are recommended for frequent partial load operation at high efficiency. They put a much lighter load on the operating current system during start-up than three-phase asynchronous motors. Their disadvantages are their higher prices and maintenance requirements. Compared to frequency controlled asynchronous motors, the direct current motor has lost some of its importance.

Gas engines

Gas engines are used if insufficient amounts of electrical energy are available. Good efficiencies, of up to 90 %, are reached if the waste heat from the cooling water and exhaust gas can be used, for example, for preheating purposes. The purchase price of a gas engine for waste heat recovery is considerably higher than that of a comparable electric motor. Its maintenance costs, which are several times higher than those of electric motors, are also a disadvantage.

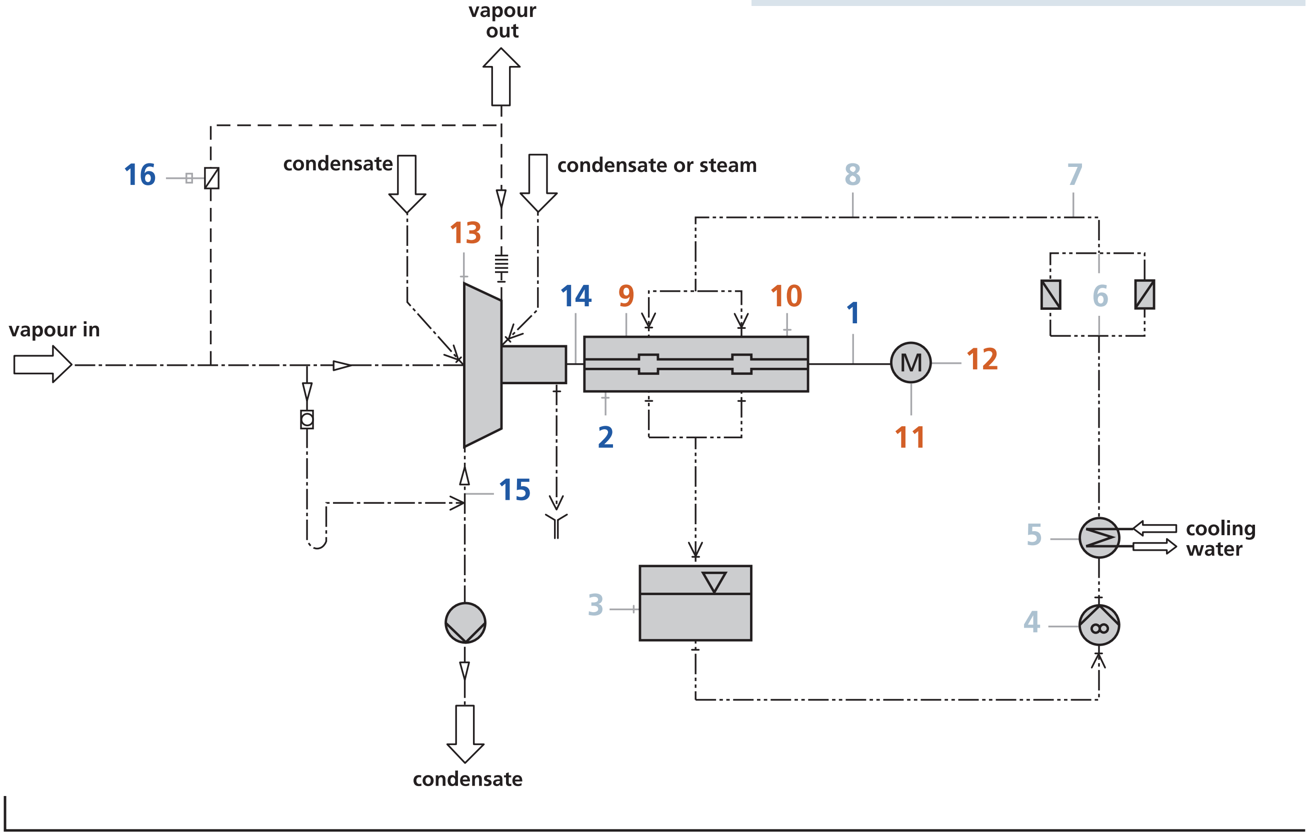
Steam turbines

The use of a variable-speed steam turbine as the prime mover of a compressor is sensible if the exhaust steam can be recovered. In this case, the relatively poor efficiency of a single-stage steam turbine, which may be used for price reasons, is of secondary importance.

Monitoring and Safety Equipment

A number of monitoring and safety systems are required to detect irregularities in compressor operation, to provide early warnings of wear and to prevent mechanical damage to the plant.

These are shown in detail in the example of a centrifugal fan:



1 Impeller speed

The speed is continuously measured by a revolution counter. The fan requires overspeed protection especially in the case of frequency converter operation. An alarm is given shortly before the maximum permissible speed is reached. When the maximum speed has been reached, the motor is automatically shut down.

2 Vibration monitoring

The vibration monitoring system monitors the dynamic behaviour of the rotating assembly. For this purpose, sensors are installed in the proximity of the bearings.

The vibration amplitude is determined by various factors, e.g. by:

- the relevant speed
- state of the bearings
- state of the impeller (incrustation/deposits)
- frequent changes in load required by the process

An alarm is given when the maximum permissible vibration is reached. Exceeding the maximum limit leads to an emergency stop of the system.

3 Oil tank levels

The oil level in the lubricating oil reservoir is measured. An alarm is given when this falls to the minimum level.

4 Oil pump

The operation of the oil pump is monitored. Pump failure leads to an emergency stop of the fan. During normal fan shutdown, the oil pump remains in operation at least until the complete standstill of the rotating assembly.
For safety reasons, centrifugal compressors are equipped with an auxiliary oil pump in addition to the directly connected main oil pump.

5 Oil cooler

A heat exchanger, supplied with cooling water, is installed in the oil circulation line for oil cooling. A temperature control loop keeps the oil temperature constant.

6/7 Oil filter differential pressure

The oil filter pressure difference (6) is measured and an alarm is given when the limit is exceeded. The pressure in the oil system (7) triggers the emergency stop of the fan when this value falls below the minimum pressure.

8 Oil flow

In addition to oil pressure monitoring, the oil flow can also be monitored and used as a shutdown condition in special cases.

9/10 Shaft bearing temperatures

The fan shaft runs on two bearings in a single bearing housing. The temperatures of intact bearings are considerably lower than the maximum permissible values. When elevated temperatures are reached, first an alarm is given. The system is immediately stopped when t_{max} is reached in order to avoid damage to shaft and impeller.

11 Motor winding temperatures

The driving motor requires protection against overheating. For this purpose, driving motors are equipped with temperature sensors in order to measure winding temperatures at different places. Excessive temperatures lead to motor shut down.

12 Motor bearing temperatures

For larger motor powers, e.g. > 100 kW, it is advisable to measure and monitor the motor bearing temperatures.

13 Fan/compressor casing temperature

Due to the compression work, the compressor casing itself is also heated by the pumped medium. An excessive casing temperature might arise if:

- the suction pressure and, consequently, the density of the pumped medium is excessive ($p_{operation} > p_{design}$)
- the compressor is operated without pumped medium
- the compressor operates in circulation mode (bypass valve of centrifugal compressor is open)

The temperature of the casing is recorded and monitored. Excessive casing temperatures first lead to an alarm and then to an emergency stop. Continuous condensate injection at the fan impeller inlet and, consequently, saturation of the vapour, limits excessive casing temperatures.

14 Shaft axial position indicator

In order to prevent major damage by gradual wear of the axial/thrust bearing, it is advisable in some cases to monitor the axial position of the shaft. If a limit is reached the compressor is automatically stopped.

15 Condensate drain

The casings of fans and especially of centrifugal compressors must be drained thoroughly in order to avoid damage to the impellers.
A condensate level monitoring system, which also triggers the emergency stop, is installed at the lowest point of the casing.

16 Surge protection for centrifugal compressors

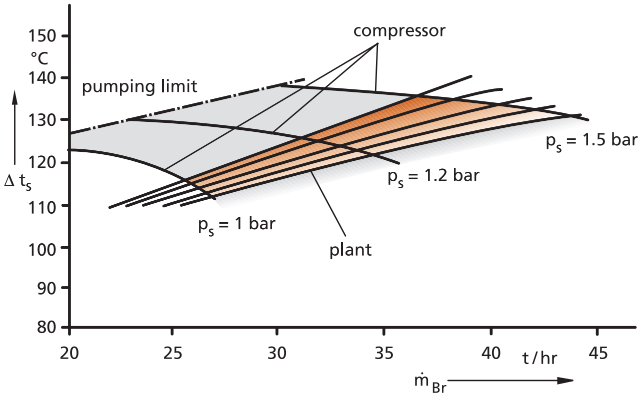
If the flow rate falls below the minimum value, e.g. during partial load operation, and thus below the stability limit of the compressor, the pumping direction of the vapour is momentarily reversed from the pressure side to the suction side. This surging leads to vibrations that may severely damage the machine.
For this reason, the machine is equipped with a surge limit safety system. If the flow rate falls below the safe pumping limit, the controller opens a bypass valve between the pressure line and the suction line in order to maintain an adequate flow rate.

Compressor Controls

Evaporation plants heated by mechanical vapour recompressors generally operate steadily to a limited extent, i.e. parameters such as mass flow rate, pressure and temperature fluctuate over time. Variations in evaporation rate (i.e. partial load operation) over a wide range are often desired. Therefore, different heat rates must be transferred. These changes in plant capacity are achieved by changing the temperature or pressure profiles.

The compressor design must take into account these variations in plant performance against the design duty. The operating behaviour of the plant is depicted in the so-called plant characteristics or performance curves. It shows the relationship between the necessary saturated steam temperature increase and the drawn-in vapour mass flow. The operating behaviour of the plant should be determined by tests to a large extent, or should at least be estimated.

The evaporator and compressor characteristic curves must correspond to each other for optimum operation of the vapour recompressor plant.



Specific changes in the flow conditions on the suction or pressure side of the compressor, for instance the suction pressure, allow the control concept to be varied. A variety of control concepts based on different performance criteria are available.

The following methods are preferred:

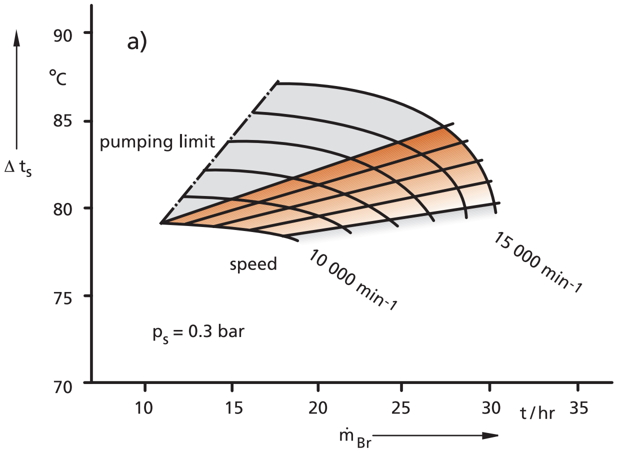
Single-stage centrifugal compressor

a) Speed control

Controlling the impeller speed and, consequently, the circumferential speed can influence the volumetric flow rate and the compression ratio. For speed control, a three-phase asynchronous motor equipped with a frequency converter is most commonly used. Especially for steep characteristic curves, i.e. for large changes in pressure against small changes in volume flow, control by continuous speed adjustment is advantageous.

The advantages of frequency converter operation are:

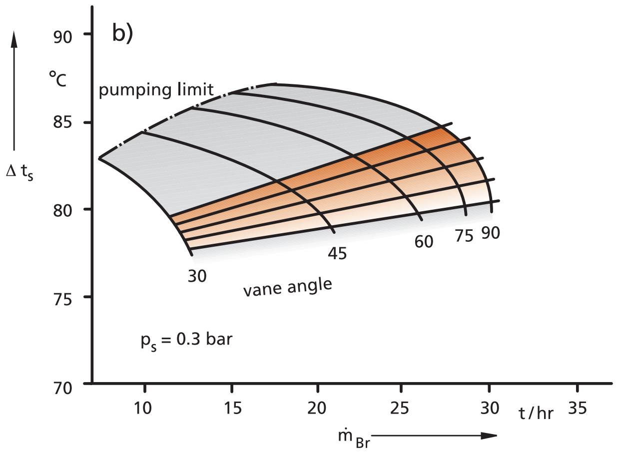
- Depending on the design, the motor can be operated at 20 to 60 % above its nominal speed so that a step-up gear is not required in most cases.
- A start-up coupling is not required.
- By limiting the starting current, the supply mains is not overloaded during start-up.
- Favourable partial load efficiencies are achieved.



b) Vane control

The vane control principle allows changes to the flow characteristic of the impeller. For this purpose, inlet guide vanes are installed in the suction nozzle of the compressor. The inlet guide vanes are adjusted from the outside by means of a drive. Whereas the compressor speed remains constant, the efficiency and performance of the impeller is changed.

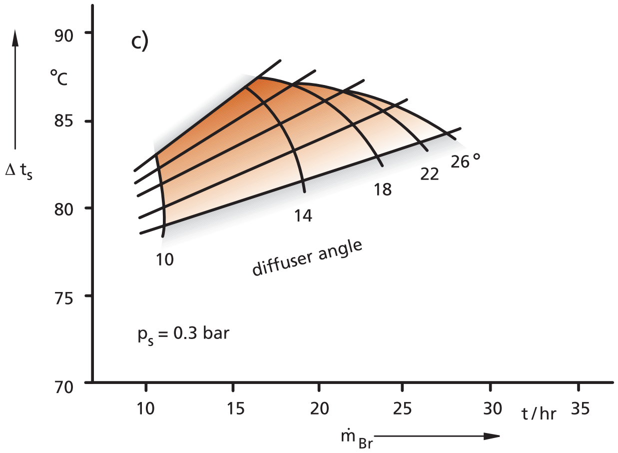
Vane control is advantageous for characteristic plant curves based on considerable pressure changes in relation to the displaced volume. This results in a large control range and good partial load efficiencies.



c) Diffuser control

Adjustable vanes in the diffuser ensure a large change in the mass flow rate with low efficiency decrease and flat characteristic plant curves.

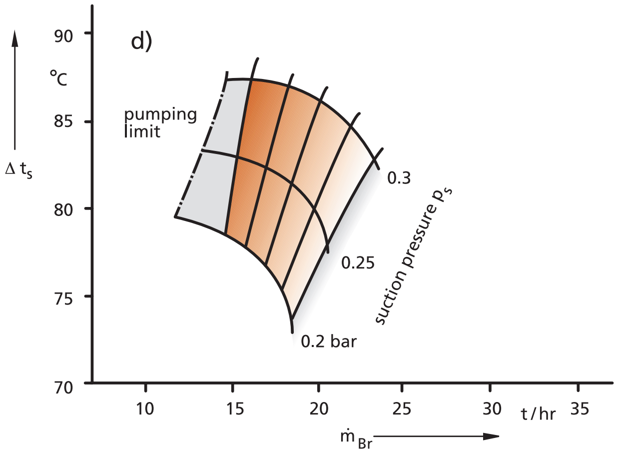
Diffuser control is used if the necessary temperature profile in the evaporator must remain approximately constant.



d) Inlet pressure control

If the process can take place at different temperatures, and the plant is not thermodynamically connected with other plants, the simple concept of controlling the pressure at the inlet by adjustments to the process parameters can be used. This control system ensures maximum variations in the mass flow rate, by changing the steam density at the evaporator separator, within the lower and upper process temperature limits. In many cases, a sufficiently large control range of the plant can be achieved in this way without special mechanical changes being necessary. Inlet pressure control can also be combined with one of the mechanical types of control, thus providing a particularly large control range.

Another possibility is the control of centrifugal compressors by throttling the suction line, thereby changing the mass flow rate. This type of control results in unfavourable partial load efficiencies.



Characteristic curves of a plant with fouling on the heating surface and for a single-stage, centrifugal compressor at different inlet pressures p_S

$\dot{m}_{Br}$ - vapour mass flow rate
Δ t_s - saturated steam temperature increase
p_s - pressure at inlet

◣ *fouling on heating surface*

1-effect falling film evaporation plant for the concentration of industrial waste water from tank cleaning

evaporation rate:
4.5 t/hr
final concentration:
40 % TS
compressor coupling power:
74 kW
drive:
frequency controlled electric motor

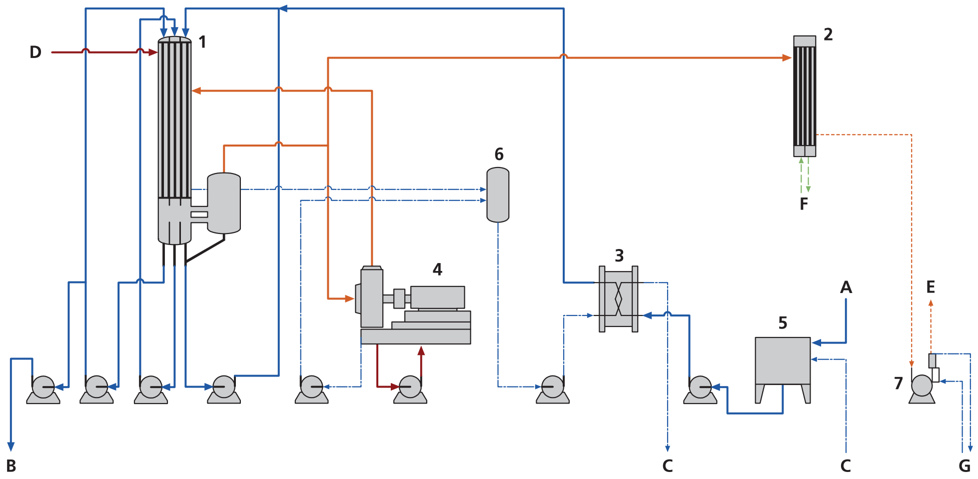
1-effect falling film evaporation plant with wrap-around separator and downstream high concentrator for various types of dairy and whey products

evaporation rate:
approx. 40 t/hr depending on the product
compressor coupling power:
390 kW

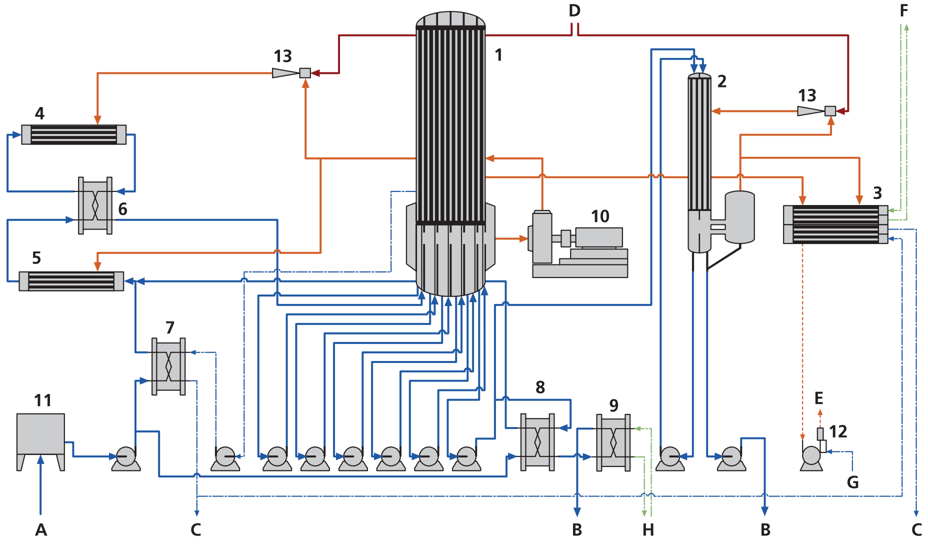
This plant concept is used for evaporation rates of 3 to approx. 55 t/hr water evaporation.

Evaporation Plants with Centrifugal Fans

1	*falling film evaporator*
2	*condenser*
3	*plate heat exchanger pre-heater*
4	*vapour recompressor (centrifugal fan)*
5	*feed tank*
6	*condensate collecting tank*
7	*vacuum pump*
A	*product*
B	*concentrate*
C	*condensate*
D	*live steam*
E	*deaeration*
F	*cooling water*
G	*service water*



1	*falling film evaporator*
2	*high concentrator*
3	*condenser*
4, 5	*pre-heaters*
6-9	*plate heat exchangers*
10	*vapour recompressor (centrifugal fan)*
11	*feed tank*
12	*vacuum pump*
13	*steam jet vapour recompressor*
A	*product*
B	*concentrate*
C	*condensate*
D	*live steam*
E	*deaeration*
F	*cooling water*
G	*service water*
H	*chilled water*



3-effect falling film evaporation plant consisting of 2 pre-evaporator effects heated by mechanical vapour recompressor and a finisher, heated by thermal vapour recompressor

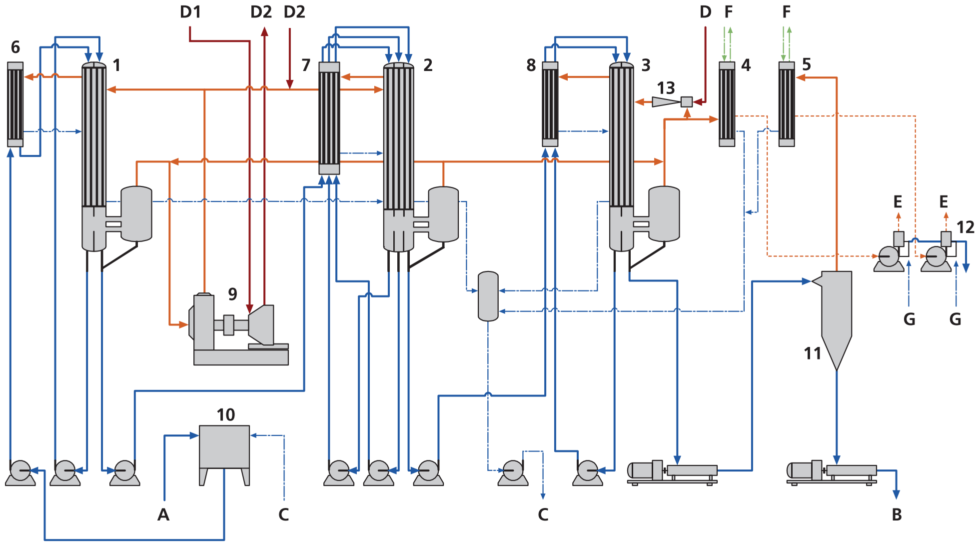
evaporation rate:
50 t/hr
concentration range:
30 - 48 % TS
steam consumption:
15.5 t/hr of 38 - 11 bar (g) turbine
3.3 t/hr of 11 bar (g) steam jet
vapour recompressor
compressor coupling power:
730 kW

The centrifugal fan for vapour recompression is driven by a steam turbine.

1-effect falling film evaporation plant for wheat starch waste water. The plant can be operated as 1-effect system or as 2-effect system

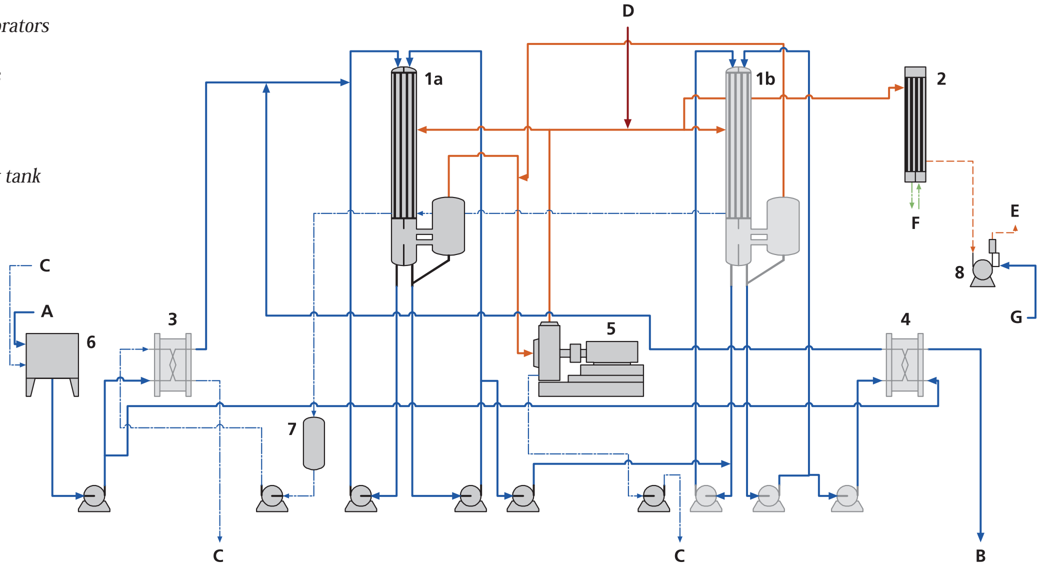
evaporation rate:
approx. 17 / 33 t/hr
concentration range:
9 - 15 % TS
compressor coupling power:
1-effect operation: 230 kW
2-effect operation: 420 kW

1, 2	*falling film pre-evaporators*
3	*high concentrator*
4, 5	*condensers*
6-8	*pre-heaters*
9	*vapour recompressor (centrifugal fan)*
10	*feed tank*
11	*flash cooler*
12	*vacuum pumps*
13	*steam jet vapour recompressor*
A	*product*
B	*concentrate*
C	*condensate*
D	*live steam*
D1	*high pressure steam*
D2	*low pressure steam*
E	*deaeration*
F	*cooling water*
G	*service water*



1a, 1b	*falling film pre-evaporators*
2	*condenser*
3, 4	*plate heat exchangers*
5	*vapour recompressor (centrifugal fan)*
6	*feed tank*
7	*condensate collecting tank*
8	*vacuum pump*
A	*product*
B	*pre-concentrate*
C	*condensate*
D	*live steam*
E	*deaeration*
F	*cooling water*
G	*service water*

The light grey equipment shows the planned plant expansion

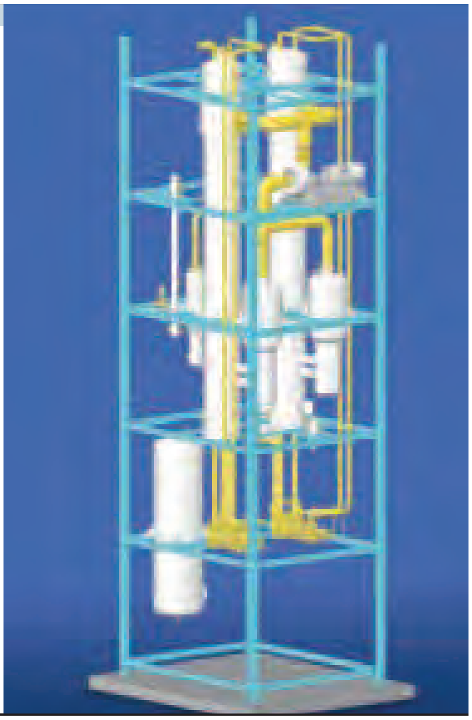


Falling film evaporation plant for different glucose solutions, consisting of a 2-effect falling film pre-evaporator heated by mechanical vapour recompressor and a 2-effect falling film finisher in counter-flow arrangement, equipped with thermal vapour recompressor and flash cooler

evaporation rate:
19 t/hr
concentration range:
32 - 83 % TS
steam consumption:
850 kg
compressor coupling power:
325 kW

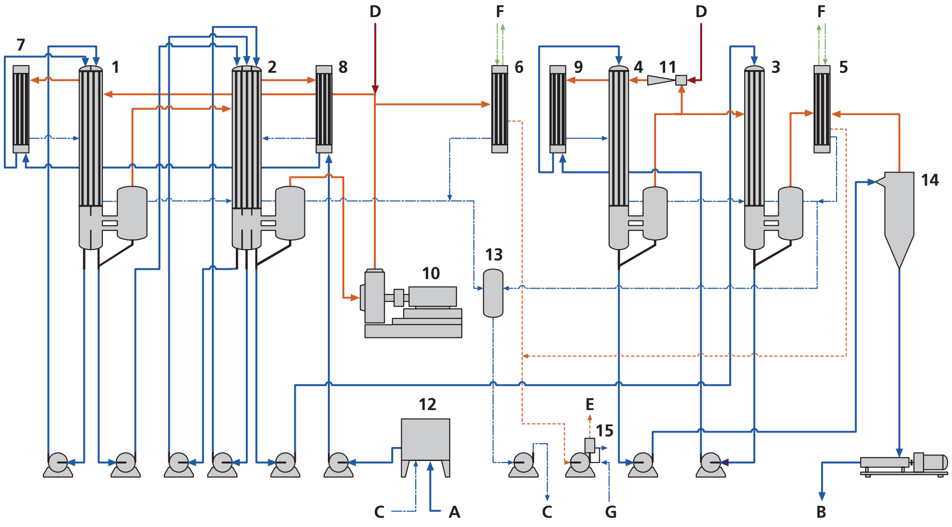
3-effect falling film, forced-circulation evaporation plant consisting of 2 parallel evaporator effects for the pre-concentration of caprolactam water

evaporation rate:
14 t/hr
concentration range:
7 - 95 % TS
steam consumption:
900 kg
compressor coupling power:
250 kW

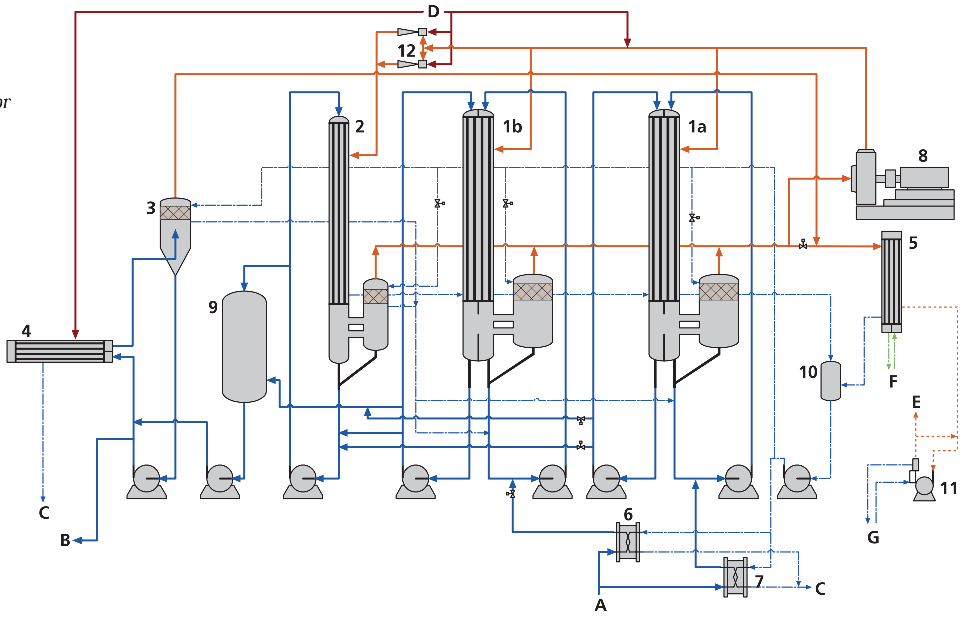


Evaporation Plants with Centrifugal Compressors

1,2	*falling film pre-evaporators*
3,4	*falling film finishers*
5,6	*condensers*
7-9	*pre-heaters*
10	*vapour recompressor (centrifugal compressor)*
11	*thermal vapour recompressor*
12	*feed tank*
13	*condensate collecting tank*
14	*flash cooler*
15	*vacuum pump*
A	*product*
B	*concentrate*
C	*condensate*
D	*live steam*
E	*deaeration*
F	*cooling water*
G	*service water*



1a	*falling film evaporator*
1b	*falling film evaporator*
2	*falling film evaporator*
3,4	*forced circulation evaporator*
5	*condenser*
6,7	*plate heat exchangers*
8	*vapour recompressor (centrifugal compressor)*
9	*buffer tank*
10	*condensate collecting tank*
11	*vacuum pump*
12	*steam jet vapour recompressor*
A	*product*
B	*concentrate*
C	*condensate*
D	*live steam*
E	*deaeration*
F	*cooling water*
G	*service water*



Our Range of Products in Summary

Evaporation plants

for the concentration of all types of liquid food, organic and inorganic solutions, waste water and other types of liquid products by means of thermal or mechanical vapour recompressors, single-effect or multi-effect systems, with additional equipment for heating, cooling, degassing, crystallization, rectification etc.

Membrane filtration

for the concentration of liquid food, process water, organic and inorganic solutions and waste water; for the separation of impurities for upgrading and valuable material recovery; based on technology and references by **GEA Filtration**, Hudson/USA.

Distillation/rectification plants

for the separation of multi-component mixtures, e.g. for the recovery of organic solvents, the recovery, purification and dehydration of bioalcohol of different qualities etc.

Lines for the production of alcohol

from the treatment of raw material, fermentation, distillation to stillage concentration/drying

Plants for crystallization

of special products as well as waste water containing salts

Product studies, engineering

for plants included in our range of products

Process Engineering
Division

GEA Wiegand

DIN ISO 9001

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CRYSTALLIZER VENDOR INFO

GEA

Vanorman, Eric

From:	Leonescu, Craig <craig.leonescu@gea.com>
Sent:	Friday, January 23, 2015 9:36 AM
To:	Vanorman, Eric
Cc:	Pugh, Lucy B.; Melches, Christian
Subject:	RE: Budget Estimate for Wastewater Crystallizer

Eric,

The following is the budget estimate for the crystallizer and centrifuge

1. Design (One Crystallizer Train): One Effect (3 Stage) MVR Heated Forced Circulation Crystallizer. The MVR will consist of Three (3) Turbofans in series.
2. Mass Balance (Per Train)
   a. Feed Rate=88 GPM (44,000 PPH), ~100 C (Total from 2 Ea. Falling Film Evaporator Trains)
   b. Discharge Rate=8,500 PPH, +/- 80 C **(±15% Moisture)**
   c. Process Condensate=37,500 PPH, 108 F
3. Major Utilities
   a. Steam
      i. Start-Up Steam=4,000 PPH
   b. Electric
      i. Turbofans Total Consumed=1,200 KW
      ii. 460/3/60: Pumps: TBD
   c. Cooling Water=600 GPM 85 F Supply/100 F Return
4. Scope of Supply:
   a. 1 Ea. FC Heat Exchanger Ti Grade 12 Tubes, Hastelloy Tubesheets and Product Contact Areas, Duplex Shells
   b. 1 Ea. FC Flash Vessel
   c. 1 Ea. Surface Condenser
   d. 3 Ea. Turbofans, with Including Lube Oil System, instrumentation. Duplex casing, Duplex/Super Duplex Impeller.
   e. 3 Ea. Turbofan 480V Motors and 480 V Drives (or Guide Vanes and Softstarts)
   f. 1 Ea. Centrifuge
   g. 1 Ea. Mother Liquor Tank
   h. 3 Ea. Condensate Collectors
   i. 1 Lot of Vapor Ducting
   j. 1 Lot of Spray Devices
   k. 1 Lot of Process Pumps including Axial Flow Crystallizer Pump (AF Pump=~175 KW Consumed)
   l. 1 Lot of Field Instruments, Control and On/Off Valving
   m. 1 Lot of Engineering
      i. PFD
      ii. P&ID
      iii. General Arrangement (Including Recommended Platform locations)
      iv. Hole & Load Drawing with equipment weights.
      v. Connection Point List
      vi. Equipment List
      vii. Manual Valve Specifications
      viii. Tag List
      ix. Piping Guideline Model

    x. Lifting Drawings
    xi. Functional Description
    xii. Equipment Outline Drawings
    xiii. O&M Manual and Spare Parts Lists

5. Exclusions:
    a. Building, Foundations, Structural Steel, Platforms, Stairways, Ladders, HVAC, Lighting, Sewers
    b. Piping & Fittings, Hangers
    c. Piping Stress Analysis and Hanger Location.
    d. Manual Valving
    e. Complete Installation of Equipment and Piping (Installation Supervision can be supplied on a T&M Basis)
    f. Cranes, Rigging
    g. Control System and HMI (This can be added if requested)
    h. MCC, including VFD's
    i. Power and Control Wiring, Pneumatics
    j. Utilities (Electric, Steam, Water, Cooling Water, Air, Chemicals, Soft Water) and associated piping, valving, instrumentation.
    k. Permits
    l. Freight (Ex Works, points of mfg.), VAT, Duties
    m. Commissioning Assistance (This can be supplied on a T&M Basis)

6. L X W X H (Per Train): TBD

7. Budget Pricing (Crystallizer and Dewatering)=US $ 8 MM

Best regards

Craig Leonescu
Senior Sales/Process Engineer

GEA Process Engineering Inc.
GEA Process Engineering
Office 410 997 6611, Fax +1 410 997 5021
Mobile 443 831 2258
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www.gea.com

We live our values.
Excellence • Passion • Integrity • Responsibility • GEA-versity

9165 Rumsey Road, Columbia, Maryland, 21045, USA

From: Leonescu, Craig
Sent: Tuesday, January 13, 2015 8:43 AM
To: 'Vanorman, Eric'
Cc: Pugh, Lucy B.; Melches, Christian (christian.melches@gea.com)
Subject: RE: Budget Estimate for Wastewater Evaporator

Hi Eric,

Sorry for the delay. We are working on the Crystallizer design now and I will have the estimate to you as soon as possible. Thanks again.

Best regards

Craig Leonescu
Senior Sales/Process Engineer

GEA Process Engineering Inc.
GEA Process Engineering
Office 410 997 6611, Fax +1 410 997 5021
Mobile 443 831 2258
craig.leonescu@gea.com
www.gea.com

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9165 Rumsey Road, Columbia, Maryland, 21045, USA

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Friday, December 19, 2014 3:18 PM
To: Leonescu, Craig
Cc: Sumpter, Ben; Pugh, Lucy B.
Subject: RE: Budget Estimate for Wastewater Evaporator

Craig:

Thank you very much! We'll be in touch the week of 1/5. You have a great holiday as well.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446   M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600   F 1.616.940.4396 Cisco 2084446
www.aecom.com

From: Leonescu, Craig [mailto:craig.leonescu@gea.com]
Sent: Friday, December 19, 2014 3:17 PM
To: Vanorman, Eric
Cc: Sumpter, Ben; Pugh, Lucy B.
Subject: RE: Budget Estimate for Wastewater Evaporator

Hi Eric,

Thanks for the email. I have sent the information to my colleague in Germany who I work with for the crystallizer design. Unfortunately, most people at GEA including my colleague and myself will be out until the new year. I have asked him to follow-up with me as soon as possible after he is back. I will try to get you something the week of 1/5. I will keep you informed.

Have a happy holiday.

Best regards

Craig Leonescu
Senior Sales/Process Engineer

GEA Process Engineering Inc.
GEA Process Engineering
Office 410 997 6611, Fax +1 410 997 5021
Mobile 443 831 2258
craig.leonescu@gea.com
www.gea.com

We live our values.
Excellence • Passion • Integrity • Responsibility • GEA-versity

9165 Rumsey Road, Columbia, Maryland, 21045, USA

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Thursday, December 18, 2014 4:05 PM
To: Leonescu, Craig
Cc: Sumpter, Ben; Pugh, Lucy B.
Subject: RE: Budget Estimate for Wastewater Evaporator

HI Craig:

Thanks for the additional information. We would like to have the information on the crystallizer by the end of the year if at all possible. We are working up our analysis of the entire treatment process and this is one of the final pieces.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446 M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600 F 1.616.940.4396 Cisco 2084446
www.aecom.com

TANK VENDOR INFO

Tank Connection

TANK CONNECTION

614 N. 2nd Street, Ste A
Rogers, AR 72756
Tel: 620-423-3010
Fax: 479-636-1656

01/22/2015

TC Quote #: QL19517

Eric Van Orman, P.E.
AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, MI 49512

Tel.: 616-940-4446
E-mail: eric.vanorman@aecom.com

Reference: Madison, WI

Dear Sir:

At the Tank Connection, we have a unique perspective on potable water, wastewater, fire protection and industrial liquid applications. We are the only tank supplier worldwide that designs, manufactures and installs all four types of steel storage tanks including bolted RTP, field-weld, shop-weld and hybrid tank designs. We know the merits of each type of construction, which allows us to objectively propose the right type of storage for your application.

In bolted tank fabrication, TC commands the top product line worldwide. We offer:

- Our precision RTP (rolled, tapered panel) construction is the #1 bolted tank design selected worldwide.
- TC's proprietary LIQ Fusion 7000 FBE™ powder coat system is the #1 performance interior tank lining available for water and wastewater storage applications worldwide.
- TC's proprietary EXT Fusion 5000 FBE & SDP (powder on powder) system provides unmatched performance compared to ALL exterior bolted tank coatings.
- TC's Quality Management System is ISO 9001:2008 certified.
- TC's synchronized hydraulic jacking process is reviewed as the top field construction process based on field safety and installed quality.
- The TC support team profiles with over 2100 years of combined storage tank experience. In bolted tank fabrication, the Tank Connection Affiliate Group is unrivaled worldwide.

Get all the facts on liquid storage at one of our websites. Download our "quick specs" at www.liquidtanks.com for ground reservoirs, elevated water tanks and all types of steel tank construction.

We are pleased to offer the following proposal for your review:

ITEM 1: (2) 225,000 GALLON TANKS

GEOMETRY / DESCRIPTION	
Tank Quantity:	
Construction Method:	TC Rolled Tapered Panel (RTP) Bolted Design – For more information please review the following TCAG brochures "*Liquid Containment Solutions*" & "*RTP Design vs. API-12B*"
Materials of Construction:	304 SS
Nominal Inside Diameter:	36.92 feet
Nominal Eave Height:	30.35 feet
Note: Nominal eave height is measured as follows: • *Steel Floor Applications – bottom of base angle to top of eave angle* • *Concrete Floor Applications – top of finished concrete floor to top of eave angle*	
Bottom Style:	**Flat Steel Floor** - Floor materials supplied by Tank Connection.
Tank Supported By:	Reinforced concrete foundation designed & supplied / installed by others meeting the requirements of AWWA D103-09
Roof Style:	Open top with wind girder
Roof Style: OPTION	Steel cone with 2" rise to 12" run (9.46°) slope
Usable Capacity:	227,103 US gallons based on 24" total freeboard

DESIGN CRITERIA	
Design Specifications:	AWWA D103-09
Seismic Design:	Per AWWA D103-09: S_S=11.1%g, S_1=7.0%g, Site Class=D, Use Group=2, I=1.25
Wind Design:	Per AWWA D103-09: 90mph, Exp. C, I=1.15
Deck Live / Snow Load:	35 pounds per square foot (if roof option is selected)
Product Stored:	Wastewater
Specific Gravity:	1.00 assumed
Product pH Range:	4 to 9 assumed
Design Pressure / Vacuum:	Atmospheric
Operating Pressure / Vacuum:	Atmospheric
Design Temperature:	176° Fahrenheit
Operating Temperature:	Ambient
Tank Empty Weight:	48,685 pounds (each tank)
Jobsite Location:	Madison, WI

SEALANTS / GASKETS / HARDWARE	
Roof Gasket:	White EPDM strip gasket – 3/32" thick (if roof option is selected)
Sidewall Sealant:	High performance moisture-cured elastomeric sealant – White
Bottom Sealant:	High performance moisture-cured elastomeric sealant – White
Hardware:	304 SS

COATINGS
NO COATINGS REQUIRED FOR 304SS PANELS

TANK COMPONENTS / ACCESSORIES		
Mark:	**Qty:**	**Description:**
--------	1	Tank Connection logo (installed on top ring)
--------	1	Liquid tank nameplate
--------	2	24" Diameter shell manway with bolt-on hinged cover
--------	2	8" Diameter 150# RFSO single flanged nozzle located in tank sidewall
--------	2	10" Diameter 150# RFSO single flanged nozzle located in tank sidewall
--------	1	10" Diameter internal 90 degree weir elbow w/ external 10" diameter schedule 10 downcomer pipe, pipe support brackets & flap valve for overflow
--------	1	Outside caged ladder with lockable hoop and intermediate rest platform(s) (if required) – OSHA – HDG – Includes a 36" square observation platform at top of tank approximately 42" below the eave line
--------	Incl	½" thick asphalt impregnated fiberboard located under steel bottom of tank
--------	Incl	4 mil polyethylene sheeting located between tank foundation & fiberboard
--------	Incl	Final drawings and engineering calculations to include a WI P.E. stamp

INSTALLATION SERVICES		
Mark:	**Qty:**	**Description:**
--------	Incl	Hydrostatic Leak Test

ITEM 2: (2) 2,250,000 GALLON TANKS

GEOMETRY / DESCRIPTION	
Tank Quantity:	2
Construction Method:	TC Rolled Tapered Panel (RTP) Bolted Design – For more information please review the following TCAG brochures "*Liquid Containment Solutions*" & "*RTP Design vs. API-12B*"
Materials of Construction:	Carbon steel
Nominal Inside Diameter:	115.86 feet
Nominal Eave Height:	31.32 feet
Note: Nominal eave height is measured as follows: • *Steel Floor Applications – bottom of base angle to top of eave angle* • *Concrete Floor Applications – top of finished concrete floor to top of eave angle*	
Bottom Style:	**Flat Steel Floor** - Floor materials supplied by Tank Connection.
Tank Supported By:	Reinforced concrete foundation designed & supplied / installed by others meeting the requirements of AWWA D103-09
Roof Style:	Open top with wind girder
Roof Style: OPTION	Aluminum geodesic dome
Usable Capacity:	2,312,438 US gallons based on 24" total freeboard

DESIGN CRITERIA

Design Specifications:	AWWA D103-09
Seismic Design:	Per AWWA D103-09: S_S=11.1%g, S_1=7.0%g, Site Class=D, Use Group=2, I=1.25
Wind Design:	Per AWWA D103-09: 90mph, Exp. C, I=1.15
Deck Live / Snow Load:	35 pounds per square foot (if aluminum geodesic dome is selected)
Product Stored:	Wastewater
Specific Gravity:	1.00 assumed
Product pH Range:	4 to 9 assumed
Design Pressure / Vacuum:	Atmospheric
Operating Pressure / Vacuum:	Atmospheric
Design Temperature:	Ambient
Operating Temperature:	Ambient
Tank Empty Weight:	278,412 pounds (each tank)
Jobsite Location:	Madison, WI

SEALANTS / GASKETS / HARDWARE

Dome Gasket:	Extruded silicone strip gasket (if aluminum geodesic dome is selected)
Sidewall Sealant:	High performance moisture-cured elastomeric sealant – White
Bottom Sealant:	High performance moisture-cured elastomeric sealant – White
Hardware:	Plastic encapsulated JS1000 coated grade 8 minimum bolts with JS1000 coated flat washers & hex nuts. Tank bottom hardware includes plastic encapsulated nuts.

COATINGS

Interior Coating:	LIQ Fusion 7000 FBE ™	6 mils nominal DFT	Range 5 - 9 mils average DFT
Exterior Primer:	EXT Fusion 5000 FBE ™	3 mils nominal DFT	Range 3 - 5 mils average DFT
Exterior Finish Coat:	EXT Fusion SDP ™	3 mils nominal DFT	Range 3 - 5 mils average DFT
Exterior Color:	Customer to specify from TC standard colors (white, tan, light gray, light green & light blue). See note #9 below for more information regarding premium and custom colors.		

Notes:
1. *All coatings are baked-on formulation, applied over an SP10 surface preparation*
2. *Touch-up coating kits for interior and exterior are provided for field application as required.*
3. *LIQ Fusion 7000 FBE - A proprietary system unmatched in performance compared to ALL bolted tank linings*
4. *EXT Fusion 5000 FBE & SDP – A proprietary exterior system that profiles as "powder fused on powder" system*
5. *DFT = dry film thickness*
6. *FBE = fusion bonded epoxy powder coating*
7. *SDP = super durable polyester powder coating*
8. *TC performs in-house holiday testing to ensure interior coating in liquid zone is 100% holiday free.*
9. *Premium colors (forest green & cobalt blue) and specially formulated colors are available for an additional fee.*
10. *Coating is NSF 61 approved*

For more information please review the following TCAG brochures "*Unmatched Liquid Coating Performance!*" & "*LIQ-Fusion 7000 FBE™…A Stronger System than Glass*"

TANK COMPONENTS / ACCESSORIES		
Mark:	**Qty:**	**Description:**
--------	1	Tank Connection logo (installed on top ring)
--------	1	Liquid tank nameplate
--------	2	24” Diameter shell manway with bolt-on hinged cover
--------	2	8” Diameter 150# RFSO single flanged nozzle located in tank sidewall
--------	2	10” Diameter 150# RFSO single flanged nozzle located in tank sidewall
--------	1	10” Diameter internal 90 degree weir elbow w/ external 10” diameter schedule 10 downcomer pipe, pipe support brackets & flap valve for overflow
--------	1	Outside caged ladder with lockable hoop and intermediate rest platform(s) (if required) – OSHA – HDG – Includes a 36” square observation platform at top of tank approximately 42” below the eave line
--------	Incl	½” thick asphalt impregnated fiberboard located under steel bottom of tank
--------	Incl	4 mil polyethylene sheeting located between tank foundation & fiberboard
--------	Incl	Final drawings and engineering calculations to include a WI P.E. stamp

INSTALLATION SERVICES		
Mark:	**Qty:**	**Description:**
--------	Incl	Hydrostatic Leak Test

FOUNDATION DESIGN- $3500.00 PER TANK SIZE	
Qty:	**Description:**
1	**FOUNDATION DESIGN DISCLAIMER:** Ringwall, turned down slab, structural mat, or base setting ring foundation design drawings and engineering calculations to include a WI P.E. stamp based on geotechnical report supplied by others. **NOTE**: Additional charges will apply if piers, pilings, etc. are required due to unsuitable soil conditions.

PRICING SUMMARY- ITEM 1- (2) 304SS 225,000 GALLON TANKS

ITEM #1 – OPEN TOP

$324,089.00	**TANK MATERIALS & ACCESSORIES** (includes all applicable discounts)
$53,591.00	**TANK INSTALLATION** (utilizing non-union, non-prevailing wage labor rates)
$5,130.00	**ESTIMATED FREIGHT** (FCA destination, 3 truckload(s), pricing excludes unloading at jobsite)

ITEM #1 – ROOF OPTION

$399,150.00	**TANK MATERIALS & ACCESSORIES** (includes all applicable discounts)
$71,704.00	**TANK INSTALLATION** (utilizing non-union, non-prevailing wage labor rates)
$5,130.00	**ESTIMATED FREIGHT** (FCA destination, XXX truckload(s), pricing excludes unloading at jobsite)

PRICING SUMMARY- ITEM 2- (2) 2,250,000 GALLON TANKS

ITEM #2 – OPEN TOP	
$616,744.00	**TANK MATERIALS & ACCESSORIES** (includes all applicable discounts)
$208,085.00	**TANK INSTALLATION** (utilizing non-union, non-prevailing wage labor rates)
$23,940.00	**ESTIMATED FREIGHT** (FCA destination, 14 truckload(s), pricing excludes unloading at jobsite)
ITEM #2 – ROOF OPTION	
$971,268.00	**TANK MATERIALS & ACCESSORIES** (includes all applicable discounts)
$295,025.00	**TANK INSTALLATION** (utilizing non-union, non-prevailing wage labor rates)
$31,550.00	**ESTIMATED FREIGHT** (FCA destination, 18 truckload(s), pricing excludes unloading at jobsite)

PRICING VALIDITY AND STEEL COSTS:

Due to current volatility in the carbon steel market, material escalation (if any) will be based on AMM (American Metals Market) published price index for hot rolled carbon steel. Pricing included in this proposal is based on today's published index. Any increase in steel costs between date of proposal and material procurement above this benchmark will be to customer's account. (Example: If steel increases $.03/per pound, this would increase the cost of a 30,000 lb. tank as follows: 30,000 lbs. x 3¢ = $900). Note: Steel is typically procured anywhere from 2 weeks after returned approval drawings to approx. 6 weeks prior to shipment).

EXCEPTIONS & CLARIFICATIONS:

GENERAL

- All exceptions & clarifications listed below apply unless specifically noted otherwise within the scope of supply.
- Please refer to attached document TC-2 005 – Terms & Conditions of Sale for additional clarifications
- Any items or specifications not specifically mentioned in this quotation are not a part of this quotation. This quotation represents our complete offering.
- All quoted materials conform to the Buy American Act with the exception of the JS1000 coated hardware. This specialized hardware is not manufactured in the US; therefore, TC sources it from a manufacturer located in Canada. Federal Register, Volume 74, #104 – Notices, dated 6/2/09 allows an exception to the Buy American Act when non-domestic materials make up less than 5% of the total material costs incorporated into a project. For more information please visit the EPA website or click on the following link http://www.epa.gov/water/eparecovery/docs/BA_De_Minimus_Waiver.pdf
- Bid bonds, performance & payment bonds, permits, sales and/or use taxes are not included.
- Foundation loading calculations are supplied by TC; however, foundation design, excavation, foundation materials, and foundation installation are the responsibility of others.
- Piping, valves, mixers, lighting, electrical wiring, control wiring, control systems, and other auxiliary equipment are supplied and installed by others.
- Insulation clips / brackets, insulation materials, insulation installation, and tank heaters are the responsibility of others, unless otherwise noted above.
- Disinfection of tank interior is the responsibility of others.
- Disinfection Disclaimer: after tank has been successfully hydrostat (leak) tested, tank must be completely drained by others. Disinfection will occur when tank is empty. All filling and draining of water is by others.
- Engineering calculations are available with submittal drawings for an additional charge.
- Three sets of drawings are provided for each size tank. Specific Professional Engineer's Seal on final drawings can also be furnished for an additional cost.
- Customer is responsible for proper tank ventilation. Tank Connection standard 20" diameter mushroom vent with insect screen is not considered a frost-free vent. If a frost-free vent is required for the application, an emergency pressure/vacuum relief valve must be added.

- Please refer to attached document TC-3 009 – Preventing Galvanic Corrosion for clarification on the use/need of cathodic protection systems with TC factory applied coatings.
- TC standard pipe brackets support only lateral loads and are intended to be used as guides only. Pipe supports stands / brackets must be supplied by others.
- TC's standard bolted tanks comply with API 650 welding requirements as applicable to bolted tank fabrication.
- Indemnification – TC will be responsible for their negligence only.

MATERIALS

- Anchor bolts, nuts, and saddles are supplied by TC only if required by final tank design.
- Unless otherwise noted, TC has quoted our standard design, fabrication, accessories (perimeter handrails, ladders, etc.) and coatings to aid in cost efficiency.

INSTALLATION

- **Installation price quoted includes a water leak test. Customer to provide sufficient water to fill the tank within 24 hours. Sufficient water supply, piping, blind flanges, and other equipment necessary to hydrostat (leak) test must be supplied and installed by customer prior to erector leaving the jobsite or additional costs will be incurred. Disposal of test water (if necessary) is the responsibility of the customer.**
- **Installation price quoted is based on summer weather conditions (April through October). Increased costs may apply during winter weather conditions (November through March).**
- Field installation of cast-in-place or epoxy style anchor bolts is the responsibility of others.
- Installation pricing is based on free and clear access all around the foundation with no overhead obstructions.
- Adequate area for material staging adjacent to foundation is required. Typical 100' minimum lay-down area is required, with 360 degree clear access provided. **See TC document TC-2 001 Field Clarifications.**
- We have based our installation bid on open work hours, utilizing all daylight hours, 7 days/week. Continuous operation of installation is required, eliminating the need for lost time.
- Sanitary facilities and trash dumpster to be provided by customer.
- Buyer must obtain insurance against loss by fire, lightning, removal, and all extended coverage perils, theft, vandalism, and malicious mischief, earthquake, negligence, and any other insurance which Buyer deems necessary (generally covered in Buyer's Risk policies). Buyer need not cover tools owned by workers or tools and equipment owned or rented by installer. Buyer is required to provide protection to prevent theft of material from jobsite.

FREIGHT

- Customer is responsible for material off-loading of trucks as they arrive at the jobsite. TC suggests the use of an all-terrain reach forklift for assistance as all pallets & crates weigh 6,000# or less. Material to be staged adjacent to jobsite.
- Freight prices quoted are FCA destination and do not include any permits, duty, sales and/or use taxes.

TERMS OF PAYMENT:

- 30% of material due upon order placement – due on receipt
- 30% of material due upon customer notification to proceed with manufacturing – due on receipt
- 40% of material due upon shipment (or upon manufacture of tank(s), if shipment is delayed by customer) – Net 15
- Installation is billed progressively every 14 days based on percentage of completion – due on receipt
- Freight is Prepaid & Add – due on receipt
- No retainage is applicable unless previously agreed upon.
- All terms of payment are subject to approval by our credit department.
- Past due invoices will be charged a service charge of 1.5% per month.
- We reserve the right to delay tank erection if payment on tank invoice is not paid in accordance with stated terms.
- In the event that water is not available at the time of tank erection completion, return trip charges may be applicable.

SCHEDULE: TBD

Tank Connection appreciates the opportunity to provide this proposal for your application. We are committed to providing the highest quality products and services available. It is our goal to provide your company with excellent customer service at every stage of project review.

If you have any questions concerning the scope of this quotation, we are available to meet with you in your office, over the phone, or via email exchange. Please advise us at you earliest convenience on our proposal and how we can assist you with your other requirements.

TC is represented by Jeff Vos with Solberg, Knowles & Associates, phone 616-699-2500. Please call us if you have any questions or if we can be of additional service.

Best Regards,

John Eaves
Liquid Division
Tank Connection
Ph: 620-423-3010 x231
Email: jeaves@tankconnection.com
Web: www.tankconnection.com

TO PLACE AN ORDER:

SIMPLY FILL OUT THE INFORMATION BELOW, SIGN & RETURN

The undersigned is authorized to purchase products on behalf of the company they represent.

PRINTED NAME: ______________________

SIGNATURE ______________________

TITLE: ______________________

DATE: ______________________

PURCHASE ORDER #: ______________________

REQUESTED DELIVERY DATE: ______________________

TANK CONNECTION
AFFILIATE GROUP

3609 N. 16TH Street
P.O. Box 579
Parsons, Kansas 67357
620.423.3010 Fax: 3999
sales@tankconnection.com

Preventing Galvanic Corrosion in Water Storage Tanks

Tanks coated with LIQ 7000 FBE™ do not require cathodic protection (CP). The exception includes water and wastewater tanks that become corrosion cells (commonly known as a battery), due to the use of dissimilar metals submerged inside the tank.

Galvanic corrosion, also known as dissimilar metal corrosion is an electrochemical process in which one metal corrodes preferentially to another when both metals are in electrical contact and immersed in an electrolyte. In water and wastewater storage applications, care should be taken to electrically isolate the connection between dissimilar metals (i.e., stainless steel piping, etc.) that are submerged in the tank. If plastic, or coated carbon steel piping is submerged in bolted tanks coated with LIQ Fusion 7000 FBE™, galvanic corrosion is not an issue. If excess dissimilar metal piping and system components are submerged, a cathodic protection (CP) system may be required.

Cathodic Protection (CP) is a technique used to control the corrosion of a metal surface (the tank) by making it the cathode of an electrochemical cell. Two common types include “galvanic/sacrificial anodes” and “impressed current” systems.

Preventing galvanic corrosion inside the tank should be addressed during the selection and specification of your internal piping and system components. It costs significantly less to prevent the development of a corrosion cell in a coated carbon steel water tank application than to treat a corrosion cell. Initial prevention is always the best approach for long life, low maintenance water storage systems.

TANK CONNECTION
1801 South 21st Street
Parsons, Kansas 67357
620.423.3010 Fax: 3999
sales@tankconnection.com

Tank Connection - Field Installation Clarifications

Quoted Field Installation Service is based on the following “Jobsite Clarifications”
(unless otherwise noted):

- **General Clarifications**
  - Installation will be performed by a TC crew or a TC-certified subcontractor.
  - A continuous installation operation is required for timely completion of a finished and useable tank. TC requests the customer be proactive in eliminating the need for lost time.
  - Non-Union installation bids are based on open work hours, utilizing all daylight hours, seven (7) days/week. Union installation bids are based on six 10-hour days, Monday thru Saturday, 7 am – 5:30 pm. If the before mentioned work hours are not acceptable to the Buyer, then the Buyer is required to provide acceptable work hours to TC prior to order placement.
  - Labor price is based on weather conditions favorable to continuous tank erection operations (e.g. summer months). Increased costs apply during seasonal periods that experience weather conditions unfavorable to continuous tank erection operations (e.g. spring, fall, and winter months).
  - Grout is not included in the scope of work, unless otherwise noted in the proposal.
  - Buyer will obtain insurance against loss by fire, lightning, removal, and all extended coverage perils, theft, vandalism, and malicious mischief, earthquake, negligence, and any other insurance which Buyer deems necessary (generally covered in Buyer’s Risk policies). Buyer need not cover tools owned by workers or tools and equipment owned or rented by installer. Buyer is required to provide protection to prevent theft of material from jobsite.
- **Safety Clarifications**
  - Tank Connection (TC) construction crews will operate within the rules and regulations of the Occupational Safety and Health Administration. If more stringent Federal, State and local safety standards apply, then TC will follow the most stringent standard.
  - The customer is required to provide all current safety standards, rules, and regulations to TC prior to order placement. If safety standards, rules or regulations are revised after the sale, then the Buyer is required to provide TC with a copy of the recently revised safety standards, rules, and regulations no less than 30-days prior to the expected start date. Changes or additions to safety and health requirements that are not already covered by standard TC safety and health policy may affect cost and schedule agreements.
  - If MSHA crew certification is required, TC must receive notice at time of order placement.
  - Onsite safety orientation, not to exceed one hour in duration, is included. If additional safety orientation or classes are required, then additional charges are applicable.
- **Final Acceptance Clarifications**
  - Dry Bulk Silos – Either an exterior spray test or a smoke test (type of testing to be determined by Tank Connection) shall be performed by tank erection crew at time of assembly completion. Sufficient water supply, hose and water disposal is by customer (1” to 1-1/2” fire hose with a fog nozzle; 30 psi to 50 psi water pressure; 40 GPM to 60 GPM water volume) is required for the exterior spray test.
  - Liquid Tanks – Installation price quoted includes a water leak test. Customer to provide sufficient water to fill the tank within 24 hours. Sufficient water supply, hose and water disposal is by customer. Disinfection is not included. If installation process, including final test, cannot be performed in one trip, remobilization cost will be at customer expense.

- **Job Site Clarifications**
    - Job site access ways, service roads, and adjacent grounds must be suitable to support continuous installation operations under all typical or expected weather conditions. Ways, roads, and grounds must be clear of obstructions, provide sufficient clear space, be paved with compacted gravel (or better material), be able to support all lifting operations (e.g. cranes, man-lifts, etc.), and ensure no standing water is retained in the work area.
    - If a temporary foundation pad is required to facilitate tank erection, then the pad shall have the following attributes: be capable of supporting the maximum weight of the finished tank, be within 1% of true level, and be at least two (2) feet larger than the finished tank diameter. The customer is responsible for engineering calculations and certifications unless otherwise agreed.
    - Photos of the installation site are requested as early as possible to enable proper preparations of crew and equipment prior to mobilization.
    - Level, compacted and maneuverable terrain to and around work area. Free and clear access 360 degrees around tank required – minimum 8 ft.
    - Top of foundation must be within 6 inches of grade unless otherwise noted in our proposal.
    - Foundation centerlines and base orientation will be established by others at 0 degrees, 90 degrees, 180 degrees, and 270 degrees and marked on the pad, prior to erector arriving at jobsite. Additional charges and/or re-mobilization charges may apply should inaccuracies or deficiencies in foundation work, performed by others, cause lost time.
- **Material Handling Clarifications**
    - Customer is responsible for material unloading at the jobsite. TC suggests the use of an all-terrain reach forklift, as all pallets & crates weigh 6,000# or less. Material to be staged within 150’ of foundation. Typical 100’ x 100’ (minimum) lay-down area is required.
- **Utility Clarifications**
    - Power supply for tools require a minimum 120 volt, 20 amp circuit 3-prong grounded, within 30 foot of foundation.
    - Power supply for project trailer, welders (if applicable) will be made available at the jobsite within 50 feet of tank foundation.
- **Facility and Services Clarifications**
    - Sanitary facilities and trash dumpster to be provided, in close proximity to work area, by customer, unless otherwise agreed.
- **Mobile Equipment Clarifications**
    - If cranes are required, adequate area for crane staging is required adjacent to foundation area. If overhead obstructions or alternate crane staging areas are preferred by customer, additional charges may be applicable.

TANK CONNECTION
AFFILIATE GROUP

3609 N. 16TH Street
P.O. Box 579
Parsons, Kansas 67357
620.423.3010 Fax: 3999
sales@tankconnection.com

Tank Connection, LLC - Terms and Conditions of Sale

1. **Proposal.** Tank Connection, LLC (Seller) hereby provides Buyer a quote containing terms, conditions, specifications, pricing, and exceptions to provide goods and/or services pursuant to Seller's understanding of Buyer's needs and expectations. Buyer represents full knowledge and understanding of all terms, specifications, and exceptions in Seller's quote known as the Proposal from this point forward.

2. **Agreement.** Buyer's acceptance of the Proposal, whether by oral or written order, constitutes Buyer's agreement to the general terms and conditions in this Agreement and the terms, conditions, specifications, pricing, and exceptions as described in the Proposal. Buyer further agrees upon date of order the terms, conditions, specifications, pricing, and exceptions as detailed in the Proposal meet all Buyer expectations and is hereby made a part of this Agreement. The Effective Date of this Agreement is the latter date of either Buyer's order if written, or Seller's Proposal.

3. **Contracts between the Parties.** This agreement reflects the entire agreement between the parties with respect to its subject matter. Except for any nondisclosure agreements between the parties, all other oral or written agreements, contracts, understandings, conditions, or representations with respect to the subject matter of this Agreement are superseded by this Agreement. The terms and conditions of this Agreement shall only be amended if specifically changed in writing and signed by an executive officer of Seller.

4. **Delivery.** Unless otherwise stated on the face hereof, the price and delivery of all goods, are FOB Seller's factory. Title to the goods shall pass to Buyer when the goods are duly delivered to Carrier at Seller's factory, except where Buyer requests a delay in shipment, in which case the title shall pass to the Buyer when the goods are ready for shipment.

5. **Risk of Loss.** The risk of loss to the goods shall pass to Buyer when the goods are duly delivered to the Carrier at Seller's factory, except where the Buyer requests a delay in shipment as described above. The processing of freight claims or loss claims is the responsibility of Buyer.

6. **Limited Warranty**. Seller warrants the goods against defects in workmanship and materials under normal and proper use and operating conditions for a period of 12 months from date of shipment. There are no understandings, agreements, representations or warranties, either express or implied, including without limitation the implied warranties or merchantability and fitness for a particular purpose respecting the goods other than or different from the seller's limited warranty.

   Seller's Limited Warranty is subject to the following limitations and conditions:

   a. Seller's Limited Warranty shall become void and terminate if, during the warranty period, Buyer (1) transfers its ownership or use of goods to another person (other than initial transfer from Buyer to final owner), or (2) puts goods to uses or operates them under conditions, including without limitation the storage of liquids or bulk material of different composition, bulk density, specific gravity, flow characteristics, or processes different from those represented to Seller prior to date of shipment, or (3) dismantles or moves tank from its original site, or (4) fails to complete all financial obligations of Seller's sale agreement.

   b. Seller's Limited Warranty shall become void and terminate if Buyer makes repairs or alterations to goods without obtaining Seller's prior written approval.

   c. Seller's Limited Warranty does not include (1) corrosion or erosion of goods caused by or resulting from elevated temperatures (above ambient), acids, chemicals or other caustic substances, (2) the suitability of any material or part selected by Buyer for use with goods, (3) galvanic corrosion due to dissimilar metal interaction of internals, not supplied by Seller.

   d. On all materials, parts or accessories purchased by Seller from vendors, Seller's Limited Warranty is limited to the duration and effect of the terms and conditions of any warranty given to Seller by such vendors, and then only to the extent that Seller is able to enforce such warranties in appropriate legal proceedings.

   e. Seller's Limited Warranty excludes structural design (this is covered by the certifying engineers certification) and operating performance issued, problems or consequences attributable in whole or in part to the correctness of design and operating parameters provided by Buyer, the correctness of interfacing work, material or services to be provided by Buyer (such as foundations or attached process or control equipment), Buyer's operating practices or maintenance, or any action by Buyer resulting in the application of abnormal pressures or weight to the structure. Buyer shall also have sole responsibility for determining whether its plans or specifications meet applicable local requirements.

f. Seller's Limited Warranty does not cover routine maintenance. Seller's Limited Warranty shall become void and terminate if tank is misused, neglected or damaged after delivery thereof to Buyer or if it is not properly operated and maintained. This includes, but is not limited to, proper operation, filling and emptying. Ventilation and pressure/vacuum relief devices must be maintained by Buyer to assure that design and operating pressures and vacuums are not exceeded. Grouting, if required, must be installed and properly maintained by Buyer. Tank and lining/coating must be maintained by Buyer as necessary to protect against wear and corrosion.

g. No person, firm or corporation is authorized to make any representation or to incur any obligation in the name of or on behalf of Seller.

h. This warranty does not cover damage caused by shipping, handling, or damage caused by operating or maintenance activities.

i. This warranty is rendered null and void by force majeure (i.e., Acts of God, wars, violence, vandalism, civil unrest and the like).

Limitation of Remedies. In the event of any failure of goods to perform as warranted, Seller will, at Seller's sole option, either replace or repair goods, or refund the purchase price of defective portion of goods supplied to Buyer. The liability of Seller is expressly limited to these remedial measures, and it is understood and agreed that the purchase price for goods is based upon Seller's Limited Warranty and the Limitation of Remedies set out herein. In no event shall Seller be responsible for any INCIDENTAL, PUNITIVE OR CONSEQUENTIAL damages, or damages from tort or negligence (including any negligence by Seller) arising out of or in connection with the use of goods, including without limitation the loss of contents or loss of profits, or for the condition or quality of material stored in the tank, or for any liability of Buyer or provide product or service to any customer of Buyer. This exclusive remedy shall not be deemed to have failed its essential purpose so long as the Seller is willing and able to repair or replace defective Products or issue a credit to the Buyer within a reasonable time after the Buyer shows to Seller that a defect is involved. Total Seller's liability shall be limited to the remaining prorated portion. Seller or its authorized representative will be the sole judge of whether or not any repairs are required under the terms of the warranty. Any action brought by Buyer arising out of or in connection with breach of Seller's Limited Warranty shall be commenced within 90 days after such a cause of action shall have occurred. Unless noted, this agreement does not contemplate any future performance by Seller after the tender of delivery of goods.

Any warranty claim shall be made to Tank Connection in writing. Once a claim has been made, Seller shall have the right to perform on-site inspection of goods. Such inspection including preparation of the tank for inspection or repair (such as removing product and washing down the tank) will be the sole responsibility and expense of the Buyer. In the alternative, if so instructed by Seller, Buyer shall ship goods, or any part thereof, claimed to be defective to Seller under its shipping instructions and by freight prepaid. If Seller is required to do work on Buyer's premises, Seller shall be granted permission to perform such work with its own service personnel under non-union conditions.

7. **Seller's Indemnity.** Buyer shall defend, release, indemnify and hold Seller, its Affiliates and Subcontractors harmless from and against any and all losses, liabilities, costs and expenses (including, without limitation, court costs and attorney's fees) arising out of any claim or cause of action by Buyer employees or invitees, their representatives, agents, heirs, beneficiaries and assigns for injury to or death of Buyer's employees or invitees or damage to Buyer's property to the extent caused by the sole or contributory negligence of Buyer.

8. **Consequential Damages.** Neither party shall be liable to the other for special, indirect, or consequential damages resulting from or arising out of this Agreement including, without limitation, damages claimed for loss of use of productive facilities or equipment, lost profits, lost production, or non-operation or increased expense of operation, whether claims or actions for such damages are based upon contract, tort, (including negligence), strict liability or otherwise.

9. **Limitation of Liability.** Seller's total liability arising at anytime from this Agreement shall not exceed the purchase price of the Agreement. These limitations apply whether the liability is based on contract, tort, strict liability or otherwise.

10. **Intellectual Property.** All devices, designs, (including drawings, plans and specifications), estimates, prices, notes, electronic data and other documents or information prepared or disclosed by Seller, and all related intellectual property rights shall remain Seller's property. Seller grants Buyer a non-exclusive, non-transferrable license to use any such material solely for Buyer's use of the Goods. Neither Seller nor Buyer shall disclose any such material to third parties without the Seller's prior written consent.

11. **Ownership of Developments.** All copyrights, patents, trade secrets, or other intellectual property rights associated with any ideas, concepts, techniques, inventions, processes, or works of authorship arising out of this Agreement shall belong exclusively to Seller.

12. **U.S. Export Compliance**. Seller's products are supplied for export from the United States in accordance with U.S. Export Administration regulations for ultimate destination to the Buyer who shall not be located in a restricted country as defined by the U.S. Export Administration and diversion contrary to U.S. law is prohibited. Buyer further agrees and warrants that all exports will conform to this regulation.

13. **Affiliates**. Buyer and Seller further agree that Seller's Affiliates may perform work for Buyer. In such event, the references to Seller in this Agreement shall mean Seller and such Affiliate of Seller. The Affiliate and Buyer shall be deemed to ratify, and agree to be bound by the terms and conditions of this Agreement with respect to its subject matter.

14. **Method of Shipment and Freight Charges.** Proposals specifically including freight or other transportation charges are based on rates in effect on the date of Buyer's order and on the routing of shipment arranged by Seller. Seller will ship goods in accordance with Buyer's routing whenever such routing will not result in an increase in freight or other transportation charges. In the event of such increases, the payment of any additional freight or other transportation charges is guaranteed by Buyer to Seller's satisfaction. The goods shall be packaged for shipment at the lowest acceptable rate by common or other carrier, or any other method deemed necessary or advisable by Seller. Marking shall be in accordance with ordinary commercial practice at place of shipment, unless otherwise designated by Buyer and accepted by Seller.

15. **Force Majeure.** Shipping and delivery dates are approximate and are based upon Sellers ability to obtain all necessary labor, materials and parts and, where applicable, the receipt of all necessary information, plans or specifications from Buyer. Seller shall not be liable for damages resulting from any delay or failure to deliver the goods, or otherwise perform under the Agreement, due to circumstances beyond its control and not occasioned by its fault or negligence, including but not being limited to, any act of government, inability to obtain materials, failure of vendors, strikes, labor disputes, civil commotion, acts of God, or other occurrences rendering Seller's performance commercially impracticable, regardless of whether such occurrences are foreseeable. In the event of a production shortage, Seller shall have the right to allocate its available goods among its customers in such a manner as Seller shall desire.

16. **Invoice & Hold.** Due to the custom nature of Seller's products and equipment, the Buyer accepts title on the later of when the units are completed or the promised ship date. Buyer will be invoiced immediately and accept responsibility for payment and any applicable storage fees.

    Storage Fees. One (1) weeks "grace period" from agreed upon promised ship date – no charge. A charge of $100/truck/week for bolted tanks will be assessed for weeks 2-7. A charge of $250/tank/week for welded tanks will be assessed for weeks 2-7.

    The maximum storage period is seven (7) weeks. Arrangements must be made for shipments so that the maximum storage period is not exceeded.

17. **Terms of Payment.** Subject to satisfactory credit approval, as set forth in paragraph 11, the following terms apply:

    <u>**DOMESTIC SALES**</u>

    Payment: 30% upon order placement by buyer
    30% due when order is released to shop for fabrication
    40% due upon receipt of invoice at shipment, of if shipment is delayed by buyer, after completion of order
    No retainage applicable
    Note: Freight Invoices are due upon receipt of invoice. A late charge of 1.5% per month will be charged on invoices not paid at maturity.

    All invoices are due upon receipt.

    <u>**INTERNATIONAL SALES**</u>

    Payment – 100% Irrevocable Letter of Credit confirmed by a major U.S. bank, payable at sight upon presentation of clean on-board Bill of Lading (ocean or air) and other shipping documents as required.

18. **Credit Approval.** This Agreement is subject to (a) execution by Buyer of such additional contract documents, security agreements, notes or other instruments as Seller shall deem necessary or desirable and (b) Seller's review and acceptance of the financial condition of Buyer. If the financial condition of Buyer at any time does not in the sole judgment of Seller, justify continuance of shipment under the terms of the Agreement, Seller reserves the right to ship under reservation, or to require full payment before shipment, delivery or erection. Additionally, Seller may at its discretion file such notices for financial protection under the lien or bond statutes of each state.

19. **Duty Drawback.** The manufacturer reserves all drawback rights for materials it produces and sells to Buyer. If Buyer exports the product which Seller manufactures, it is agreed that evidence of exportation shall be supplied to Seller to facilitate its claim of drawback upon request and without charge to Seller.

20. **Security Interest.** To secure payment for goods, Buyer grants to Seller a security interest in the goods and agrees that Seller shall have the rights and remedies of a secured party under the Uniform Commercial Code. Buyer designates Seller as its attorney-in-fact to execute any financing statements on behalf of Buyer necessary to perfect such security interest.

21. **Taxes.** Seller's prices do not include sales, excise or similar taxes levied by government authority, either foreign or domestic. Consequently, in addition to the prices specified herein, the amount of any present or future sales, use, excise or other similar tax applicable to this transaction, shall be paid by Buyer as part of the sale, or in lieu thereof, Buyer shall provide Seller with a tax exemption certificate acceptable to taxing authorities of the Shipped-To state. On any material picked up by Buyer at the plant, the tax jurisdiction of the FOB state is applicable.

22. **Additional Work and Inspection.** No extra labor, materials or parts will be furnished under this Agreement, unless it has been ordered by Buyer or Seller's sales order form, and the prices and terms of sales are approved by Seller. Seller may at its option subcontract labor, material and parts required by this Agreement without Buyer's consent. The goods shall be, at Seller's option, subject to inspection and testing during manufacture. Any inspection by Buyer shall be made prior to shipment at Seller's factory or point of shipment. Unless otherwise agreed to, Seller shall not be responsible for unpacking, storage, field assembly of goods, or construction of foundations. Furthermore, Seller shall not be responsible for the choice of use or linings, sealants, and gasket materials not sold hereunder; or the installation, attachment, or connection of piping, conveying and ventilating equipment, or other attachment of accessories or components not sold hereunder.

23. **Patent Infringement.** Seller, at it's own expense, shall defend the Buyer against any claims which may be instituted against the Buyer alleging infringement of United States Patents relating to the subject matter of the accompanying sales proposal, provided the Buyer gives Seller immediate notice in writing of any such alleged patent infringement claim and permits Seller, through its own counsel, to defend such claim. In such cases, Buyer shall furnish Seller with all needed information and assistance. The obligations of Seller hereunder shall not extend to any infringement claims arising as a result of the use of the equipment as part of any combination of other devices, machinery or parts.

24. **Cancellation.** Buyer's cancellation of any order is required to be in writing, and Buyer is subject to pay a cancellation fee equal to 25% of the total purchase price plus all non-recoverable costs and expenses.

25. **Law.** The rights and obligations of the parties shall be governed by the domestic laws of the State of Kansas without regard to its conflict of law rules or the United Nations Convention for the International Sale of Goods.

26. **Arbitration.** Any dispute, controversy or claim arising under this agreement shall be settled by arbitration in Wichita, Kansas, pursuant to the American Arbitration Association rules.

27. **Agreement Amendment.** This Agreement contains the entire agreement between Seller and Buyer, and no modification of this Agreement shall be binding upon Seller unless evidenced by an agreement amending this Agreement in writing signed by an executive officer of Seller after the Effective Date hereof. No oral or written statements by Seller's sales representatives, or other agents, made after the date hereof shall modify or vary the express terms hereof unless evidenced by an agreement in writing signed by an executive officer of Seller after the date hereof. To the extent any advertising or promotional material of Seller contradicts or disagrees with the terms hereof, Seller and Buyer agree that the terms hereof shall control and that such advertising and/or promotional materials are not part of the agreement between Seller and Buyer.

28. **Confidentiality.** At all times hereafter, termination of this Agreement notwithstanding, Buyer shall treat as confidential and shall not, without Seller's prior written consent, divulge to any third party or, except to the extent necessary for performance hereunder, make any use of any proprietary information process or thing, owned or supplied by Seller or representatives of Seller which is disclosed or made available to Buyer by or on behalf of Seller.

29. **Severability.** It is intended that if any provision of this Agreement is unenforceable for any reason, it shall be adjusted rather than voided, if possible, in order to achieve the intent of the parties. In any event, all other provisions of this Agreement shall be deemed valid, binding, and still enforceable.

DISPOSAL INFO

Waste Management

Vanorman, Eric

From: Golamb, Carolyn <cgolamb@wm.com>
Sent: Friday, January 09, 2015 11:54 AM
To: Vanorman, Eric
Subject: RE: Brine waste disposal - Pricing Request

As we discussed on the phone, Vickery does handle brine water and can take large amounts. However, it depends on the quality of the Brine. Sodium Chloride is not a problem, but Calcium Chloride can be hard for us to blend and filter. Therefore, I would need to see a sample to determine acceptability/pricing. However, I have provided ballpark pricing, contingent upon a sample for concentrated Brine Water out of Madison, WI.

DISPOSAL: $0.10 - $0.20 per gallon disposal.
3,000 gallon minimum disposal charged.
ENVIRONMENTAL FEE: 7.5% of Disposal Charge.

TAXES (if hazardous): $4.95 per Ton.

TRANSPORTATION: $2,190.00 per Trip (bulk only-no drums/totes).
$110.00/load extra if requesting a Vacuum Tanker.
$175.00/trip extra for Sunday & Holiday pickups.

DEMURRAGE: $110.00 per hour after the first free hour loading. No unloading demurrage.

RINSE CYCLE: $105.00 for first rinse cycle, $95.00 per rinse cycle thereafter per load.
If using Vickery Env. provided transportation, the first rinse cycle will be waived.

FUEL SURCHARGE: The following scale will be used to calculate the Fuel Surcharge:

Fuel Cost/Gallon	Surcharge as % of Transp. Invoice
$3.34 - $3.419	28%
$3.42 - $3.499	29%
$3.50 - $3.579	30%
$3.58 - $3.659	31%
$3.66 - $3.739	32%
$3.74 - $3.819	33%
$3.82 - $3.899	34%
$3.90 - $3.979	35%
$3.98 - $4.059	36%
$4.06 - $4.139	37%
$4.14 - $4.219	38%
$4.22 - $4.299	39%
$4.30 - $4.379	40% . . .

The Fuel Price Index (Midwest PADD2) for the current week (Sun-Sat) is based on the Index published on that Monday.

SOLIDS SURCHARGE: For each load received, on a per gallon basis, all total suspended solids over 0.1% will be assessed a surcharge at the rate of $0.07 for every one percent.

Thank you for giving Vickery Environmental the opportunity to bid on this waste stream. This quotation is good for 60 days. Quotation is contingent upon a Waste Profile Sheet and/or a sales sample for analysis. The following restrictions apply: Reactive Cyanides <250 ppm, Reactive Sulfides <500 ppm, Flashpoint >212 ºF., oil content <5%, PCB's <25 ppm (non-TSCA), VOC's <5%, No Benzene Neshap waste. Material must be water miscible, liquid pumpable and compatible with our process. To obtain approval, please complete a Waste Profile Sheet and send with analytical to the address/fax listed below. If you have any questions, please call me at 419/547-7791 ext 3309.

Sincerely,

Carolyn Golamb
Facility Service Manager/Deepwell Account Manager
cgolamb@wm.com

Vickery Environmental, Inc.
A Waste Management Company
3956 State Route 412
Vickery, OH 43464
Phone: 419/547-7791 Ext 3309
Cell: 419/307-7261
Fax: 419/547-6144
Visit our Website: www.wmsolutions.com

Think Green. ® Think Waste Management.

From: Vanorman, Eric [mailto:Eric.Vanorman@aecom.com]
Sent: Wednesday, January 07, 2015 4:32 PM
To: Golamb, Carolyn
Subject: Brine waste disposal - Pricing Request

Hi Carolyn:

Below is my contact information. Attached is the feed water data (prior to concentration) to our process. The effluent column shown would likely be concentrated at least 100X more for disposal. Please let me know if you have any questions.

Thanks,

Eric Van Orman, P.E.
Project Manager, Water
D 1.616.940.4446 M 1.616.558.4490
eric.vanorman@aecom.com

AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, Michigan 49512
T 1.616.942.9600 F 1.616.940.4396 Cisco 2084446
www.aecom.com

Recycling is a good thing. Please recycle any printed emails.

INDUSTRIAL WASTE & DISPOSAL SERVICES AGREEMENT

Exhibit A

CUSTOMER INFORMATION
AECOM
5555 Glenwood Hills Pkwy, SE, Suite 300
Grand Rapids, MI 49512
Contact Name: Eric Van Orman
Contact Phone: 616-942-9600

GENERATOR INFORMATION (If different from Customer Information)
Madison Company
Madison, WI

PROFILE NUMBER:	
DISPOSAL FACILITY:	**Madison Prairie Landfill**
PROFILE EXPIRATION DATE:	
PO NUMBER:	

Service Information	Material / Ticket Description	Anticipated Volume	Rate / UOM / Minimum
Transportation	Delivery of roll off container		$75/box
Transportation	Hauling of 20yd or 30yd roll off container		$185/box
Direct Landfill	Brine Waste	+/- 9-26 tons daily	$25/ton + State Gen Tax
Tax	WI Generator Tax		$13/ton applies to direct landfill
Fuel	Landfill Fuel Surcharge		*See Note Below
Environmental	Environmental Surcharge		10% - applies to trans

Acceptance of soil is contingent upon landfill approval

Fees below are on an as needed basis only:

Digout (frozen load): $60.00/load	Washout Fee: $100.00/load	Certificate of Burial / Destruction: $55.00/each event

Containers provided by WM:	**Quantity:**	**Size:**	**Quantity:**	**Size:**

Additional Information/Special Handling:

- **Acceptance of waste is contingent upon the completion, submittal and approval of special waste profile sheet, required analytical, Industrial Waste & Disposal Services Agreement (ISA), and Exhibit A. All loads must be manifested. Confirmation will be sent to customer upon approval to ship into designated facility.**
- **Prices quoted herein are valid for 60 days from Tuesday, January 27, 2015 unless Waste Management is hired for this project prior to the expiration of this 60 day period in which case pricing remains valid in accordance with the terms of the Service Agreement**
- **The fuel surcharge percentage can fluctuate on a weekly basis; www.wm.com provides the current Fuel Surcharge and DOE average. The actual percentage rate applied to the total project invoice will be determined the week that the invoice is generated.**
- **If Waste Management (or a Waste Management contracted hauler) is NOT providing the transportation services, you must ensure that the transporter is licensed and approved to haul the Special Waste or Hazardous Waste.**
- **Please see profile approval form for special handling instructions.**

THE WORK CONTEMPLATED BY THIS EXHIBIT A IS TO BE DONE IN ACCORDANCE WITH THE TERMS AND CONDITIONS OF THE INDUSTRIAL SERVICES AGREEMENT OR OTHER CONTRACTUAL AGREEMENT BETWEEN THE PARTIES DATED: ____________

COMPANY Waste Management of Wisconsin, Inc.
By: ____________ ____________
Name: Joel Meyer Date
Title Industrial Account Manager

CUSTOMER AECOM
Signature: ____________ ____________
Name: Eric Van Orman Date
Title: ____________

WASTE MANAGEMENT

INDUSTRIAL WASTE SERVICES & DISPOSAL AGREEMENT

COMPANY: Waste Management of Wisconsin, Inc.
A WASTE MANAGEMENT COMPANY

Name: Joel Meyer
Date:
Title: Industrial Account Manager

Effective Date of Agreement:

CUSTOMER:

Name:
Date:
Title:

Initial Term: 36 months

This Industrial Waste & Disposal Services Agreement, consisting of the terms and conditions set forth herein, and Exhibit A, and/or Confirmation Letter(s) and the Profile Sheet(s) entered into from and after the date hereof from time to time (all of the foregoing being collectively referred to as the “Agreement”), is made as of the Effective Date shown above by and between the Customer named above, on its and its subsidiaries and affiliates behalf (collectively, “Customer”) and the Waste Management entity named above (“the Company”).

TERMS AND CONDITIONS

1. SERVICES PROVIDED. The Company will provide Customer with collection, management, transportation, disposal, treatment, and recycling services (“Services”) for Customer’s non-hazardous solid waste, special waste, and/or hazardous waste (collectively "Industrial Waste") as described on Exhibit A and/or Confirmation Letter(s) and/or applicable Profile Sheets. **Solid Waste** means garbage, refuse and rubbish including those which are recyclable but excluding Special Waste and Hazardous Waste. **Special Waste** includes polychlorinated biphenyl ("PCB") wastes, industrial process wastes, asbestos containing material, petroleum contaminated soils, treated/decharacterized wastes, incinerator ash, medical wastes, demolition debris and other materials requiring special handling in accordance with applicable federal, state, provincial or local laws or regulations. **Hazardous Waste** means any toxic or radioactive substances, as such terms are defined by applicable federal, state, provincial or local laws or regulations. All Industrial Waste that is generated, handled and/or collected by Customer shall be managed exclusively by Company during the term of this Agreement. When Company handles special or hazardous waste for Customer, Customer will provide Company with a Generator's Waste Profile Sheet ("Profile Sheet") describing all special or hazardous waste, and provide a representative sample of such waste on request. In the event this Agreement includes transportation by Company, Customer shall, at the time of tender, provide to Company accurate and complete documents, shipping papers or manifests as are required for the lawful transfer of the special or hazardous waste under all applicable federal, state or local laws or regulations. Tender of delivery shall be considered nonconforming if not in accordance with this Paragraph.

2. CUSTOMER WARRANTIES. Customer hereby represents and warrants that all waste material delivered by Customer to Company shall be in accordance with waste descriptions given in this Agreement and shall not be or contain any Nonconforming Waste. “Nonconforming Waste” means: (a) non-hazardous Solid Waste that contains regulated Special Waste or Hazardous Waste; (b) waste that is not in conformance with the description of the waste in Exhibit A, the Confirmation Letter(s) or the Profile Sheet incorporated herein; (c) waste that is or contains any infectious waste, radioactive, volatile, corrosive, flammable, explosive, biomedical, biohazardous material, regulated medical or hazardous waste or toxic substances, as defined pursuant to or listed or regulated under applicable federal, state or local law, except as stated on the Profile Sheet or Confirmation Letter; or (d) waste that is prohibited from being received, managed or disposed of at the designated disposal facility by federal, state or local law, regulation, rule, code, ordinance, order, permit or permit condition. Customer (including its subcontractors) represents and warrants that it will comply with all applicable laws, ordinances, regulations, orders, permits or other legal requirements applicable to the Industrial Waste.

3. TERM OF AGREEMENT; RIGHT OF FIRST REFUSAL. The Initial Term of this Agreement shall be 36 months, commencing on the Effective Date set forth above. This Agreement shall automatically renew thereafter for additional terms of twelve (12) months each (“Renewal Term”) unless either party gives to the other party written notice of termination at least ninety (90) days prior to the termination of the then-existing term; provided however, that the terms and conditions of this Agreement shall remain in full force and effect, in accordance with its terms, with respect to any uncompleted or unfinished Service provided for in an Exhibit A, Confirmation Letter and/or Profile Sheet until such Service is completed. Customer grants to Company a right of first refusal to match any offer which Customer receives or intends to make after the completion of any Term of this Agreement relating to any services provided hereunder and further agrees to give Company prompt written notice of any such offer and a reasonable opportunity to respond to it.

4. INSPECTION; REJECTION OF WASTE. Title to and liability for Nonconforming Waste shall remain with Customer at all times. Company shall have the right to inspect, analyze or test any waste delivered by Customer. If Customer’s Industrial Waste is Nonconforming Waste, Company can, at its option, reject Nonconforming Waste and return it to Customer or require Customer to remove and dispose of the Nonconforming Waste at Customer’s expense. Customer shall indemnify, hold harmless (in accordance with Section 9) and pay or reimburse Company for any and all costs, damages and/or fines incurred as a result of or relating to Customer's tender or delivery of Nonconforming Waste or other failure to comply or conform to this Agreement, including costs of inspection, testing and analysis.

5. SPECIAL HANDLING; TITLE. If Company elects to handle, rather than reject, Nonconforming Waste, Company shall have the right to manage the same in the manner deemed most appropriate by Company given the characteristics of the Nonconforming Waste. Company may assess and Customer shall pay additional fees associated with delivery of Nonconforming Waste, including, but not limited to, special handling or disposal charges, and costs associated with different quantities of waste, different delivery dates, modifications in operations, specialized equipment, and other operational, environmental, health, safety or regulatory requirements. Title to and ownership of acceptable Industrial Waste shall transfer to Company upon its final acceptance of such waste.

6. COMPANY WARRANTIES. Company hereby represents and warrants that: (a) Company will manage the Industrial Waste in a safe and workmanlike manner in full compliance with all valid and applicable federal, state and local laws, ordinances, orders, rules and regulations; and (b) it will use disposal facilities that have been issued permits, licenses, certificates or approvals required by valid and applicable laws, ordinances and regulations necessary to allow the facility to accept, treat and/or dispose of Industrial Waste. Except as provided herein, Company makes no other warranties and hereby disclaims any other warranty, whether implied or statutory.

7. LIMITED LICENSE TO ENTER. When a Customer is transporting Industrial Waste to a Company facility, Customer and its subcontractors shall have a limited license to enter a disposal facility for the sole purpose of offloading Industrial Waste at an area designated, and in the manner directed, by Company. Customer shall, and shall ensure that its subcontractors, comply with all rules and regulations of the facility, as amended. Company may reject Industrial Waste, deny Customer or its subcontractors entry to its facility and/or terminate this Agreement in the event of Customer's or its subcontractors' failure to follow such rules and regulations.

8. CHARGES AND PAYMENTS. Customer shall pay the rates set forth on Exhibit A or a Confirmation Letter, which may be modified as provided in this Agreement. The rates may be adjusted by Company to account for: any increase in or to recoup all or any portion of, disposal, transportation, fuel or environmental compliance fees or costs; any change in the composition of the Industrial Waste; increased costs due to uncontrollable circumstances, including, without limitation, changes in local, state or federal laws or regulations, imposition of taxes, fees or surcharges and acts of God such as floods, fires, etc. Company may also increase the charges to reflect increases in the Consumer Price Index for the municipal or regional area in which the Services are rendered. Increases in charges for reasons other than as provided above require the consent of Customer which may be evidenced verbally, in writing or by the actions and practices of the parties. All rate adjustments as provided above and in Paragraph 5 shall take effect upon notification from Company to Customer. Customer shall pay the rates in full within 30 days of receipt of each invoice from Company. Customer shall pay a late fee on all past due amounts accruing from the date of the invoice at a rate of eighteen percent (18%) per annum or, if less, the maximum rate allowed by law.

9. INDEMNIFICATION. The Company agrees to indemnify, defend and save Customer harmless from and against any and all liability (including reasonable attorneys fees) which Customer may be responsible for or pay out as a result of bodily injuries (including death), property damage, or any violation or alleged violation of law, to the extent caused by Company's breach of this Agreement or by any negligent act, negligent omission or willful misconduct of the Company or its employees, which occurs (1) during the collection or transportation of Customer's Industrial Waste by Company, or (2) as a result of the disposal of Customer's Industrial Waste, after the date of this Agreement, in a facility owned by a subsidiary or affiliate of Waste Management, Inc., provided that the Company's indemnification obligations will not apply to occurrences involving Nonconforming Waste.

Customer agrees to indemnify, defend and save the Company harmless from and against any and all liability (including reasonable attorneys fees) which the Company may be responsible for or pay out as a result of bodily injuries (including death), property damage, or any violation or alleged violation of law to the extent caused by Customer's breach of this Agreement or by any negligent act, negligent omission or willful misconduct of the Customer or its employees, agents or contractors in the performance of this Agreement or Customer's use, operation or possession of any equipment furnished by the Company.

Neither party shall be liable to the other for consequential, incidental or punitive damages arising out of the performance of this Agreement.

10. UNCONTROLLABLE CIRCUMSTANCES. Except for the obligation to make payments hereunder, neither party shall be in default for its failure to perform or delay in performance caused by events beyond its reasonable control, including, but not limited to, strikes, riots, imposition of laws or governmental orders, fires, acts of God, and inability to obtain equipment, permit changes and regulations, restrictions (including land use) therein, and the affected party shall be excused from performance during the occurrence of such events.

11. ASSIGNMENT. This Agreement shall be binding on and shall inure to the benefit of the parties and their respective successors and assigns.

12. ENTIRE AGREEMENT. This Agreement represents the entire understanding and agreement between the parties relating to the management of waste and supersedes any and all prior agreements, whether written or oral, between the parties regarding the same; provided that, the terms of any national service agreement between the parties shall govern over any inconsistent terms herein.

13. TERMINATION; LIQUIDATED DAMAGES. Company may immediately terminate this Agreement, (a) in the event of Customer's breach of any term or provision of this Agreement, including failure to pay on a timely basis or (b) if Customer becomes insolvent, the subject of an order for relief in bankruptcy, receivership, reorganization dissolution, or similar law, or makes an assignment for the benefit of its creditors or if Company deems itself insecure as to payment ("Default"). Notice of termination shall be in writing and deemed given when delivered in person or by certified mail, postage prepaid, return receipt requested. In the event Customer terminates this Agreement prior to the expiration of any Initial or Renewal Term for any reason other than as provided herein, or in the event Company terminates this Agreement for Customer's Default, liquidated damages in addition to the Company's legal fees shall be paid and calculated as follows: 1) if the remaining Initial Term under this Agreement is six or more months, Customer shall pay its most recent monthly charges multiplied by six; 2) if the remaining Initial Term under this Agreement is less than six months, Customer shall pay its most recent monthly charges multiplied by the number of months remaining in the Term; 3) if the remaining Renewal Term under this Agreement is three or more months, Customer shall pay its most recent monthly charges multiplied by three; or 4) if the remaining Renewal Term under this Agreement is less than three months, Customer shall pay its most recent monthly charges multiplied by the number of months remaining in the Renewal Term. Customer acknowledges that the actual damage to Company in the event of termination is difficult to fix or prove, and the foregoing liquidated damages amount is reasonable and commensurate with the anticipated loss to Company resulting from such termination and is an agreed upon fee and is not imposed as a penalty. Collection of liquidated damages by Company shall be in addition to any rights or remedies available to Company under this Agreement or at common law.

14. MISCELLANEOUS. (a) The prevailing party will be entitled to recover reasonable fees and court costs, including attorneys' fees, in interpreting or enforcing this Agreement. In the event Customer fails to pay Company all amounts due hereunder, Company will be entitled to collect all reasonable collection costs or expenses, including reasonable attorneys fees, court costs or handling fees for returned checks from Customer; (b) The validity, interpretation and performance of this Agreement shall be construed in accordance with the law of the state in which the Services are performed; (c) If any provision of this Agreement is declared invalid or unenforceable, then such provision shall be deemed severable from and shall not affect the remainder of this Agreement, which shall remain in full force and effect; (d) Customer's payment obligation for Services and the Warranties and Indemnification made by each party shall survive termination of this Agreement.

Agreed & Accepted

COMPANY

Signed: ______________________________

Authorized Signatory

CUSTOMER

Signed: ______________________________

Authorized Signatory

WASTE MANAGEMENT

EZ Profile™

Requested Facility: ______________________ ☐ Unsure Profile Number: ____________

☐ Check if there are multiple generator locations. Attach locations. ☐ COD ☐ Renewal? Original Profile Number: ____________

A. GENERATOR INFORMATION (MATERIAL ORIGIN)

1. Generator Name: ______________________
2. Site Address: ______________________
   (City, State, ZIP) ______________________
3. County: ______________________
4. Contact Name: ______________________
5. Email: ______________________
6. Phone: ____________ 7. Fax: ____________
8. Generator EPA ID: ______________________ ☐ N/A
9. State ID: ______________________ ☐ N/A

B. BILLING INFORMATION ☐ SAME AS GENERATOR

1. Billing Name: ______________________
2. Billing Address: ______________________
   (City, State, ZIP) ______________________
3. Contact Name: ______________________
4. Email: ______________________
5. Phone: ____________ 6. Fax: ____________
7. WM Hauled? ☐ Yes ☐ No
8. P.O. Number: ______________________

C. MATERIAL INFORMATION

1. Common Name: ______________________
   Describe Process Generating Material: ☐ See Attached

2. Material Composition and Contaminants: ☐ See Attached

1.	
2.	
3.	
4.	
	≥100%

3. State Waste Codes: ______________________ ☐ N/A
4. Color: ______________________
5. Physical State at 70˚F: ☐ Solid ☐ Liquid ☐ Other: ____________
6. Free Liquid Range Percentage: ________ to ________ ☐ N/A (Solid)
7. pH: ____________ to ____________ ☐ N/A (Solid)
8. Strong Odor: ☐ Yes ☐ No Describe: ____________
9. Flash Point: ☐ <140˚F ☐ 140˚–199˚F ☐ ≥200˚ ☐ N/A (Solid)

D. REGULATORY INFORMATION

1. EPA Hazardous Waste? ☐ Yes* ☐ No
   Code: ______________________
2. State Hazardous Waste? ☐ Yes ☐ No
   Code: ______________________
3. Is this material non-hazardous due to Treatment, Delisting, or an Exclusion? ☐ Yes* ☐ No
4. Contains Underlying Hazardous Constituents? ☐ Yes* ☐ No
5. Contains benzene **and** subject to Benzene NESHAP? ☐ Yes* ☐ No
6. Facility remediation subject to 40 CFR 63 GGGGG? ☐ Yes* ☐ No
7. CERCLA or State-mandated clean-up? ☐ Yes* ☐ No
8. NRC or State-regulated radioactive or NORM waste? ☐ Yes* ☐ No

***If Yes, see Addendum (page 2) for additional questions and space.**

9. Contains PCBs? → If Yes, answer a, b and c. ☐ Yes ☐ No
   a. Regulated by 40 CFR 761? ☐ Yes ☐ No
   b. Remediation under 40 CFR 761.61 (a)? ☐ Yes ☐ No
   c. Were PCB imported into the US? ☐ Yes ☐ No
10. Regulated and/or Untreated Medical/Infectious Waste? ☐ Yes ☐ No
11. Contains Asbestos? ☐ Yes ☐ No
    → If Yes: ☐ Non-Friable ☐ Non-Friable – Regulated ☐ Friable

E. ANALYTICAL AND OTHER REPRESENTATIVE INFORMATION

1. Analytical attached ☐ Yes
   Please identify applicable samples and/or lab reports:
2. Other information attached (such as MSDS)? ☐ Yes

F. SHIPPING AND DOT INFORMATION

1. ☐ One-Time Event ☐ Repeat Event/Ongoing Business
2. Estimated Quantity/Unit of Measure: ______________________
   ☐ Tons ☐ Yards ☐ Drums ☐ Gallons ☐ Other: ____________
3. Container Type and Size: ______________________
4. USDOT Proper Shipping Name: ☐ N/A
   ____

G. GENERATOR CERTIFICATION (PLEASE READ AND CERTIFY BY SIGNATURE)

By signing this EZ Profile™ form, I hereby certify that all information submitted in this and all attached documents contain true and accurate descriptions of this material, and that all relevant information necessary for proper material characterization and to identify known and suspected hazards has been provided. Any analytical data attached was derived from a sample that is representative as defined in 40 CFR 261 - Appendix 1 or by using an equivalent method. All changes occurring in the character of the material (i.e., changes in the process or new analytical) will be identified by the Generator and be disclosed to Waste Management prior to providing the material to Waste Management.

If I am an agent signing on behalf of the Generator, I have confirmed with the Generator that information contained in this Profile is accurate and complete.

Name (Print): ______________________ Date: ____________

Title: ______________________

Company: Waste Management of Wisconsin, Inc.

Certification Signature

THINK GREEN.

QUESTIONS? CALL 800 963 4776 FOR ASSISTANCE

Last Revised April 26, 2013

WASTE MANAGEMENT

EZ Profile™ Addendum

Only complete this Addendum if prompted by responses on EZ Profile™ (page 1) or to provide additional information. Sections and question numbers correspond to EZ Profile™.

Profile Number: ________________

C. MATERIAL INFORMATION

Describe Process Generating Material (Continued from page 1): If more space is needed, please attach additional pages.

Material Composition and Contaminants (Continued from page 1): If more space is needed, please attach additional pages.

5.	
6.	
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10.	
	≥100%

D. REGULATORY INFORMATION

Only questions with a "Yes" response in Section D on the EZ Profile™ form (page 1) need to be answered here.

1. EPA Hazardous Waste
   a. Please list all USEPA listed and characteristic waste code numbers:
   b. Is the material subject to the Alternative Debris standards (40 CFR 268.45)? ☐ Yes ☐ No
   c. Is the material subject to the Alternative Soil standards (40 CFR 268.49)? → If Yes, complete question 4. ☐ Yes ☐ No
   d. Is the material exempt from Subpart CC Controls (40 CFR 264.1083 and 265.1084)? ☐ Yes ☐ No
      → If Yes, please select one of the following:
      ☐ Waste has been determined to be LDR exempt [265.1083(c)(4) and 265.1084(c)(4)] based on the fact that it meets all applicable organic treatment standards (including UHCs for D-coded characteristic wastes) or a Specified Technology has been utilized.
      ☐ Waste does not qualify for a LDR exemption, but the average VOC at the point of origination is <500 ppmw and this determination was based on analytical testing (upload copy of analysis) or generator knowledge.
2. State Hazardous Waste → Please list all state waste codes: ________________________________
3. For material that is Treated, Delisted, or Excluded → Please indicate the category, below:
   ☐ Delisted Hazardous Waste ☐ Excluded Waste under 40 CFR 261.4 → Specify Exclusion: ________________
   ☐ Treated Hazardous Waste Debris ☐ Treated Characteristic Hazardous Waste → If checked, complete question 4.
4. Underlying Hazardous Constituents → Please list all Underlying Hazardous Constituents:
5. Benzene NESHAP → Please include percent water/moisture in chemical composition.
   a. Are you a TSDF? → If yes, please complete Benzene NESHAP questionnaire. If not, continue.
   b. What is your facility's current total annual benzene quantity in Megagrams? ☐ <1 Mg ☐ 1–9.99 Mg ☐ ≥10 Mg
      1. Flow weighted average benzene concentration is ___________ ppmw.
   c. Is this waste soil from remediation at a closed facility? ☐ Yes ☐ No
      1. Benzene concentration in remediation waste is ___________ ppmw.
   d. Has material been treated to remove 99% of the benzene or to achieve <10 ppmw? ☐ Yes ☐ No
   e. Is material exempt from controls in accordance with 40 CFR 61.342? ☐ Yes ☐ No
      → If yes, specify exemption: ________________________________
   f. Based on your knowledge of your waste and the BWON regulations, do you believe that this waste stream is subject to treatment and control requirements at an off-site TSDF? ☐ Yes ☐ No
6. 40 CFR 63 GGGGG → Does the material contain <500 ppmw VOHAPs at the point of determination? ☐ Yes ☐ No
7. CERCLA or State-Mandated clean up → Please submit the Record of Decision or other documentation to assist others in the evaluation for proper disposal.
8. NRC or state regulated radioactive or NORM Waste → Please identify Isotopes and pCi/g: ________________________________

THINK GREEN.®

QUESTIONS? CALL 800 963 4776 FOR ASSISTANCE

Last Revised April 26, 2013

WASTE MANAGEMENT

Additional Profile Information

Profile Number: _______________

C. MATERIAL INFORMATION

Material Composition and Contaminants (Continued from page 2): If more space is needed, please attach additional pages.

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40.	
	≥100%

D. REGULATORY INFORMATION

1. EPA Hazardous Waste
   a. Please list all USEPA listed and characteristic waste code numbers (Continued from page 2):

Disposal Fuel Surcharge Table

Rate effective as of June 1, 2013

DOE avg. at Least ($/gallon)	WM Surcharge %
$ 0.95	
$ 0.96	0.03
$ 0.97	0.06
$ 0.98	0.09
$ 0.99	0.12
$ 1.00	0.15
$ 1.01	0.18
$ 1.02	0.21
$ 1.03	0.24
$ 1.04	0.27
$ 1.05	0.30
$ 1.06	0.33
$ 1.07	0.36
$ 1.08	0.39
$ 1.09	0.42
$ 1.10	0.45
$ 1.11	0.48
$ 1.12	0.51
$ 1.13	0.54
$ 1.14	0.57
$ 1.15	0.60
$ 1.16	0.63
$ 1.17	0.66
$ 1.18	0.69
$ 1.19	0.72
$ 1.20	0.75
$ 1.21	0.78
$ 1.22	0.81
$ 1.23	0.84
$ 1.24	0.87
$ 1.25	0.90
$ 1.26	0.93
$ 1.27	0.96
$ 1.28	0.99
$ 1.29	1.02
$ 1.30	1.05
$ 1.31	1.08
$ 1.32	1.11
$ 1.33	1.14
$ 1.34	1.17
$ 1.35	1.20
$ 1.36	1.23
$ 1.37	1.26
$ 1.38	1.29
$ 1.39	1.32
$ 1.40	1.35
$ 1.41	1.38
$ 1.42	1.41
$ 1.43	1.44
$ 1.44	1.47
$ 1.45	1.50
$ 1.46	1.53
$ 1.47	1.56
$ 1.48	1.59
$ 1.49	1.62
$ 1.50	1.65
$ 1.51	1.68
$ 1.52	1.71
$ 1.53	1.74
$ 1.54	1.77
$ 1.55	1.80
$ 1.56	1.83
$ 1.57	1.86
$ 1.58	1.89
$ 1.59	1.92
$ 1.60	1.95
$ 1.61	1.98
$ 1.62	2.01
$ 1.63	2.04
$ 1.64	2.07
$ 1.65	2.10
$ 1.66	2.13
$ 1.67	2.16
$ 1.68	2.19
$ 1.69	2.22
$ 1.70	2.25
$ 1.71	2.28
$ 1.72	2.31
$ 1.73	2.34
$ 1.74	2.37
$ 1.75	2.40
$ 1.76	2.43
$ 1.77	2.46
$ 1.78	2.49
$ 1.79	2.52
$ 1.80	2.55
$ 1.81	2.58
$ 1.82	2.61
$ 1.83	2.64
$ 1.84	2.67
$ 1.85	2.70
$ 1.86	2.73
$ 1.87	2.76
$ 1.88	2.79
$ 1.89	2.82
$ 1.90	2.85
$ 1.91	2.88
$ 1.92	2.91
$ 1.93	2.94
$ 1.94	2.97
$ 1.95	3.00
$ 1.96	3.03
$ 1.97	3.06
$ 1.98	3.09
$ 1.99	3.12
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$ 2.83	5.64
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$ 2.85	5.70
$ 2.86	5.73
$ 2.87	5.76
$ 2.88	5.79
$ 2.89	5.82
$ 2.90	5.85
$ 2.91	5.88
$ 2.92	5.91
$ 2.93	5.94
$ 2.94	5.97
$ 2.95	6.00
$ 2.96	6.03
$ 2.97	6.06
$ 2.98	6.09
$ 2.99	6.12
$ 3.00	6.15
$ 3.01	6.18
$ 3.02	6.21
$ 3.03	6.24
$ 3.04	6.27
$ 3.05	6.30
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$ 3.27	6.96
$ 3.28	6.99
$ 3.29	7.02
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$ 3.56	7.83
$ 3.57	7.86
$ 3.58	7.89
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$ 3.60	7.95
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$ 3.62	8.01
$ 3.63	8.04
$ 3.64	8.07
$ 3.65	8.10
$ 3.66	8.13
$ 3.67	8.16
$ 3.68	8.19
$ 3.69	8.22
$ 3.70	8.25
$ 3.71	8.28
$ 3.72	8.31
$ 3.73	8.34
$ 3.74	8.37
$ 3.75	8.40
$ 3.76	8.43
$ 3.77	8.46
$ 3.78	8.49
$ 3.79	8.52
$ 3.80	8.55
$ 3.81	8.58
$ 3.82	8.61
$ 3.83	8.64
$ 3.84	8.67
$ 3.85	8.70
$ 3.86	8.73
$ 3.87	8.76
$ 3.88	8.79
$ 3.89	8.82
$ 3.90	8.85
$ 3.91	8.88
$ 3.92	8.91
$ 3.93	8.94
$ 3.94	8.97
$ 3.95	9.00
$ 3.96	9.03
$ 3.97	9.06
$ 3.98	9.09
$ 3.99	9.12
$ 4.00	9.15

Disposal Fuel Surcharge Table

Rate effective as of June 1, 2013

DOE avg. at Least ($/gallon)	WM Surcharge %
$ 4.01	9.18
$ 4.02	9.21
$ 4.03	9.24
$ 4.04	9.27
$ 4.05	9.30
$ 4.06	9.33
$ 4.07	9.36
$ 4.08	9.39
$ 4.09	9.42
$ 4.10	9.45
$ 4.11	9.48
$ 4.12	9.51
$ 4.13	9.54
$ 4.14	9.57
$ 4.15	9.60
$ 4.16	9.63
$ 4.17	9.66
$ 4.18	9.69
$ 4.19	9.72
$ 4.20	9.75
$ 4.21	9.78
$ 4.22	9.81
$ 4.23	9.84
$ 4.24	9.87
$ 4.25	9.90
$ 4.26	9.93
$ 4.27	9.96
$ 4.28	9.99
$ 4.29	10.02
$ 4.30	10.05
$ 4.31	10.08
$ 4.32	10.11
$ 4.33	10.14
$ 4.34	10.17
$ 4.35	10.20
$ 4.36	10.23
$ 4.37	10.26
$ 4.38	10.29
$ 4.39	10.32
$ 4.40	10.35
$ 4.41	10.38
$ 4.42	10.41
$ 4.43	10.44
$ 4.44	10.47
$ 4.45	10.50
$ 4.46	10.53
$ 4.47	10.56
$ 4.48	10.59
$ 4.49	10.62
$ 4.50	10.65
$ 4.51	10.68
$ 4.52	10.71
$ 4.53	10.74
$ 4.54	10.77
$ 4.55	10.80
$ 4.56	10.83
$ 4.57	10.86
$ 4.58	10.89
$ 4.59	10.92
$ 4.60	10.95
$ 4.61	10.98
$ 4.62	11.01
$ 4.63	11.04
$ 4.64	11.07
$ 4.65	11.10
$ 4.66	11.13
$ 4.67	11.16
$ 4.68	11.19
$ 4.69	11.22
$ 4.70	11.25
$ 4.71	11.28
$ 4.72	11.31
$ 4.73	11.34
$ 4.74	11.37
$ 4.75	11.40
$ 4.76	11.43
$ 4.77	11.46
$ 4.78	11.49
$ 4.79	11.52
$ 4.80	11.55
$ 4.81	11.58
$ 4.82	11.61
$ 4.83	11.64
$ 4.84	11.67
$ 4.85	11.70
$ 4.86	11.73
$ 4.87	11.76
$ 4.88	11.79
$ 4.89	11.82
$ 4.90	11.85
$ 4.91	11.88
$ 4.92	11.91
$ 4.93	11.94
$ 4.94	11.97
$ 4.95	12.00
$ 4.96	12.03
$ 4.97	12.06
$ 4.98	12.09
$ 4.99	12.12
$ 5.00	12.15
$ 5.01	12.18
$ 5.02	12.21
$ 5.03	12.24
$ 5.04	12.27
$ 5.05	12.30
$ 5.06	12.33
$ 5.07	12.36
$ 5.08	12.39
$ 5.09	12.42
$ 5.10	12.45
$ 5.11	12.48
$ 5.12	12.51
$ 5.13	12.54
$ 5.14	12.57
$ 5.15	12.60
$ 5.16	12.63
$ 5.17	12.66
$ 5.18	12.69
$ 5.19	12.72
$ 5.20	12.75
$ 5.21	12.78
$ 5.22	12.81
$ 5.23	12.84
$ 5.24	12.87
$ 5.25	12.90
$ 5.26	12.93
$ 5.27	12.96
$ 5.28	12.99
$ 5.29	13.02
$ 5.30	13.05
$ 5.31	13.08
$ 5.32	13.11
$ 5.33	13.14
$ 5.34	13.17
$ 5.35	13.20
$ 5.36	13.23
$ 5.37	13.26
$ 5.38	13.29
$ 5.39	13.32
$ 5.40	13.35
$ 5.41	13.38
$ 5.42	13.41
$ 5.43	13.44
$ 5.44	13.47
$ 5.45	13.50
$ 5.46	13.53
$ 5.47	13.56
$ 5.48	13.59
$ 5.49	13.62
$ 5.50	13.65
$ 5.51	13.68
$ 5.52	13.71
$ 5.53	13.74
$ 5.54	13.77
$ 5.55	13.80
$ 5.56	13.83
$ 5.57	13.86
$ 5.58	13.89
$ 5.59	13.92
$ 5.60	13.95
$ 5.61	13.98
$ 5.62	14.01
$ 5.63	14.04
$ 5.64	14.07
$ 5.65	14.10
$ 5.66	14.13
$ 5.67	14.16
$ 5.68	14.19
$ 5.69	14.22
$ 5.70	14.25
$ 5.71	14.28
$ 5.72	14.31
$ 5.73	14.34
$ 5.74	14.37
$ 5.75	14.40
$ 5.76	14.43
$ 5.77	14.46
$ 5.78	14.49
$ 5.79	14.52
$ 5.80	14.55
$ 5.81	14.58
$ 5.82	14.61
$ 5.83	14.64
$ 5.84	14.67
$ 5.85	14.70
$ 5.86	14.73
$ 5.87	14.76
$ 5.88	14.79
$ 5.89	14.82
$ 5.90	14.85
$ 5.91	14.88
$ 5.92	14.91
$ 5.93	14.94
$ 5.94	14.97
$ 5.95	15.00
$ 5.96	15.03
$ 5.97	15.06
$ 5.98	15.09
$ 5.99	15.12
$ 6.00	15.15
$ 6.01	15.18
$ 6.02	15.21
$ 6.03	15.24
$ 6.04	15.27
$ 6.05	15.30
$ 6.06	15.33
$ 6.07	15.36
$ 6.08	15.39
$ 6.09	15.42
$ 6.10	15.45
$ 6.11	15.48
$ 6.12	15.51
$ 6.13	15.54
$ 6.14	15.57
$ 6.15	15.60
$ 6.16	15.63
$ 6.17	15.66
$ 6.18	15.69
$ 6.19	15.72
$ 6.20	15.75
$ 6.21	15.78
$ 6.22	15.81
$ 6.23	15.84
$ 6.24	15.87
$ 6.25	15.90
$ 6.26	15.93
$ 6.27	15.96
$ 6.28	15.99
$ 6.29	16.02
$ 6.30	16.05
$ 6.31	16.08
$ 6.32	16.11
$ 6.33	16.14
$ 6.34	16.17
$ 6.35	16.20
$ 6.36	16.23
$ 6.37	16.26
$ 6.38	16.29
$ 6.39	16.32
$ 6.40	16.35
$ 6.41	16.38
$ 6.42	16.41
$ 6.43	16.44
$ 6.44	16.47
$ 6.45	16.50
$ 6.46	16.53
$ 6.47	16.56
$ 6.48	16.59
$ 6.49	16.62
$ 6.50	16.65
$ 6.51	16.68
$ 6.52	16.71
$ 6.53	16.74
$ 6.54	16.77
$ 6.55	16.80
$ 6.56	16.83
$ 6.57	16.86
$ 6.58	16.89
$ 6.59	16.92
$ 6.60	16.95
$ 6.61	16.98
$ 6.62	17.01
$ 6.63	17.04
$ 6.64	17.07
$ 6.65	17.10
$ 6.66	17.13
$ 6.67	17.16
$ 6.68	17.19
$ 6.69	17.22
$ 6.70	17.25
$ 6.71	17.28
$ 6.72	17.31
$ 6.73	17.34
$ 6.74	17.37
$ 6.75	17.40
$ 6.76	17.43
$ 6.77	17.46
$ 6.78	17.49
$ 6.79	17.52
$ 6.80	17.55
$ 6.81	17.58
$ 6.82	17.61
$ 6.83	17.64
$ 6.84	17.67
$ 6.85	17.70
$ 6.86	17.73
$ 6.87	17.76
$ 6.88	17.79
$ 6.89	17.82
$ 6.90	17.85
$ 6.91	17.88
$ 6.92	17.91
$ 6.93	17.94
$ 6.94	17.97
$ 6.95	18.00
$ 6.96	18.03
$ 6.97	18.06
$ 6.98	18.09
$ 6.99	18.12
$ 7.00	18.15

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	
PROPOSED AMENDMENTS TO 35 Ill. Adm. Code 302.102 and 302.208(g) WATER QUALITY STANDARDS FOR CHLORIDES	)	**R18-32** **(Rulemaking - Water)**
	)	

CERTIFICATE OF SERVICE

I, Fredric Andes, hereby certify that I have filed the attached NOTICE OF ELECTRONIC FILING and ILLINOIS ASSOCIATION OF WASTEWATER AGENCIES' PRE-FILED QUESTIONS TO JAMES E. HUFF, P.E., in PCB R2018-032 upon the attached service list by electronic mail on May 30, 2019.

Dated: May 30, 2019

Respectfully submitted,

_/s/ Fredric Andes ___________________

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