Environment and Natural Resources Trust Fund (ENRTF) M.L. 2016 Work Plan

Date of Report: May 1, 2017

Date of Next Status Update Report: December 1, 2017

Date of Work Plan Approval: June 7, 2016

Project Completion Date: June 30, 2018

Does this submission include an amendment request? No

PROJECT TITLE: Analyzing Alternative for Muncipal Wastewater Treatment

Project Manager: Scott Kyser

Organization: Minnesota Pollution Control Agency

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Location: Statewide

Total ENRTF Project Budget:	**ENRTF Appropriation:**	**$180,000**
	Amount Spent:	**$27,690**
276	**Balance:**	**$152,310**

Legal Citation: M.L. 2016, Chp. 186, Sec. 2, Subd. 04m

Appropriation Language:

$180,000 the second year is from the trust fund to the commissioner of the Minnesota Pollution Control Agency to analyze alternatives for improved treatment of sulfate and salty parameters at municipal wastewater plants to inform the development and implementation of wild rice, sulfate, and other water quality standards. This appropriation is available until June 30, 2019, by which time the project must be completed and final products delivered.

I. PROJECT TITLE: Analyzing Alternative for Muncipal Wastewater Treatment

II. PROJECT STATEMENT:

The goal of this project is analyze alternatives for improved treatment of sulfate and salty parameters at municipal wastewater plants. This analysis will inform implementation of the wild rice, sulfate and other water quality standards.

The MPCA has begun the administrative process to revise the existing 10 mg/L wild rice sulfate standard to better reflect the complex biochemistry necessary to support wild rice. Currently there are few effluent limits in wastewater treatment plant (WWTP) permits derived from the existing wild rice sulfate standard. Although specifics about how a revised standard may be implemented are limited, more WWTPs are likely to have sulfate limits in the future.

Municipal WWTPs are not designed to remove sulfate or salty parameters from their wastewater. In order to remove sulfate or salty parameters, a treatment plant would need to upgrade or change their treatment processes. The proposed study will allow affected communities to better understand sulfate and salty parameter treatment alternatives and their costs before beginning pilot testing and design work.

A document that summarizes and critically evaluates potential sulfate and salty parameter treatment technologies would provide essential support to municipalities in Minnesota. If this information were made available municipalities they would not have to incur costs on hiring consultants to evaluate it on a project by project basis. It would also be useful to know how sulfate and the salty parameters (chloride, sulfate, salinity, dissolved materials, etc) could be effectively co-removed.

The treatment plant engineering design community has the best resources available to both critically evaluate sulfate and salty parameter treatment alternatives and their associated costs for municipal treatment plants. The design community possesses knowledge and costing experience that the MPCA does not have. MPCA would issue a competitive Request for Proposals (RFP) to solicit a sulfate and salty parameter treatment alternatives analysis that critically evaluates the applicability of sulfate treatment technologies and their costs for municipal utilities. At a minimum, the treatment alternatives in table 1 including source reduction will be evaluated for removal potential for both salty parameters and sulfate.

The MPCA believes there would be additional value in a more detailed “Case Analysis” exercise where the contractor would perform initial sulfate and salty parameter treatment plant design for a representative small, medium and large scale municipality. This approach would identify design concerns that could only come to light through the design process. Since a WWTP that simultaneously treats human waste and potentially removes sulfate and salty parameters to low levels has never been designed in Minnesota, this step would provide crucial implementation information. A “Case Analysis” exercise is common in federal EPA guidance documents for evaluating wastewater treatment technologies and provides critical insight.

III. OVERALL PROJECT STATUS UPDATES

Project Status as of December 1, 2016: Update #1 to LCCMR

The MPCA issued the RFP to select a contractor to perform the work in our 2016 Work Plan submitted to the LCCMR. We selected a contractor following MN contracting rules using a selection team of four MPCA engineers and two engineers from the city of Moorhead and the city of Duluth respectively.

The selected contractor was a combined proposal from the consulting firms of Bolton and Menk and Barr Engineering. Their submitted proposal is attached to the e-mail this document was sent with. The final bid came to $179,940. They will sign the finalized contract with the MPCA on Dec 5th, 2016 and begin work on that date. There have been no expenditures to date. We expect preliminary results to be included in our next update.

Project Status as of May 1, 2017: Update #2 to LCCMR

Work tasks completed to-date include:

- Reviewed and revised treatment technology categories
- Identified treatment technologies and conducted review of available literature for primary treatment technologies and concentrate management technologies
- Developed technology screening approach including screening for sulfate removal and other parameters (N, P, Hg, TDS, Cl)
- Participated in kick-off meeting with MPCA to review proposed approach and receive review comments (3/30/17)
- Conducted preliminary technology screening

Deliverables provided:

- Revised technology categories
- List of sulfate removal technologies identified up through date of MPCA meeting on 3/30/17
- Draft concepts for screening of the other parameters and visualization of influent-effluent sulfate condition scenarios
- Preliminary screening results (internal draft to BMI, See table below)

DRAFT Treatment Technology Descriptions		
Primary Sulfate Removal Categories	Technology	Technology description
Influent source sulfate reduction	Change Drinking Water Source (if groundwater source)	Change drinking water to a surface water source with lower chloride concentrations.
	Change Drinking Water Coagulant (if alum and surface water source)	Change drinking water treatment process to use ferric chloride instead of aluminum sulfate as the primary coagulant.
	Restrict Industrial Discharges	Implement tighter pretreatment requirements to reduce sulfate concentration in discharges.
Chemical precipitation	Gypsum Precipitation	Calcium is added in the form of lime, and combines with sulfate to form gypsum solids, which can be removed from the water in a clarifier. Final concentration is limited by solubility of gypsum to >1,500 mg/L.
	Ettringite Precipitation (CESR or SAVMIN)	Lime and Gibbsite are added to form ettringite, which can be removed in a clarifier. Gibbsite can be recovered from ettringite and reused.
	Ettringite Precipitation with Aluminum Recovery (LoSO4)	Lime and aluminum reagent are added to form ettringite, which can be removed in a clarifier. Sludge is then processes to recover aluminum reagent for reuse. Designed for mine water treatment of nanofiltration (NF) reject.
	Barite Precipitation	Barium chloride or barium hydroxide is added, then barium combines with sulfate to form barium sulfate, which is removed in a clarifier.
	Co-Precipitation with Aluminum	Sulfate ions can form complexes with aluminum precipitates and be removed from solution at pH 4-5.
Ion exchange	Conventional Ion Exchange	A strong base anion exchange resin can be used to remove all anions along with sulfate and sulfite.
	Sulf-IX	Sulfate removal is completed in a two-stage process. Feed water passed through a series of contactors containing cation exchange resin to remove calcium and magnesium, then passed through a second set of contactors containing anion exchange resins to remove sulfate.
Membranes	Closed-circuit Desalination Reverse Osmosis (CCD RO)	Uses conventional RO membranes. Permeate is produced at a rate equal to the incoming flow rate, and when a desired (high) recovery percentage is reached, brine is throttled out of the system, displaced by feedwater in a single "plug flow" sweep.
	Electrodialysis Reversal (EDR)	An electric current is used to move dissolved salt ions through layers of charged membranes.
	Zero Discharge Desalination (ZDD)	Combines conventional reverse osmosis with electrodialysis metathesis on the concentrate management side.
	Membrane distillation	A separation process that is thermally-driven, in which only vapor molecules transfer through a microporous hydrophobic membrane. Membrane distillation is driven by the vapor pressure difference that results from the temperature difference across the hydrophobic membrane.
	Nanofiltration (NF)	Pressure is applied to force a solution through the membrane. The membrane allows the water to pass through but restricts some salts and other compounds. NF membranes have a larger pore size than conventional RO; monovalent ions can pass through the membrane.
	Conventional Reverse Osmosis (RO)	Pressure is applied to force a solution through a spiral-wound membrane. The membrane allows the water to pass through but restricts some salts and other compounds. Membranes have a smaller pore size than NF; monovalent ions are rejected by the membrane/cannot pass through.
	Vibratory Shear Enhanced Processing (VSEP)	High-pressure membrane treatment. In contrast to traditional spiral-wound membranes, VSEP uses flat-sheet membranes in a cross-flow configuration, which reduces the boundary layer at the membrane surface, which in combination with applied vibratory shear, reduces the boundary layer at the membrane surface.
	Forward osmosis	Uses natural osmotic process to separate water from dissolved solids. Driving force for this separation is a "draw" solution of higher concentration than the feed water. The osmotic gradient between the two streams creates a flow of water through the membrane, allowing clean water to mix with the draw solution separating it from salt and other contaminants.
Electrochemical treatment	Electrocoagulation	Metal ions formed in an electrochemical cell are used to precipitate metal hydroxides, which can remove anions such as sulfate from solution through adsorption.
	Electrochemical Reduction	Sulfate is reduced to sulfide on graphite electrode at temperature of 120 degrees Celsius.
Biological treatment	Constructed Wetlands	Bacteria present in wetland sediments reduce sulfate to sulfide, which then removes metals from industrial wastewaters. Needs carbon source. Limited sulfate removal capacity.
	Floating Wetlands	Islands consisting of floating media and wetland plants can remove sulfate from a larger body of water. Floating wetlands are most practical in existing water bodies. Needs carbon addition. Limited sulfate removal capacity.
	Pit Lake or In-Pit Treatment	Mining application. Naturally-occurring microbiological communities in pit lakes remove sulfate to sulfide with addition of carbon amendment. Needs carbon source. Limited sulfate removal capacity.
	Constructed Trench Bioreactors/ Permeable Reactive Barriers	Water is routed through a soil bed trench packed with carbon substrate, which grows a biofilm to reduce sulfate to sulfide. Needs carbon source. Limited sulfate removal capacity.
	Suspended-Growth Reactor (Activated Sludge Modification)	Anaerobic suspended-growth treatment, similar to an activated sludge process, could be used upstream of traditional activated sludge treatment systems, but would require a long solids retention time. A sequencing batch reactor (SBR) allows for more efficient biological removal in the liquid phase and lower tank volume, but requires more sophisticated operations and control. This can be implemented upstream of traditional activated sludge systems. Fluidized bed reactors can maintain about 5x the bacteria concentration as mixed reactors, and the reactor size can be smaller.
	UASB Reactor with Sulfide Treatment	A UASB reactor provides sufficient SRT to grow sulfate-reducers and reduce sulfate to sulfide. A second reactor can then be optimized to oxidize sulfide to elemental sulfur, which can be recovered.
	Packed Bed Bioreactor	Sulfate reducing bacteria retained on synthetic or natural media in a tank, where sulfate is reduced to sulfide
	Packed Bed Sulfide Reactor (BioSulphide)	Commercial process to produce sulfide from sulfate reduction primarily designed to precipitate and recover metals from industrial wastewaters.
	Bioelectrochemical	Bioreactors with electrodes can reduce sulfate to recover sulfur as elemental sulfur or iron sulfide using electrons (Chanlun Chun's lab at U of M Duluth).
	Sulfate reduction deammonification	Using a biological metabolism similar to ANAMMOX, sulfate can be used to remove ammonia.
	Liquid-phase biofilters	Biofilms growing on GAC or biochar can reduce sulfate to sulfide, which can be precipitated with metal as metal sulfides (Sebastian Behren's lab at U of M).
	Sulfate reduction denitrification and nitrification integrated process (SANI)	SANI includes removal of ammonia, nitrate, and sulfate in three separate reactors. Sulfate is reduced to sulfide, which feeds dinitrifiers in a second reactor. Ammonia is then removed in a third, aerated reactor. This system would replace activated sludge treatment and decrease sludge production.
Evaporative treatment	LM-HT Concentrator	The system involves the direct contact of hot gases and water/brine to evaporate water and produce a more concentrated brine or salt slurry, which is then stabilized and disposed. No heat exchangers are used, less fouling, but requires a source of hot gas for the process.
	Mechanical evaporation / Zero Liquid Discharge (ZLD)	ZLD includes brine concentration, where brine is heated and recirculated until about 95% is converted to high purity distillate, followed by crystallization which uses heat to reduce brine concentrate to a dry solid. Overall water recovery up to 99%. High-purity distillate suitable for reuse, discharge, or aquifer reinjection. Produces solid salt cake suitable for landfill disposal.

Project Status as of December 1, 2017: Update #3 to LCCMR

Project Status as of May 1, 2018: Update #4 to LCCMR

Project Status as of June 30, 2018: Final written report due to LCCMR.

Overall Project Outcomes and Results: A document that summarizes and critically evaluates potential municipal sulfate and salty parameter treatment technologies and their associated costs and implementation concerns for representative wastewater treatment plants.

IV. PROJECT ACTIVITIES AND OUTCOMES:

ACTIVITY 1: Administration of Sulfate and Salty Parameter Treatment Alternative RFP
Description: The RFP will encourage the state and national design community to apply for funds to complete an analysis of sulfate and salty parameter treatment options. The RFP contracting process will be managed by the MPCA contract staff, reviewed by MPCA engineers and out-state municipal wastewater engineers and will comply with all state and federal regulations. The final candidate will be selected by a committee of MPCA engineering staff and out-state municipal wastewater engineers under the guidance of the MPCA contract unit. Once the best candidate is selected, funds and necessary design information will be delivered to the contractor by the MPCA. The grantee will have ten months to complete the deliverable for activity 1. A presentation of likely feasible treatment alternatives to a panel of engineering experts will be required before activity 1 will be completed. The panel of experts will include UMN engineering and scientific faculty, MPCA staff and engineering experts from outside the MPCA. A written summary evaluating each alternative with the selection of a most feasible alternative for a municipal WWTP will be the deliverable for activity 1.

The selected party, will at a minimum, review the feasibility of the nine selected technology categories below in Table 1. The goal is to understand all preliminary advantages and disadvantages of each selected sulfate treatment approach in order to rank them and find the most feasible treatment technology. Feasibility will be defined as a holistic evaluation of the technology considering relative costs, design, operational, waste stream handling and other life-cycle analysis concerns. Eliminating a technology as being feasible is just as important as finding an alternative that is feasible. Each treatment alternative must also be evaluated as to whether it will additionally remove other 'salty parameters', but removing sulfate will be considered the primary goal of each alternative.

The selected party will be provided with four representative effluent sulfate treatment goals and four representative sulfate influent conditions to evaluate each alternative against. A given treatment technology might work well for certain scenarios (low influent sulfate, high effluent target) but not for others (high influent sulfate, low effluent target). The selected party will, to the extent possible, determine how each treatment technology would work across the range of provided treatment goals.

The MPCA has selected the treatment alternatives listed below but does not consider this list to be complete. The selected party will demonstrate having evaluated whether other treatment alternatives not listed might be feasible or whether linking several treatment alternatives in new ways might generate a new feasible alternative. The selected party must understand that the list below represents categories and that the specifics of the technologies within each category must be illuminated in the alternative analysis. This project should not involve collecting any water samples or physically evaluating treatment technologies at the bench or pilot scale; the goal is a white paper level analysis of feasibility.

Table 1. The minimum nine categories of sulfate treatment technologies required for review in activity 1

Sulfate Influent Source Reduction
Chemical Precipitation with Lime, Barium, Ettringite
Sulfate Ion Exchange
Nanofiltration, Reverse Osmosis and Associated Membrane Technologies
Electrodialysis
Activated Sludge Retrofit
Anaerobic Treatment Processes (Sulfate Digestion, Anammox & other Sidestream Unit Operations)

Constructed Wetlands
Permeable Reactive Barriers

Summary Budget Information for Activity 1: **ENRTF Budget: $ 100,000**
Amount Spent: $ 27,690
Balance: $ 72,310

Outcome	**Completion Date**
1. MPCA publically issues RFP	July 1, 2016
2. MPCA finalizes candidate selection and initiates project kickoff	November 1, 2016
3. Update #1 to LCCMR	December 1, 2016
4. Update #2 to LCCMR	May 1, 2017
5. Final alternative analysis and most feasible alternative due to MPCA allowing for changes based on panel input	September 1, 2017

Project Status as of December 1, 2016: Update #1 to LCCMR

The selected contractor has not begun work on activity 1. They will begin work on this once the final contract has been signed on Dec 6th, 2016.

Project Status as of May 1, 2017: Update #2 to LCCMR
The contractor has developed a list of technologies that could remove sulfate and developed a screening technology to rank and score those technologies. There have been good interactions with MPCA staff in developing the screening technology and results of the project are preliminary good. The preliminary best technology to remove sulfate for a municipal wastewater treatment plant is reverse osmosis with evaporation and crystallization (highest score of 90/100; see ranking below).

DRAFT Technology Screening Summary

Group 1: > 90
Reverse osmosis
Nanofiltration
Group 2 : 75 - 90
Barite precipitation
Ettringite precipitation
Sulf-IX
EDR
VSEP
CCD RO
Group 3: < 74
Conventional ion exchange
UASB
LM-HT concentrator
Packed bed bioreactor
ZLD with mechanical evaporator/crystallizer

Budget status:

- Spent through 4/13/17: $27,690

ACTIVITY 2: Sulfate and Salty Parameter Treatment Case Analysis

Description: The candidate will select the most promising sulfate and salty parameter treatment technologies from Activity 1 and begin a preliminary design for three representative municipalities using the average wet weather flows described in the table below. The goal of design would be to unearth implementation concerns only discoverable through initial design and to get a better sense of costs and relevant implementation concerns. The information found in this preliminary design would be used to inform the final deliverable with respect to costs and design considerations.

Facility Size	Average Wet Weather Flow (MGD)	Sulfate Treatment Target
Small	0.5	Most Restrictive
Medium	2.5	Most Restrictive
Large	10	Most Restrictive

A facility plan level analysis as defined in the ten state standards (section 11; http://www.10statesstandards.com/wastewaterstandards.pdf) will be used as a guide to the level of analysis required for each facility size. Detailed design (sewering, electrical, structural, pumping, etc…), financing methods, construction schedules, population projections and environmental review will not be required. Unit operation train diagrams and general flow diagrams will be required. A conceptual understanding of the proposed WWTP design, operation and maintenance should be the goal of activity 2.

The contractor should also generally comment on whether new WWTP construction would be required for each scenario or whether a conventional activated sludge WWTP or pond could be retrofitted to treat sulfate. The MPCA will provide theoretical WWTPs specifications for retrofit considerations. The facility plan documents do not need to go into specific design of retrofitted plants; a general comment on the feasibility of retrofitting the representative WWTPs for treating sulfate is all that will be required.

It is not reasonable to expect the contractor to develop a facility plan for each of the various influent sulfate concentrations and treatment targets in activity 1 using the given budget. The facility plans will use the most restrictive treatment scenario (highest influent sulfate, lowest effluent target from activity 1) but the contractor will be required to generally comment on how well the treatment would scale in response to the other treatment scenarios. The facility plan will also consider whether this treatment will remove other salty parameters as a secondary goal. The same panel of experts from Activity 1 will review this project activity and provide recommendations for improvement as needed before final deliverable.

Summary Budget Information for Activity 2:

ENRTF Budget: $ 80,000
Amount Spent: $ 0
Balance: $ 80,000

Outcome (must match up)	**Completion Date**
1. Selected contractor begins case analysis	September 1, 2017
2. Contractor presents final results to panel of review experts (See Partners, Page 6)	By May 1, 2018
3. Final report due to MPCA allowing for changes based on panel input	May 31, 2018
4. Final report deliverable to LCCMR	June 20, 2018

Project Status as of December 1, 2017: Update #3 to LCCMR

Project Status as of May 1, 2018: Update #4 to LCCMR

Project Status as of June 30, 2018: Final written report due to LCCMR.

Final Report Summary:

The final report will be a written document describing all of the results from activity 1 and activity 2. It will explain why each sulfate treatment alternative was eliminated as being feasible, why the most feasible treatment alternative was chosen and all associated costs and implementation concerns of that chosen treatment alternative.

V. DISSEMINATION:

Description: The final deliverable will be available on the MPCA webpage and will be disseminated electronically to the MPCA wastewater listserv and MPCA twitter page. The draft report after activity 1 will not be disseminated electronically.

MPCA webpage:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/wastewater/index.html

Twitter Site:
http://twitter.com/MnPCA?ref_src=twsrc^google|twcamp^serp|twgr^author

The selected contractor will be required to present the results of the report after completion of both activity 1 and activity 2 at MN conferences for wastewater engineers and environmental professionals. A list of recommended conferences to be presented at will be provided in the RFP.

Project Status as of December 1, 2016: Update #1 to LCCMR

The project has not officially begun yet. Nothing to report in this section.

Project Status as of May 1, 2017:

The contractor has begun the process of submitting research abstracts to MN wastewater conferences. They are targeting a November 2017 conference for presentation of initial research results.

Project Status as of December 1, 2017:

Project Status as of May 1, 2018:

Project Status as of June 30, 2018:

VI. PROJECT BUDGET SUMMARY:

A. ENRTF Budget Overview:

Budget Category	$ Amount	Overview Explanation
Professional/Technical/Service Contracts:	$180,000	Determining reasonable sulfate treatment alternatives and their associated costs
TOTAL ENRTF BUDGET:	**$180,000**	

Explanation of Use of Classified Staff: MPCA will donate in-kind time to develop the RFP, select the contractor and monitor the progress of the project. No funds from the ENRTF will be used for MPCA staff funding.

Explanation of Capital Expenditures Greater Than $5,000: None

Number of Full-time Equivalents (FTE) Directly Funded with this ENRTF Appropriation: None

Number of Full-time Equivalents (FTE) Estimated to Be Funded through Contracts with this ENRTF Appropriation: 1.5 FTE for a registered professional engineer

B. Other Funds:

Source of Funds	$ Amount Proposed	$ Amount Spent	Use of Other Funds
Non-state	None		
State	$38,248	$0	In-Kind FTE dollar equivalent for contracts unit and Engineering Review
TOTAL OTHER FUNDS:	**$38,248**	**$0**	

VII. PROJECT STRATEGY:

A. Project Partners: Review committee including engineers and scientists from the University of Minnesota, Met Council, Moorehead and Western Lake Superior Sanitary District.

B. Project Impact and Long-term Strategy:

In 2015, the MPCA began the administrative process to revise the existing 10 mg/L wild rice sulfate standard to better reflect the complex biochemistry necessary to support wild rice. Currently there are few effluent limits in wastewater permits derived from the existing wild rice sulfate standard. Although specifics about how a revised standard may be implemented are still in development, more municipal WWTPs are likely to have sulfate limits in the future.

This work will aid and inform the implementation of the wild rice sulfate standard. The project will provide accurate costs and implementation concerns for municipal WWTPs with regards to sulfate treatment. These costs and implementation concerns are absolutely essential for permitting WWTPs to comply with the wild rice sulfate standard.

The greatest benefit to this project is that it will provide a generalized sulfate preliminary design document for municipal WWTPs. This document will eliminate the need for municipal WWTPs to individually perform a sulfate treatment study, collectively saving municipal WWTPs hundreds of thousands of dollars in implementation costs!

C. Funding History:

Funding Source and Use of Funds	Funding Timeframe	$ Amount
No previous funding for this project.		$0

IX. VISUAL COMPONENT or MAP(S): See attached

X. RESEARCH ADDENDUM: None

XI. REPORTING REQUIREMENTS:

Periodic work plan status update reports will be submitted no later than Dec 1 2016, May 1 2017, December 1 2017 and May 1 2018. A final report and associated products will be submitted by June 30th, 2018.

DRAFT Treatment Technology Descriptions		
Primary Sulfate Removal Categories	Technology	Technology description
Influent source sulfate reduction	Change Drinking Water Source (if groundwater source)	Change drinking water to a surface water source with lower chloride concentrations.
	Change Drinking Water Coagulant (if alum and surface water source)	Change drinking water treatment process to use ferric chloride instead of aluminum sulfate as the primary coagulant.
	Restrict Industrial Discharges	Implement tighter pretreatment requirements to reduce sulfate concentration in discharges.
Chemical precipitation	Gypsum Precipitation	Calcium is added in the form of lime, and combines with sulfate to form gypsum solids, which can be removed from the water in a clarifier. Final concentration is limited by solubility of gypsum to >1,500 mg/L.
	Ettringite Precipitation (CESR or SAVMIN)	Lime and Gibbsite are added to form ettringite, which can be removed in a clarifier. Gibbsite can be recovered from ettringite and reused.
	Ettringite Precipitation with Aluminum Recovery (LoSO4)	Lime and aluminum reagent are added to form ettringite, which can be removed in a clarifier. Sludge is then processes to recover aluminum reagent for reuse. Designed for mine water treatment of nanofiltration (NF) reject.
	Barite Precipitation	Barium chloride or barium hydroxide is added, then barium combines with sulfate to form barium sulfate, which is removed in a clarifier.
	Co-Precipitation with Aluminum	Sulfate ions can form complexes with aluminum precipitates and be removed from solution at pH 4-5.
Ion exchange	Conventional Ion Exchange	A strong base anion exchange resin can be used to remove all anions along with sulfate and sulfite.
	Sulf-IX	Sulfate removal is completed in a two-stage process. Feed water passed through a series of contactors containing cation exchange resin to remove calcium and magnesium, then passed through a second set of contactors containing anion exchange resins to remove sulfate.
Membranes	Closed-circuit Desalination Reverse Osmosis (CCD RO)	Uses conventional RO membranes. Permeate is produced at a rate equal to the incoming flow rate, and when a desired (high) recovery percentage is reached, brine is throttled out of the system, displaced by feedwater in a single "plug flow" sweep.
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	Membrane distillation	A separation process that is thermally-driven, in which only vapor molecules transfer through a microporous hydrophobic membrane. Membrane distillation is driven by the vapor pressure difference that results from the temperature difference across the hydrophobic membrane.
	Nanofiltration (NF)	Pressure is applied to force a solution through the membrane. The membrane allows the water to pass through but restricts some salts and other compounds. NF membranes have a larger pore size than conventional RO; monovalent ions can pass through the membrane.
	Conventional Reverse Osmosis (RO)	Pressure is applied to force a solution through a spiral-wound membrane. The membrane allows the water to pass through but restricts some salts and other compounds. Membranes have a smaller pore size than NF; monovalent ions are rejected by the membrane/cannot pass through.
	Vibratory Shear Enhanced Processing (VSEP)	High-pressure membrane treatment. In contrast to traditional spiral-wound membranes, VSEP uses flat-sheet membranes in a cross-flow configuration, which reduces the boundary layer at the membrane surface, which in combination with applied vibratory shear, reduces the boundary layer at the membrane surface.
	Forward osmosis	Uses natural osmotic process to separate water from dissolved solids. Driving force for this separation is a "draw" solution of higher concentration than the feed water. The osmotic gradient between the two streams creates a flow of water through the membrane, allowing clean water to mix with the draw solution separating it from salt and other contaminants.
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	UASB Reactor with Sulfide Treatment	A UASB reactor provides sufficient SRT to grow sulfate-reducers and reduce sulfate to sulfide. A second reactor can then be optimized to oxidize sulfide to elemental sulfur, which can be recovered.
	Packed Bed Bioreactor	Sulfate reducing bacteria retained on synthetic or natural media in a tank, where sulfate is reduced to sulfide
	Packed Bed Sulfide Reactor (BioSulphide)	Commercial process to produce sulfide from sulfate reduction primarily designed to precipitate and recover metals from industrial wastewaters.
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	Mechanical evaporation / Zero Liquid Discharge (ZLD)	ZLD includes brine concentration, where brine is heated and recirculated until about 95% is converted to high purity distillate, followed by crystallization which uses heat to reduce brine concentrate to a dry solid. Overall water recovery up to 99%. High-purity distillate suitable for reuse, discharge, or aquifer reinjection. Produces solid salt cake suitable for landfill disposal.