Technical Report No. 66

STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 3

MUNICIPAL WATER AND WASTEWATER UTILITIES

3.1 INTRODUCTION

Wastewater treatment plant (WWTP) effluent that is discharged to surface water or groundwater can be a major source of chlorides in the environment. The primary source of chlorides passing through WWTPs are point-of-entry ion-exchange water softeners in homes and businesses. These systems generate chlorides during regeneration cycles, and the chloride-containing waste flow is discharged into sanitary sewers. Additional sources of chlorides to WWTPs are aluminum chloride ($AlCl_3$) and ferric chloride ($FeCl_3$) which are used as coagulants to remove contaminants during wastewater treatment as well as stormwater carrying dissolved deicing and anti-icing salts into the sanitary sewer system. Conventional wastewater treatment processes do not remove chloride from wastewater, resulting in chlorides being discharged in the effluent to the receiving waterbody. Increasingly stringent chloride concentration limitations in waterbodies require that many WWTPs implement measures to reduce effluent chloride concentrations. Chloride loading at the plants can be reduced either at the source or by removal at WWTPs. Source reduction can generally be achieved by reducing the use of or improving the efficiency of point-of-entry water softeners or by centrally softening the water supply prior to distribution. The removal of chloride at WWTPs requires additional treatment processes at the plant. This chapter provides a description of the chloride reduction alternatives available for municipal water and wastewater utilities.

3.2 SOURCES OF CHLORIDES TO WASTEWATER TREATMENT PLANTS AND CHLORIDE EFFLUENT LIMITS

Sources of Chloride to Wastewater Treatment Plants

Areas with naturally hard groundwater used as a source for drinking water supply often have a high prevalence of water softening in homes and businesses. Wisconsin is generally considered to have hard groundwater (>120 mg/l as $CaCO_3$) which induces substantial water softening activity. Map 3.1 shows average total hardness of groundwater by township throughout the State measured from private well water samples collected by several state and county agencies over the past 25 years from both shallow and deep wells.[1] The hardness of water is primarily determined by the amount of calcium (Ca) and magnesium (Mg) ions. Hard water can lead to scale buildup in plumbing and appliances, which can decrease their efficiency and performance. Hard water can also inhibit lathering of soap and other cleaning agents, decreasing their effectiveness. Hardness can be removed by a process commonly referred to as water softening. Most water softening is currently done at the household level using point-of-entry[2] ion-exchange water softeners. Ion-exchange water softeners replace calcium and magnesium ions in the influent water supply with cations from an exchange resin, often sodium ions, as shown in Figure 3.1 Once the resin material gets saturated with calcium and magnesium ions, a regeneration cycle flushes the system with a salt brine solution, typically sodium chloride. The sodium chloride in the brine dissociates, and the sodium ions displace the calcium and magnesium ions in the resin. The displaced calcium and magnesium ions are flushed out as wastewater, along with the chloride ions that were dissociated from the sodium ions in the brine. The regeneration process is shown in Figure 3.2. This wastewater gets conveyed to the WWTP and is a significant source of chloride loading to the plant. Chapter 4 of this report contains a more in-depth discussion on private water softening. Additional sources of chloride from households include cleaning products, food preparation and waste, human waste, and other household products as well as naturally occurring chloride concentrations in the water supply.[3]

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[1] *University of Wisconsin-Stevens Point, "*Well Water Quality Viewer: Private Well Data for Wisconsin*," Version 14, April 2024.*

[2] Point-of-entry refers to systems located at the point where the water supply enters the building before the water is distributed throughout the building.

[3] *A. Overbo et al, "*Chloride Contributions from Water Softeners and Other Domestic, Commercial, Industrial, and Agricultural Sources to Minnesota Waters*," January 2019.*

Chlorides can also enter wastewater treatment plants from the use of deicing products. Sodium chloride rock salt and brine are applied to roads, parking lots, and sidewalks to improve safety during winter storm events. Inflow of stormwater runoff into a sanitary collection system can transport dissolved deicing products containing chlorides to the receiving wastewater treatment plant. In communities that have combined sewers, stormwater and sewage wastewater are collected within the same pipes that convey the water to the WWTP. In separate stormwater systems, deicing products can enter the sanitary sewer system via infiltration and inflow. This can occur at manholes and cracks in sanitary pipes or infrastructure.

Additionally, WWTPs commonly use chloride-containing compounds as coagulants during the treatment process. Aluminum chloride, ferric chloride, ferrous chloride, and others are used to remove phosphorus and other contaminants from wastewater and to control odors. When added to the wastewater, these compounds dissociate, allowing the cation to bind with the contaminant and settle out, while the liberated chloride ion remains in the wastewater. As traditional wastewater treatment processes do not remove chloride, the chloride ions pass through and get discharged to the receiving waterbody in the effluent. Similarly, wastewater from industries that use these chloride-containing coagulant compounds are a source of chloride loading to WWTPs.

Figure 3.3 illustrates the aforementioned sources of chlorides to WWTPs. The *Business as Usual* scenario shows unmitigated use of point-of-entry water softeners. The *With Centralized Softening* scenario depicts removal of point-of-entry water softeners due to implementation of centralized softening, which is discussed in detail later in this chapter.

Chloride Effluent Limits

Chlorides can contaminate surface water and groundwater, impact soils, and be toxic to organisms, especially those in freshwater ecosystems. Elevated concentrations of chloride salts in the environment above naturally occurring levels can impact the growth, physiology, and reproduction of organisms, and in the most severe cases, can cause mortality. Due to the harmful impacts chlorides have on freshwater systems, the State of Wisconsin has promulgated two water quality criteria for chloride to protect aquatic life: an acute toxicity criterion and a chronic toxicity criterion.[4] The acute toxicity criterion sets a daily chloride maximum concentration of 757 milligrams per liter (mg/l) that is not to be exceeded more than once every three years. A waterbody is considered impaired for chronic toxicity if the four-day running average daily

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[4] Wisconsin Department of Natural Resources, *Wisconsin Consolidated Assessment and Listing Methodology (WisCALM*), 2022.

maximum concentration exceeds 395 mg/l more than once every three years. Waterbodies that exceed either criterion are deemed impaired under Section 303(d) of the Clean Water Act.

Based on the water quality criteria in the receiving waterbody, the Wisconsin Department of Natural Resources (WDNR) sets water quality-based effluent limitations (WQBELs) for pollutants in wastewater effluent. WQBELs are set to ensure that discharges to waters of the State are in compliance with water quality standards. WQBELs vary among WWTPs based on the specific receiving waterbody and the extent to which the discharge will impact the concentration of the pollutant with respect to the water quality standard. Increasingly stringent effluent limits for chloride necessitate wastewater treatment plants to undertake efforts to reduce chloride concentrations in their effluent. Facilities that are unable to attain their WQBEL within the permit term can apply for a water quality standard variance to receive additional time to meet the discharge limit. A chloride variance requires that the wastewater facility develop and implement a plan to reduce chloride discharges through means such as source reduction and operational changes. During the variance period, incremental progress must be made towards meeting the WQBEL. Table 3.1 lists the 14 wastewater facilities in the Study area that have chloride variances.

3.3 CHLORIDE REMOVAL ALTERNATIVES AT WASTEWATER TREATMENT PLANTS

The two main chloride reduction approaches for WWTPs include removal of chlorides at the WWTP via additional treatment processes or achieving source reduction. Source reduction of chloride reduces the amount of chloride in the influent to the WWTP. This can be achieved by improving the efficiency of point-of-entry water softening systems in homes and businesses, disconnecting softeners in homes where softening is not needed, or by treating the public water supply for hardness prior to distribution. Treating the public water supply, or centralized softening, will reduce or eliminate the need for softening in homes and businesses. Removal of chlorides at the WWTP would require the implementation of additional treatment processes that specifically remove chloride and manage the waste stream from the chloride removal process. While technologically feasible, chloride removal at WWTPs is typically not a viable alternative due to prohibitively high costs, and as such is not being widely implemented in the State or country.

Chlorides can be removed from wastewater by either forcing the flow through membranes or utilizing an ion exchange system similar to the point-of-entry water softening systems described earlier in this chapter. These methods can be operated at wastewater treatment plants, known as end-of-pipe treatment, to remove chloride from the effluent and reduce chloride loading in the receiving waterbody. With membrane filtration technologies, water molecules pass through the membranes while chloride ions and other dissolved solids get blocked and removed. The primary membrane-based alternatives for chloride removal at WWTPs are reverse osmosis and electrodialysis reversal. The resulting brine wastewater from all the chloride removal processes needs to be treated and disposed of appropriately. Reduction of brine volume is needed for economical storage and disposal. The primary alternatives for chloride removal at WWTPs are described in the following sections.

Reverse Osmosis

Reverse osmosis (RO) systems remove chloride from water by passing the water under pressure through a semipermeable membrane. Under high pressure in the system, water moves through the membrane by diffusion, and chloride ions and other dissolved solids are rejected by the membrane and remain on the feed water side of the membrane, as shown conceptually in Figure 3.4. The clean water that passes through the membrane is called permeate, and the recovery rate is the ratio of permeate flow to feed flow, which can be up to 70 to 80 percent.[5] The remaining portion of the flow remains on the feed water side of the membrane and is known as reject, as it contains the constituents that were rejected by the membrane. RO systems can remove chloride and other dissolved inorganic compounds at an efficiency greater than 98 percent.[6] When preceded by a pretreatment step, such as filtration and addition of antiscalant chemicals, reverse osmosis systems can also remove nearly all the particulates from wastewater, as well as phosphorus, nitrogen, mercury, sulfate, and organic compounds.[7]

RO units are commonly used in a spiral-wound configuration, where the membranes are wrapped around a central perforated pipe. Figure 3.5 shows a cross section of a spiral-wound RO unit. Spacers are inserted between layers of membrane material to provide channels into which feed flow is pumped. As the water flows through the system, water molecules pass through the membranes and enter the perforated pipe, which collects and conveys the permeate flow. With the migration of water molecules into the central pipe, the feed flow within the spacer channels becomes increasingly concentrated as reject flow and is diverted from the system. Figure 3.6 illustrates the spiral-wound configuration and Figure 3.7 shows a series of RO units in operation at a treatment plant.

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[5] *M.M. Tare et al., "*Economics of desalination in water resource management – a comparison of alternative water resources for arid/semi arid zones in developing countries," Desalination*, 81: 57-76, 1991.*

[6] *S. Adham et al., "*Comparison of Advanced Treatment Methods for Partial Desalting of Tertiary Effluents," *September 2009.*

[7] *Minnesota Pollution Control Agency, "*Analyzing Alternatives for Sulfate Treatment in Municipal Wastewater," *May 2018.*

The efficiency of RO systems can be impacted by membrane fouling, the pressure applied in the system, the initial concentration of salts and dissolved compounds, along with myriad other factors. Fouling is generally the biggest source of decreased RO performance and occurs when the membrane pores get clogged by salts or particulates. When this occurs, the recovery rate of the system decreases due to less water being able to pass through the membrane. Fouling can be reduced by implementing adequate pretreatment directly upstream of the RO system to remove organic matter and suspended solids. The continuous flow of the system helps to remove reject from the membrane, however cleaning and backwashing of the membranes are needed to further reduce fouling.

The amount of pressure applied to the feed water also impacts the efficiency of the system. Generally, higher applied pressures yield higher recovery rates, as more water passes through the membrane and the constituent salts and dissolved solids are rejected. The degree to which a feed flow pressure achieves a certain removal efficiency is tied to the initial concentration of salts and dissolved solids in the feed flow. Higher feed flow salt concentrations create a stronger osmotic pressure that drives water from the lower concentration permeate flow to the higher feed flow. As this is not the desired direction of diffusion, higher system pressure needs to be applied to overcome the higher osmotic pressure. This can either reduce system performance if the same amount of pressure is applied, or it can increase operating costs by increasing the system pressure to achieve a desired treatment outcome.

Electrodialysis Reversal

Electrodialysis reversal (EDR) systems utilize semipermeable membranes to remove dissolved solids similar to reverse osmosis systems, however movement through the membrane is driven by electrical charge rather than pressure. In EDR systems, electrical potential is used to move ions in the water toward oppositely charged electrodes, which traps the ions between membranes, as illustrated in Figure 3.8. This creates a reject stream in which the ions are separated from the permeate stream. The polarity of the electrodes can be periodically reversed, causing the ions to migrate in the opposite direction. Reversing the polarity reduces fouling by effectively backwashing the membrane and removing ions that have accumulated on the membrane surface.

The removal efficiency of EDR systems can range from 50 to 95 percent, depending on the configuration and applied electrical power.[8] Pretreatment is needed for EDR systems to remove organic matter and suspended solids. When compared to reverse osmosis, EDR systems are less prone to fouling because

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[8] *AECOM,* Chloride Compliance Study for NSWTP*, June 2015.*

electrically neutral particulates are not pulled into the membrane by the electrical charge as they are with pressure in RO systems, but rather remain suspended in the reject flow. Additionally, EDR systems have lower energy consumption than RO systems and can achieve a recovery rate of 80 percent.[9]

Ion Exchange

Ion exchange systems contain a column of ion exchange resin that is engineered to react with a specific target ion. When the feed stream comes into contact with the exchange resin, dissolved ions in the water exchange with ions on the resin, removing the dissolved ions. Once the resin exchange capacity is fully utilized, the system needs to be regenerated by flushing it with a brine solution that dislodges the removed ions and replaces them with the exchange ions on the resin material. This process is similar to ion exchange water softening commonly used in homes and businesses, with the key distinction that a different resin is used that targets chloride for removal and a regeneration solution is used that does not introduce chloride into the regeneration waste stream.

An important aspect of ion exchange systems is the affinity of the resin for the target ion in the water. Different resins have different levels of affinity for various ions, so it is important to use a resin that is formulated to have the highest affinity for the target ion. Other ions in the water of similar charge to the target ion can interact with the resin, which consumes exchange capacity of the resin and decreases the removal efficiency of the target ion. When ions are present in the water that have a higher affinity for the resin than the target ion, the removal efficiency can be significantly reduced. In the absence of other ions with competing affinity, ion exchange systems can achieve a 98 percent removal efficiency.[10]

For ion exchange pretreatment is often needed to remove particulate matter and dissolved organic compounds. These constituents can bind to the resin or physically block the dissolved ions in the water from interacting with the exchange resin, which would decrease the removal efficiency of the system. Pretreatment technologies for ion exchange systems are typically granular media filtration or membrane removal. Because the constituents removed in pretreatment are common wastewater treatment constituents, backwash from cleaning the pretreatment system can be recirculated back to the headwaters of the WWTP.

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[9] *R.A. Al-Rashed,* "An Assessment of Community-Scale Electrodialysis Desalination Systems and Improved Scale Mitigation through Pulsed Operation," *Massachusetts Institute of Technology, September 2022.*

[10] *AECOM, 2015,* op. cit.

Considerations for WWTP Chloride Removal

When compared to the alternative of centrally softening the water supply prior to distribution, discussed in detail in the following section of this chapter, removal of chloride at municipal WWTPs is generally considered to be significantly more expensive. The main cost driver for end-of-pipe chloride removal is treatment and disposal of the chloride waste brine, which is typically not applicable to centralized softening. Disposal cost increases as the volume of waste produced increases, therefore reducing the waste brine from a liquid down to a solid crystallized form drastically reduces the cost of disposal due to the substantial decrease in volume. However, the costs are still often prohibitive for most communities, generally making chloride removal at wastewater treatment plants an infeasible alternative.[11] Additionally, as chloride is one of the more difficult contaminants to remove from water, the wastewater must be treated to near-drinking water quality in order to remove chloride, which can be costly[12]. Table 3.2 summarizes the various considerations for each chloride removal technology discussed.

Reduction and Disposal of Wastewater Brine

Reverse osmosis and electrodialysis reversal systems both generate a waste stream of concentrated salt brine in large volumes. Due to its toxicity to aquatic organisms, the brine needs to be properly disposed of rather than discharged in the WWTP effluent. Because disposal costs can be significant, the brine needs to be reduced in volume to make disposal economically feasible and storage logistically practical.

Waste brine minimization can be achieved by the processes of evaporation and crystallization. These methods are often used in conjunction with each other to produce the highest degree of brine volume reduction. Evaporation processes use heat to boil away excess water from the brine, leaving behind a more concentrated product. The reduced brine can be further concentrated with the addition of a seeded slurry, which can yield a water recovery rate of 95 to 99 percent, with the brine containing 17 percent solids.[13] Evaporation systems can be highly energy-intensive due to the large amounts of energy needed to continually heat the brine to a sufficient level. The energy costs can be prohibitively high and increase greenhouse gas emissions from the plant if the energy is not from a carbon-neutral source.[14] Once the brine

[11] *B. Bakshi, E.M. Doucette, and S.J. Kyser, "Centralized softening as a solution to chloride pollution: An empirical analysis based on Minnesota cities," February 2021.*

[12] *Personal communication with WDNR, December 2024.*

[13] *AECOM, 2015,* op. cit.

[14] *MCPA, 2018,* op. cit.

has been sufficiently reduced, a crystallizer can be used to generate a solid product in the form of salt crystals.

After the waste brine has been reduced, the product needs to be either disposed of or processed for beneficial use. Disposal options are generally limited to landfills, industrial waste facilities, or deep well injection. Deep well injection is strictly regulated to protect groundwater drinking water sources and is prohibited in Wisconsin. This can make finding an injection site difficult, potentially requiring the waste to be transported a substantial distance at a prohibitive cost. Deep well injection when permitted is generally better suited to a liquid brine rather than a slurry or solid, however liquid brine would be more costly to transport due to its larger volume and weight as compared to a more concentrated form. Landfills and industrial waste facilities on the other hand are better suited for sludge or solid waste products. The waste brine slurry or crystalized solids would need to be characterized to determine that it is in conformance with the requirements of the landfill or industrial waste facility. Disposal in a landfill does pose the risk of groundwater chloride contamination if the waste leaches through the landfill liner or in the event of a breach of the liner.

An alternative to disposal of the waste brine is to process it for beneficial reuse. Brine can be refined for winter roadway deicing and anti-icing products in the form of liquid brine for pretreatment and solid salt crystals for road salt. Any waste brine that is used as a commercial product needs to be analyzed to assure that there are no harmful, prohibited, or otherwise undesirable substances in the brine that would be present in the final product. Additional processing may be required to further refine the brine to comply with any specifications for the end product, which may require additional equipment and cost. Similarly, space would be needed to store the brine product onsite before it gets shipped. For winter deicing products, storage requirements may be larger during the non-winter period when waste brine continues to be produced while there is no seasonal demand or use for roadway deicing.

Costs

Commission staff reviewed available cost figures for chloride removal systems at wastewater treatment plants, of which reverse osmosis was the only alternative with sufficient cost data. Table 3.3 summarizes these data by per million gallons per day (MGD) treated in order to account for wastewater flows from industrial and commercial sources as well as residential. These costs are for RO systems paired with evaporation and crystallization brine reduction systems. Capital cost would decrease in the absence of brine reduction systems, however operations and maintenance (O&M) costs would increase significantly due to much higher disposal costs as previously discussed. Costs can vary substantially based on a multitude of factors, including the amount of chloride removal required, the brine minimization and disposal method, the water quality profile, and other factors specific to each location. Appendix X contains additional details on these cost data. RO systems were determined to be the most likely end-of-pipe alternative to achieve chloride effluent requirements, so cost estimates were primarily focused on reverse osmosis, however preliminary evaluations suggest EDR systems may have comparable costs. Prior to proceeding with development of a chloride removal system at a WWTP, a preliminary study should be completed to assess alternatives and costs specific to that plant.

End-of-pipe chloride removal is likely to result in an overall net increase in fees for rate payers. The cost of construction and ongoing operation of the chloride removal and brine reduction systems will likely be passed on to rate payers, while rate payers will still incur the full costs of operating their at-home water softeners.

Need for Blending to Protect Receiving Water

The high removal efficiency of RO systems can result in an effluent with minimal concentrations of total dissolved solids (TDS). This can be problematic to the aquatic systems into which the WWTP discharges, as naturally occurring levels of TDS are important for healthy aquatic systems. Discharging effluent with minimal TDS could pose the risk of reducing TDS concentrations in the stream to a detrimental level. As a result, the treated effluent needs to be blended with effluent that bypassed the chloride treatment process to achieve a final TDS concentration that is suitable for the receiving stream while maintaining an acceptable concentration of chloride. Final TDS concentrations and the extent of blending needed will vary among WWTPs based on the specific wastewater profile, RO treatment level, and the receiving waterbody.

3.4 CENTRALIZED SOFTENING AT WATER SUPPLY FACILITIES

Softening drinking water at a central plant prior to distribution can be an effective method for reducing chlorides entering WWTPs, and in turn, for reducing chloride concentrations in the WWTP effluent. Centralized softening requires the construction and operation of a central water treatment plant that receives the source groundwater and treats it for hardness before sending it into the public water distribution system, as shown in Figure 3.3. This results in water being supplied to homes and businesses that is sufficiently softened, reducing or eliminating the need for private point-of-entry water softeners. For centralized softening the removal of hardness-causing calcium and magnesium ions from the source water can be achieved with lime softening, reverse osmosis, electrodialysis reversal, ion-exchange, or distillation.

Lime Softening

Lime softening is a process that uses hydrated lime and soda ash to precipitate out hardness-causing ions from water. It is suitable for centralized water softening plants, but it is not feasible at a residential scale or at multiple smaller locations throughout the distribution system, such as at individual wellheads. Lime (calcium hydroxide, $Ca(OH)_2$) is added to water to remove carbonate hardness, and soda ash (sodium carbonate, Na_2CO_3) is used to remove non-carbonate hardness. The addition of lime and soda ash increases the potential of hydrogen (pH) of the water. For removal of calcium hardness, a dosage of lime and soda ash are added to raise the pH of the water to between 10.3 to 10.6. This causes the precipitation of calcium carbonate ($CaCO_3$), which removes calcium hardness. If magnesium hardness is present at levels that cause scale buildup, excess lime treatment is needed, in which additional lime is added to further raise the pH to 11.[15] This additional increase in pH causes magnesium hydroxide ($Mg(OH)_2$) to precipitate, which removes magnesium hardness. A small portion of the calcium carbonate and magnesium hydroxide precipitate will dissolve back into the water, resulting in a remaining hardness at equilibrium of about 50 to 85 mg/l as $CaCO_3$. This process is shown in Figure 3.9.

Once calcium and magnesium have been sufficiently precipitated out of the water, the settled solids are removed, leaving the remaining clear water at a pH of around 10.3 to 11, depending on whether excess lime treatment was needed to precipitate magnesium. The pH needs to be lowered before entry into the distribution system, which is commonly accomplished with recarbonation. Recarbonation adds carbon dioxide into the water to reduce the pH to between approximately 8.3 to 8.7.[16] Water with higher pH is too saturated with calcium carbonate and it will precipitate out in pipes and equipment, creating excess scale that can reduce flow capacity, as shown in Figure 3.10. Conversely, water with lower pH is under-saturated with calcium carbonate and will remove existing protective scale in pipes and equipment, potentially leading to leaching of lead, copper, and other metals into the water.

The lime sludge that is removed from settling basins needs to be disposed of or processed for beneficial use, as discharging directly into a lake or stream is prohibited. Lime sludge commonly is piped into a lagoon to reduce the moisture content by evaporation. Once sufficiently reduced, the lime sludge can either be disposed of in a municipal solid waste landfill or used beneficially. Treatment plants located near agricultural

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[15] *Magnesium hardness at more than 40 mg/l as $CaCO_3$ causes scale build-up in water heaters at normal operating temperatures. This is the general threshold for when magnesium hardness needs to be removed. Minnesota Rural Water Association, "Minnesota Water Works Operations Manual," 2020.*

[16] Ibid.

areas could supply lime residue to agricultural producers for land application onto farm fields, which provides calcium for crops and helps neutralize soil acidity. For treatment plants located near mining sites, the sludge could potentially be disposed of into the mines. Disposal into mines offers the benefit of neutralizing the acidic water that often leaches out of the mine and causes water quality problems.[17] Lime sludge can also be processed for use in construction, cement manufacturing, wastewater treatment, and sulfur oxides (SO_x) control from coal combustion.[18] The extent of processing and moisture removal will vary depending on the intended use of the lime sludge and the specific characteristics of the sludge.

Costs for constructing and operating lime softening plants vary substantially based on numerous factors,[19] however, generally lime central softening is three to four times more cost effective as a chloride reduction strategy than removal of chloride at WWTPs when considering unmitigated home-based ion-exchange water softening.[20] When compared to RO central softening, which will be discussed further in the next section, lime softening is generally more cost effective for larger communities, while RO softening is considered more cost effective for smaller communities. [21,22] Commission staff reviewed cost data from multiple projects and studies to develop a range of capital costs standardized by population. Table 3.4 summarizes this review. Capital costs per capita can differ greatly based on population size, where plants serving larger communities will benefit from economies of scale, thus reducing the per capita cost. Source water quality also has an impact on the cost of lime softening at a municipal plant. Plants with source water that contains high levels of suspended solids or other contaminants may require pretreatment processes, which will increase the cost. Additionally, the amount of hardness in the source water impacts cost, where harder source water may require more treatment and potentially a larger facility. The cost data presented in Table 3.4 vary substantially. This data came from literature review and personal communications and are based solely on cost and population data; they do not include any additional factors or characteristics that

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[17] *A National Drinking Water Clearinghouse Fact Sheet,* Tech Brief Eight: Lime Softening*, June 1998.*

[18] *R.J. Baker, J. van Leeuwen, and D.J. White, "Applications for Reuse of Lime Sludge from Water Softening," Iowa State University, July 2005.*

[19] *Minnesota Pollution Control Agency, "Alternatives for addressing chloride in wastewater effluent," December 2018.*

[20] *B. Bakshi, E.M. Doucette, and S.J. Kyser, 2021,* op. cit.

[21] *For the purpose of this analysis, smaller communities are those with a served population under 9,000 people and larger communities are those with a served population of 9,000 or greater.*

[22] *Bakshi et al., 2021*, op. cit.

can impact cost as previously discussed. To obtain more specific cost data, a municipality or utility would need to complete a cost estimate for their specific service area, facility, and water source.

Reverse Osmosis

Reverse osmosis (RO) systems for centralized softening function in much the same way as described previously for dissolved solids removal at wastewater treatment plants, where the feed water is forced under pressure through a semipermeable membrane that passes water molecules but rejects hardness-causing ions and other dissolved solids, as shown in Figure 3.4. For treatment of raw drinking water, the use of RO for removal of hardness should not generate any chloride. The waste stream from centralized softening RO can therefore be routed to the wastewater treatment plant. The calcium and magnesium in the concentrate end up in the WWTP effluent, as occurs in the case of the waste brine from point-of-entry ion-exchange softeners, however the RO concentrate does not contain chloride. Conveyance of the RO concentrate to the WWTP can be problematic, as high levels of hardness can lead to rapid scale buildup in pipes and pumps in the conveyance system and at the facility reducing flow capacity, increasing maintenance costs, and potentially shortening the lifespan of the infrastructure.

Reverse osmosis systems have high removal efficiencies and can effectively eliminate many constituents other than hardness, including nitrates, arsenic, iron, ammonia, PFAS, and radium. Such pure water, devoid of hardness, can cause serious issues in the drinking water distribution system including removal of scale in piping that protects the water from lead exposure. To prevent against scale corrosion, a degree of hardness must be added back into the RO permeate to achieve the necessary level of hardness in the finished water. This is accomplished through bypassing a portion of the raw source water around the RO system and blending it with the treated permeate, reintroducing a specified level of hardness. The portion of flow that bypasses the RO system depends on the original hardness of the source water, the desired hardness of the finished water, and the profile of other constituents present in the source water. Achieving the correct level of hardness in the finished water can be difficult depending on the presence of other constituents in the source water. Higher concentrations of other constituents to be removed can require an increasingly large portion of the inflow, if not all, to pass through the RO system, producing increasingly pure permeate. Reintroducing the needed hardness via bypass and blending also reintroduces a portion of the other constituents, potentially exceeding allowable concentrations of regulated contaminants based on drinking water standards. Additionally, maintaining the level of hardness needed to protect scale in the water distribution system may mean a continuation of some degree of point-of-entry softening at homes and businesses.

In addition to influencing the portion of flow needed to be passed through the RO system and the extent to which blending can occur, other constituents in the source water can impact the function and maintenance of an RO system. Metals present in the source water can cause damage to the RO system when the metals are in an oxidized state. This can be a significant threat to the RO system, as only a small amount of oxidized metal can cause expensive damage.[23] Calcium chloride can be added to the raw water to alleviate this risk, which can add maintenance costs and will add chloride into the water. Metals in the source water that are in an unoxidized state do not pose a hazard to RO systems and can be effectively removed by the membranes.

One of the major drawbacks of reverse osmosis systems is the amount of water that is wasted. Generally between 10 to 25 percent of the inflow ends up in the reject waste stream.[24,25] This puts additional demand on the groundwater supply, as maintaining the existing municipal water demand requires increasing the amount of water drawn from source wells. Consequently, the hydraulic loading to the wastewater treatment plant also increases due to receiving both the waste flow from the RO system and existing municipal wastewater flows. Increasing the WWTP hydraulic loading by up to 25-percent, depending on the source water chemistry and other factors, can potentially create additional cost considerations if the plant would need additional capacity. Another disadvantage of reverse osmosis systems is the amount of energy required for operation. RO systems require substantial amounts of energy to constantly generate the pressure needed to force the water through the membranes. The amount of energy needed can vary significantly depending on the amount of flow being treated, the specific constituents in the source water, and their respective concentrations. Additionally, the lifespan of RO membranes is approximately one to two years, which is appreciably shorter than the approximate ten year lifespan of EDR membranes. [26] More frequent replacement of membrane units will incur additional costs.

Commission staff reviewed capital cost data for construction of reverse osmosis central softening plants from literature sources, completed projects, and supplier estimates. The costs were standardized by

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[23] *Personal communication with Snyder & Associates, February 2024*.

[24] *Snyder & Associates, "*Water Softening & the Harmful Impacts on Wastewater Treatment*," 2024*.

[25] *Barr Engineering Co., "*Engineering Cost Analysis of Current and Recently Adopted, Proposed, and Anticipated Changes to Water Quality Standards and Rules for Municipal Stormwater and Wastewater Systems in Minnesota," *February 2017*.

[26] *Desalt EDR, "*Understand the Basics of Electrodialysis Reversal (EDR): A Complete Guide," *March 2023*.

population and presented on a per capita basis, as summarized in Table 3.5.[27] The per capita capital costs varied significantly for the dataset reviewed. Costs are highly sensitive to case-specific factors such as the source water quality, total flow through the plant, and the target hardness level to be achieved by the treatment. Source water with high levels of suspended solids or other contaminants may require pretreatment processes, which add additional costs. Additionally, feed flows that contain high concentrations of dissolved solids require higher operating pressure and more energy, along with potentially requiring additional treatment cells. While increased operating pressure and energy may not drastically impact capital costs, this can be expected to increase operation and maintenance costs. Larger plants that handle higher flow rates for larger populations benefit from economies of scale, where the per capita capital costs are generally lower than that for a similar plant of smaller size.

Electrodialysis Reversal

Electrodialysis reversal (EDR) utilizes electrical charge and semipermeable membranes to remove ions from water. As discussed previously in this chapter, electrodes attract ions of opposite electrical charge and trap the ions between membranes, creating separate clean permeate flows and concentrated reject waste flows. This process is shown in Figure 3.8. To reduce fouling and improve the efficiency and lifespan of EDR systems, pretreatment can be used upstream of EDR processes to remove organics and larger solids. However, EDR is less prone to fouling and less dependent on pretreatment than reverse osmosis systems. The use of voltage differential to *draw* ions into the membranes (EDR) rather than pressure to *force* ions into the membranes (RO) results in less fouling from constituents with a neutral charge. Additionally, the periodic reversal of polarity of the electrodes further dislodges buildup of ionic materials and breaks up scale before it can accumulate to damaging amounts. Beyond the removal of hardness-causing calcium and magnesium ions, EDR systems also remove phosphorus, nitrogen, mercury, nitrate, sulfate, arsenic, and other charged constituents.

For water treatment EDR softening, like reverse osmosis and lime softening, does not produce chloride as a waste product. The waste stream can be conveyed to the wastewater treatment facility and the calcium and magnesium can be discharged into the receiving waterbody. Similar to the waste stream of RO softening systems, EDR waste flow can be challenging to convey due to the high degree of hardness that causes rapid scale formation within pipes. This can lead to increased maintenance costs to control the amount of scale buildup and maintain flow capacity within the pipes. Pumps and other equipment will also

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[27] *Of the twenty data points, nineteen represent construction of a new plant and one is for adding RO equipment to an existing facility.*

need to be maintained to control scale buildup, and the lifespan of the equipment may be shortened due to the excessive hardness in the EDR waste flow.

Similar to reverse osmosis, treating source water via EDR can achieve a very high removal efficiency, often exceeding 90-percent removal.[28] While this very pure water can be beneficial for certain uses such as in various industries, pumping such pure water into the municipal water distribution system can have serious health risks. The lack of hardness in the water creates an affinity for those minerals, which leads to dissolution of the scale within the pipes back into the drinking water. Scale in distribution system piping is an important barrier that prevents lead and copper from leaching from the pipes into the water. To alleviate leaching of metals, a level of hardness needs to be in the water to maintain the protective scale. This can be accomplished by running the EDR system to remove the desired amount of hardness. Factors such as the amount of voltage differential in the electrodes, the amount of power supplied to the system, and the number of electrodialysis cells can impact the overall hardness removal efficiency. While blending untreated water with fully treated pure water can also create the desired hardness in the finished water, this may require higher energy use and costs to achieve the higher level of purification.

One of the disadvantages of EDR systems for treating source water is that substantial doses of certain added treatment chemicals can severely damage the membranes, leading to expensive repairs or replacement. Alum, for example, which is used to settle out suspended solids, can be particularly damaging to the EDR membranes.[29] When the source water is relatively clean of suspended solids and organics, large amounts of feed chemicals are not needed, reducing this damage risk. Another disadvantage of EDR systems is the amount of water that is wasted in the reject concentrate stream. Similar to reverse osmosis, wasted water from EDR systems can be over 20 percent of the inflow. To meet the existing municipal water demands, the amount of water drawn from the source wells would need to increase. This increase in source water pumping puts additional demands on groundwater resources and increases the hydraulic loading to the wastewater treatment plant.

An advantage of EDR systems over RO is that the membrane lifespan is approximately ten years when maintained and operated correctly, whereas the lifespan of the membranes in reverse osmosis systems is approximately one to two years.[30] This difference is primarily due to the electrodialysis current reversal step

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[28] Ibid.

[29] *S. Adham* et al., *September 2009,* op. cit.

[30] *Desalt EDR, March 2023,* op. cit.

in EDR systems that cleans the membrane surfaces. Additionally, EDR systems are generally more energy efficient than other separation processes, which can result in lower operating costs.

While EDR can successfully remove ions and other dissolved solids and has distinct advantages over other technologies, it is being implemented less frequently in new water treatment facilities than in years past. Suppliers and consultants with which Commission staff communicated indicated that they do not expect electrodialysis reversal to be installed in many future water treatment plants and in some cases do not offer it as an alternative. As such, Commission staff were unable to obtain cost data for constructing and operating an EDR central softening facility. As with other technologies, it would be expected that costs would vary significantly depending on the source water quality and other factors specific to each location and community needs. As with any centralized softening option, a municipality or utility district will need to complete a preliminary study prior to proceeding with a centralized EDR softening facility.

Ion-Exchange

Ion-exchange softening at a centralized plant works in the same general way that household point-of-entry ion-exchange water softeners work, where an exchange resin captures calcium and magnesium ions and releases sodium ions. When the ion exchange resin in saturated with calcium and magnesium, it is regenerated with a sodium chloride salt brine, where the sodium ions replace the calcium and magnesium on the resin, and the chloride ions pass into the waste stream along with the dislodged calcium and magnesium. The ion exchange and regeneration processes are shown in Figure 3.2. While ion-exchange softening at a centralized plant still generates chloride, it can reduce the amount of chloride produced compared to ion-exchange softening in homes and businesses. Point-of-entry ion-exchange softening typically removes nearly all the hardness from the water, however between 100 and 150 mg/l of hardness (as $CaCO_3$) is generally considered acceptable for household use.[31] Softening water in a centralized facility allows for bypassing a portion of source water inflow, which can be blended with the softened water to achieve a resulting hardness within the acceptable range and reduce the amount of regeneration salt required. Additionally, the hardness in the water entering the distribution system can maintain the protective scale within the pipes, safeguarding against heavy metals leaching from the pipes.

The chloride-containing waste brine from ion exchange softening would need to be contained, processed, and disposed of appropriately, as it cannot be discharged directly into surface waters due to its high chloride levels and toxicity to aquatic organisms. An important distinction between ion-exchange softening done

[31] *Barr Engineering Co, 2017,* op. cit.

centrally rather than at the point-of-use is that the waste stream is generated at one central location, making it feasible to capture the majority of the chloride-containing waste and prevent it from entering the wastewater treatment plant and ultimately the receiving waterbody. The waste brine from a central ion-exchange softening plant would need to be dewatered to reduce the volume and make disposal more cost effective, as brine disposal can be very expensive due to the large volumes of waste produced.

Ion exchange brine minimization can be accomplished by evaporation and crystallization, which reduces the water content of the brine and consequently reduces the volume. Evaporation concentrates the brine by utilizing heat to boil away excess water. Once the brine has been sufficiently concentrated, a crystallizer can be used to produce solid salt crystals. Evaporation and crystallization are often used in combination with each other to yield the highest degree of brine volume reduction. Evaporation processes are very energy intensive due to continually heating the brine to the required temperature. This can substantially increase operating costs as well as increase greenhouse gas emissions of the water treatment plant.

Once the ion-exchange brine is fully reduced, it can either be disposed of or processed for beneficial reuse. If the brine is reduced to a solid salt crystal form, the most suitable disposal option is in a landfill. The solid waste would need to be characterized to assure that it complies with rules governing accepted materials for the facility. It is important to consider the long-term fate of the chloride disposed of in a landfill. While well-designed landfill liners can remain intact for centuries,[32] ultimately liner failure and contamination of groundwater will occur. Conversely, brine that has been reduced to a concentrated liquid would not be suitable for landfill disposal. Deep well injection could be an option for concentrated liquid brine, however deep well injection is not legal in Wisconsin. Therefore, for well injection disposal the liquid waste brine would need to be transported out of state at a significant cost.

Another option for handling the waste brine is to process it for beneficial reuse. Brine in liquid form can be used for winter deicing, either as a direct application to roadways prior to a storm event or as a prewet applied to rock salt prior to application, thus reducing the overall amount of chloride introduced into the environment. Waste brine that has been reduced to a salt crystal can similarly be used as rock salt for winter deicing. In order to be used as a deicing product, ion exchange waste brine must be analyzed to determine that no substances are present in the final product that are harmful or otherwise undesired. In cases where undesired substances are present in the brine or rock salt, further processing may be needed before deicing use. Additionally, adequate space would be needed to store the product prior to distribution for use. Space

[32] *R.K. Rowe and H.P. Sangam, "Durability of HDPE geomembranes,"* Geotextiles and Geomembranes, *20: 77-95, 2002.*

demands would likely be larger during summer months when no winter deicing occurs and the waste brine deicing products accumulate.

Commission staff reviewed the literature for available data on capital costs for constructing an ion-exchange centralized softening plant. Available data was limited, but costs can be expected to vary substantially based on the source water quality, the initial hardness level, presence of other constituents in the source water, waste brine disposal method, and various other factors. Prior to pursuing centralized ion-exchange softening, a municipality or utility district should complete a preliminary feasibility study.

Distillation

Distillation is one of the oldest water treatment methods and can remove most impurities from water. In this process, the source water is boiled to create steam, which is captured in a cooling chamber where it comes into contact with condensing coils and returns to liquid form. Most compounds in the source water remain in the boil chamber, resulting in up to a 99.5 percent removal efficiency.[33] Distillation systems effectively remove dissolved solids, including hardness-causing ions; fluoride; nitrate; many organic compounds; heavy metals; and other constituents. The boil stage of the process also inactivates microorganisms. Some volatile organic compounds (VOCs) are not removed from conventional distillation systems. VOCs with boiling points at or below that of water also vaporize in the boil stage and get condensed along with the water steam, resulting in the presence of VOCs in the finished water. Additional design considerations can be implemented to remove VOCs prior to the condensation stage, such as activated carbon filters, gas vents, and creating separate condensation chambers for the water steam and VOCs, respectively.

Continued operation of the distillation system will concentrate contaminants and other constituents in the liquid in the boil chamber. This liquid needs to be periodically drained for disposal. For distillation systems operated for hardness removal only, the waste stream can be conveyed to the WWTP, as it contains concentrated levels of natural hardness. Similar to RO and EDR systems, the waste flow can be challenging to convey due to the high concentrations of calcium and magnesium that cause rapid scale buildup in pipes, which can reduce flow capacity, increase maintenance, and potentially shorten the lifespan of the conveyance system equipment. The distillation concentrate should be periodically analyzed to identify the constituents present. The presence of certain toxic substances may require a different disposal method.

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[33] *University of Nebraska-Lincoln, "*Drinking Water Treatment: Distillation*," December 2013*.

Operation of a distillation water treatment system can be very costly, largely due to the vast amount of energy needed to constantly boil the raw source water. The amount of energy required is proportional to the amount of water treated. Larger treatment plants will likely experience significantly higher operation cost compared to smaller plants. Additionally, regular maintenance is required to keep the system functioning effectively. The heat and concentration of hardness in the boil chamber can lead to rapid precipitation of scale, which can be harmful to the system and would need regular maintenance. While distillation is technologically feasible, the high operation cost makes it impractical on a municipal scale.

Considerations for Centralized Softening at Water Treatment Plants

Centralized softening can be an effective approach for reducing chlorides entering local waterways via wastewater treatment plant effluent by decreasing the need for point-of-entry ion-exchange softeners in homes and businesses. Each alternative for central softening technology has a unique set of considerations and costs as discussed in the preceding sections and summarized in Table 3.6 and Table 3.7. Additional higher-level considerations, such as costs incurred by rate payers and the likelihood of achieving chloride discharge requirements, are also important factors to evaluate.

Reduction in Home and Business Softening

For centralized softening to achieve meaningful chloride reduction to WWTPs, removal or adequate reduction in use of at-home water softeners must occur. Ideally a central softening plant would be operated to remove hardness to the extent that at-home softeners would not be needed, however this may not always be practical. A certain level of hardness causes precipitation of minerals from the water to create the formation of scale. Some scale is essential in existing water distribution systems that have metal pipes, because scale acts as a buffer between the water and the pipes, preventing potential leaching of lead, copper, and other metals into the water that could be harmful for human consumption. Even in newer public distribution systems that do not contain lead, older homes often contain privately owned lead pipes and fixtures that also require a protective layer of scale. A hardness between 100 and 200 mg/l as $CaCO_3$ will maintain scale; lower levels of hardness may be corrosive and remove scale, while higher levels of hardness may cause excess scale buildup.[34] Water in homes and businesses is considered ideally softened when hardness is between approximately 60 and 120 mg/l as $CaCO_3$, however many softeners are operated to

[34] *World Health Organization, "*Guidelines for Drinking-water Quality, Fourth Edition Incorporating the First Addendum*," 2017.*

produce even softer water.[35] The delicate balance between hardness needed for scale in the distribution system and preferred hardness in homes creates a narrow range of hardness at which a central softening plant could potentially safely operate and allow homeowners to fully disconnect their softeners. Additionally, some centralized softening plants may not be able to operate within this range (100-200 mg/l as $CaCO_3$) based on the specific water chemistry and distribution system. Where complete removal of at-home softeners would not be feasible, a reduction in the amount of chloride produced from point-of-entry softeners could nonetheless be achieved via a relative reduction in softener use. Prior to constructing a central softening plant, an analysis must be completed to determine how the change in water chemistry will impact the distribution system and water supply.

A robust public outreach and education program would also need to be considered to inform the public on the responsible use of at-home water softeners if centralized softening is implemented. A major obstacle to reducing chloride from in-home softeners is that homeowners can be hesitant to reduce the level of softening they do in their homes or to disconnect their softener entirely. The reduction in hardness of the supplied water would require homeowners to recalibrate their softeners for the new level of hardness. Softeners that are not recalibrated will run regeneration cycles more frequently than needed, resulting in unnecessary use of salt. In cases where central softening supplies adequately softened water that requires no further softening within homes, homeowners could completely disconnect their softeners. Incentives or municipal regulation and oversight may be needed to facilitate recalibration or removal of point-of-entry water softeners. Municipalities can offer free pickup services for disconnected water softeners to alleviate cost and logistical considerations facing homeowners. Similarly, where a degree of at-home softening is still needed, municipalities can offer services or informational resources to assist residents in optimizing the efficiency of their softeners. Financial incentives could also be used to either remove or optimize softeners as appropriate.

Similarly, homeowners may also need to adjust their expectations for an acceptable level of hardness in their drinking water. Many homeowners are accustomed to the fully softened water produced by most point-of-entry water softeners. In comparison, centrally softened water may not be softened to the same level, as previously discussed, and the increase in hardness is likely to be perceptible.[36] While these increased

[35] *United States Department of Energy,* "Understanding and Dealing With Hard Water," *www.energy.gov/energysaver, accessed on April 16, 2024.*

[36] *Minnesota Pollution Control Agency, December 2018,* op. cit.

levels of hardness are still adequate for appliance health and soap lathering, some homeowners may object to it and require an adjustment period.

While most of the focus of centralized softening is on household water use and the need or desire to have softened water, other water uses do not require softened water, such as irrigation, hose bibs, utility sinks, toilets, and other cold water taps. When softening occurs at the point-of-entry, water for these uses can be plumbed to bypass the softener, resulting in softening only the water that requires it. This would be an expensive retrofit in an existing home or business but could be more easily done during new construction. It would require additional piping which would add some cost.

Costs

Construction of a central softening plant requires a substantial capital cost as well as ongoing operations and management costs. Additionally, distribution system upgrades would be necessary. New infrastructure would be needed to convey the water from the source wells to the central softening plant and to connect the plant to the existing distribution system. As discussed earlier, upgrades to the existing distribution system may also be needed in order to account for water chemistry changes to be able to safely convey the softened water, which may incur further significant capital costs. A portion of these costs would likely be passed on to water utility customers through higher monthly rates. However, these increased fees for rate payers can be offset by the reduction in or elimination of the cost of operating at-home water softeners. The extent of cost savings would depend in part on the degree to which at-home softening is still required. Homeowners can experience savings through reductions in salt purchases for water softeners, less softener energy consumption, less frequent softener replacement expenses, and potentially reduced wastewater fees due to reduced wastewater flows. These savings may counteract the water utility rate increases, resulting in an overall net savings for some users.[37]

Additional potential costs may be incurred with any needed expansion of the hydraulic capacity of the receiving WWTP. As discussed previously, reverse osmosis (RO) and electrodialysis reversal (EDR) central softening systems produce a reject waste stream that can be up to 20 percent of the central softening plant flow, which would need to be routed to the WWTP. Prior to constructing an RO or EDR softening plant, an analysis should be completed to determine whether the WWTP has sufficient hydraulic capacity to handle this added flow. In cases where the WWTP does not have sufficient hydraulic capacity, the plant will need to be upgraded to expand its capacity. This may require a substantial capital cost. In addition to impacting

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[37] *B. Bakshi, E.M. Doucette, and S.J. Kyser, 2021,* op. cit.

the WWTP loading, the softening plant waste flow will also require an increase in source water pumping in order to meet the existing municipal water demand. The impact of this increase in pumping to the groundwater table at the well locations and potential need for additional wells would require further evaluation. Drilling a new well or wells would also have a significant capital cost.

3.5 OTHER MUNICIPAL CHLORIDE REDUCTION ALTERNATIVES

While centralized softening can be an effective method for reducing chloride as discussed in detail in Section 3.4, additional approaches can similarly achieve source reduction. Raw source water can be softened at individual wellheads prior to distribution rather than at a central softening plant. Within households, point-of-entry water softener system efficiency can be improved by calibrating softeners or upgrading older, inefficient systems with newer technology. Water quality trading for chloride could help WWTPs achieve compliance with discharge permit requirements, however the State pollution trading program would first need to be expanded to include chloride trading.

Softening at Wellheads Prior to Distribution

An alternative to centralized softening that also provides softened water to the distribution system is installing softening systems at the source water wellheads. As with centralized softening, this would reduce or eliminate the need for point-of-entry ion-exchange water softeners in homes and businesses. Wellhead softening could be accomplished with the same technologies as used for centralized softening, operated on a smaller and more distributed scale. These technologies are reverse osmosis, electrodialysis reversal, lime softening, and ion-exchange. Many of the considerations for each technology that were previously discussed in the context of central softening are applicable to systems operated at individual wellheads. Positioning multiple systems at spread out locations, however, poses additional considerations and challenges.

Communities with a number of wellhead locations would have multiple systems to maintain and operate, potentially spread out over a broad geographic area. This makes system automation increasingly necessary, as it is not practical to have an operator on site at each location. Of the previously listed alternatives, reverse osmosis offers the possibility for the highest degree of automation. Ion-exchange systems would need to be monitored to assess the available exchange capacity of the exchange resin, and regeneration salts would need to be manually added when depleted. Lime softening systems require operators to monitor the pH of the water and type of hardness present in order to apply treatment doses accordingly. As such, lime softening and ion-exchange are not economically feasible nor operationally viable for systems with multiple wellheads.[38]

While residuals from each treatment alternative were discussed in the context of centralized softening, having multiple treatment systems spread out at various locations pose additional considerations for handling residuals of softening at wellheads. For RO or EDR systems, transmission pipelines would need to be constructed from each wellhead to convey the reject waste flow to the WWTP. This would likely be a much larger and more costly construction project than building a pipeline from a single, centralized plant for communities with a larger number of wellheads. For ion exchange systems, another obstacle to use at individual wellheads is the space needed to construct a facility to store and process the chloride-containing waste brine. Each wellhead site would need to contain a brine minimization system to reduce the volume of waste brine and decrease the cost of brine disposal. The potentially large amount of space needed for a brine minimization system at each wellhead may be another factor that makes ion-exchange an infeasible alternative for use at individual wellheads.

Improve Point-of-Entry Softening Efficiency

Improving the efficiency of private water softening systems in homes and businesses is another method to reduce the amount of chloride entering WWTPs. Ion-exchange water softeners remove hardness-causing calcium and magnesium ions at the water supply entry point of a home or building. An ion-exchange resin is used to capture calcium and magnesium ions from the water, which exchange with sodium ions that get released into the softened water. When the resin gets saturated with calcium and magnesium, a regeneration cycle flushes the system with a sodium chloride brine. The sodium chloride brine dissociates into its constituent ions, where the sodium ions replace the calcium and magnesium ions on the resin beads, and the chloride ions, along with the dislodged calcium and magnesium ions, gets flushed out of the system as wastewater (see Figure 3.2).

Regeneration cycles of older water softeners are typically timer-based, meaning cycles are run at a specified time interval, regardless of whether there is remaining softening capacity in the resin. Newer systems regenerate using demand-based, or metered, cycles, which run after a specified amount of water has passed through the system. Demand-based systems operate more efficiently than timer-based systems, resulting in less salt used and less chloride generated to treat a given amount of water. Timer-based systems become increasingly less efficient during periods of lower water use. In the most extreme cases when no water runs

[38] *Minnesota Pollution Control Agency, December 2018,* op. cit.

through the system, such as when a homeowner is away for an extended period, the timer-based system will continue to regenerate despite there being no use of the system.

Regardless of the type of softener, system calibration is essential to optimizing salt use and reducing chloride waste production. A poorly calibrated softener can be very inefficient, irrespective of softener type. To properly calibrate a softener, the hardness of the source water and the capacity of the water softener must be known. The hardness of the source water can be determined using a test kit. The softener capacity is defined in grains, or grains per pound of salt, and can be found on the softener label or in the specifications. For metered systems, the system capacity in grains can be divided by the water hardness in grains per gallon to give the number of gallons the system can treat between regeneration cycles. Calibrating timer-based systems requires an additional step of defining the amount of water used per person per day in the household. A generally accepted value for water use is 70 gallons per person per day.[39,40] To calibrate the softener, the per person water use is multiplied by the number of people in the household, giving the amount of water passing through the softener per day. That number is multiplied by the source water hardness to get the total grains of hardness passing through the system on a daily basis. Lastly, to provide the number of days at which to set the regeneration cycle, the softener capacity is divided by the grains of hardness that pass through the system per day. Once a softener is properly calibrated, the hardness of the pre-softened water should be tested periodically and the softener recalibrated as needed in response to changes in hardness. Similarly, for timer-based softeners, the system should also be recalibrated when the number of people living in the household changes. Homeowners can reduce the amount of salt used in their water softener by installing a bypass valve or operating a built-in bypass value. A bypass valve allows a portion of untreated source water to bypass the softener and be blended with the softened water, providing finished water with a certain amount of hardness. The bypass valve can be operated to produce a blend that has a level of hardness that is acceptable to the homeowner while reducing the amount of salt used.

Policy methods can be utilized to make efficient water softeners more prevalent and easier to obtain. Some municipalities in the State have developed rebate programs for installation of higher efficiency softeners to help offset the cost of upgrading their WWTP. Similarly, programs could be created that offer softener

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[39] *Southeastern Wisconsin Regional Planning Commission, "*A Regional Water Supply Plan for Southeastern Wisconsin*," December 2010.*

[40] *This value could be refined based on actual water use in a given household. Households with young children, for example, may use more water 70 gallons per person per day.*

calibration services to residents at no or low cost. From a regulatory perspective, state plumbing code could mandate high efficiency softeners be installed during new builds, sale of a home, and at time of replacement.

Water Quality Trading Programs

Water quality trading is a market-based approach to reducing pollution, where a point source discharger can purchase credits from a credit generator. Credit purchasers are typically municipal wastewater treatment facilities or private industries that face high pollutant reduction costs to comply with Wisconsin Pollutant Discharge Elimination System (WPDES) permit requirements. Credit sellers are often landowners or agricultural producers that can install water quality best management practices (BMP) on their land to reduce their own pollutant load, generating a credit. Credit generators can also be a point source discharger with unused permit discharge capacity. When credits are purchased, the seller agrees to implement and maintain a BMP on their land that offsets the amount of pollutant discharge exceedance by the buyer.

The amount of pollutant the seller is required to reduce to offset the excess pollutant of the buyer is determined by a trade ratio. The trade ratio functions like a multiplier and is always a value greater than one, which results in a larger amount of pollutant reduction. For example, a trade ratio of 2:1 means that two pounds of pollutant reduction needs to be achieved by the credit-generating BMP for every one pound of pollutant reduction required at the credit buyer facility. The ratio value is computed to ensure the amount of pollutant reduction from the credit-generating BMP has the same effect as would occur if the reduction occurred at the point source facility.[41] Factors that determine the trade ratio are the distance between the credit generator and credit user, chemical form of the traded pollutant, modeling uncertainty in computing load reductions, and habitat benefits. Trade ratios can be reduced by having credit generators located upstream of the credit buyer, using BMPs with a high probability of removal success, and selecting a credit generator that is a point source discharger rather than a nonpoint source.[42]

To assist with the buying and selling of water quality pollution credits, 2019 Wisconsin Act 151 mandated the Wisconsin Department of Administration to contract with a third party to operate a centralized clearinghouse to manage water quality trading credits[43]. The clearinghouse connects credit sellers and

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[41] *Wisconsin Department of Natural Resources,* "Water Quality Trading" factsheet*, accessed April 9, 2024*.

[42] Ibid.

[43] *Southeastern Wisconsin Regional Planning Commission,* "Legal and Policy Considerations for the Management of Chloride*," April 2024*.

buyers, establishes pollutant reduction projects, maintains a bank of credits available for sale, and oversees contracts for sale of credits. Upon receipt of a request to buy credits, the clearinghouse will determine whether adequate credits are available to meet the request. In cases where additional credits are needed, the clearinghouse will identify credit-generating projects to satisfy the request.

At the time of writing, chloride is not eligible for water quality trading for WPDES permit requirements.[44] Only phosphorus and total suspended solids (TSS) are eligible for trading in Wisconsin. As such, water quality trading is not currently an option for chloride reduction. However, should the water quality trading program be augmented to include chloride trading, trading could become a viable reduction option at that time. Potential chloride trading programs could include a trade between a WWTP and a municipality to reduce winter deicing chloride loading. This could be achieved by reducing salt use, switching a portion of deicing from rock salt to salt brine, or by using prewet on rock salt application. In this case the WWTP utility would pay for the deicing equipment upgrades and personnel training to facilitate the transition. A WWTP could also potentially work with homeowners to optimize water softeners and upgrade older, inefficient units to reduce chloride generation from homes and businesses.[45] The WWTP would fund the development and implementation of the softener optimization informational program as well as potentially subsidize service work and upgrading to newer, more efficient softeners. More detailed studies would be needed to ensure sufficient chloride loading reduction would occur to make these viable trade options.

[44] *Electronic mail communication with the Wisconsin Water Quality Trading Clearinghouse, April 2024.*

[45] *Some WWTPs with chloride variances in the Region have implemented similar public outreach and household water softener optimization programs to reduce chloride loading at the WWTP.*

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Chapter 3

MUNICIPAL WATER AND WASTEWATER UTILITIES

TABLES

Table 3.1
Facilities in Southeastern Wisconsin with Individual Chloride Variances: January 2024

Facility Name	Permit Number	County
City of Brookfield	0023469-09	Waukesha
East Troy Wastewater Treatment Facility	0020397-10	Walworth
Fontana-Walworth Water Pollution Control Commission	0036021-07	Walworth
Hartford Water Pollution Control Facility	0020192-09	Washington
Norway Sanitary District No. 1	0031470-08	Racine
Oconomowoc Wastewater Treatment Plant	0021181-09	Waukesha
Paddock Lake Wastewater Treatment Facility	0025062-10	Kenosha
Slinger Wastewater Treatment Facility	0020290-10	Washington
Sussex Wastewater Treatment Facility	0020559-08	Waukesha
Twin Lakes Wastewater Treatment Facility	0021695-10	Kenosha
Village of Union Grove	0028291-10	Racine
City of Waukesha	0029971-09	Waukesha
City of West Bend	0025763-11	Washington
Yorkville Sewer Utility District No. 1	0029831-09	Racine

Source: Wisconsin Department of Natural Resources

Table 3.2
Summary of Considerations for Chloride Removal Technologies at WWTPs

Consideration	Reverse Osmosis	Electrodialysis Reversal	Ion-Exchange
Removes other compounds found in wastewater	X	X	
Pretreatment required[a]	X	X	X
Waste is suitable for disposal at landfill[b]	X	X	X
Waste may have beneficial reuse	X	X	
Requires waste volume reduction	X	X	X

[a] *Pretreatment is required to achieve optimal removal efficiency and recovery rate.*

[b] *When paired with brine volume reduction processes.*

Source: SEWRPC

Table 3.3
Summary of Costs for Chloride Removal by Reverse Osmosis at Municipal Wastewater Treatment Plants

	Capital Costs[a] (Millions of dollars/MGD[b])	O&M Annual Costs[a] (Millions of dollars/MGD)
Minimum	7.0	1.0
Maximum	17.0	5.0
Arithmetic Mean	12.8	3.0
n-Value	5	4

Note: Costs presented in this table are for reverse osmosis systems paired with evaporation and crystallization brine reduction systems. Additional information can be found in Appendix X.

[a] *All costs are expressed in year 2023 dollars.*

[b] *Million gallons per day.*

Sources: AECOM, Minnesota Pollution Control Agency, and SEWRPC

Table 3.4
Summary of Capital Costs for Centralized Lime Softening

	Capital Costs (Dollars per Capita)[a]
Minimum	$220
Maximum	$29,300
Median	$640
Arithmetic Mean	$3,380
n-Value	25

[a] *All costs are expressed in year 2023 dollars.*

Source: Barr Engineering Co.; Bolton and Menk, Inc.; Minnesota Pollution Control Agency; Snyder & Associates; and SEWRPC

Table 3.5
Summary of Capital Costs for Centralized Reverse Osmosis Softening

	Capital Costs (Dollars per Capita)[a]
Minimum	$70
Maximum	$7,810
Median	$2,020
Arithmetic Mean	$2,310
n-Value	20

[a] *All costs are expressed in year 2023 dollars.*

Source: AECOM; Bolton and Menk, Inc.; The Messenger; Minnesota Pollution Control Agency; Newterra Corporation; Snyder & Associates; and SEWRPC

Table 3.6
Summary of Considerations for Central Softening Technologies

Consideration	Lime	Reverse Osmosis	Electrodialysis Reversal	Ion-Exchange	Distillation
Produces chloride in waste flow				X	
Feasible on smaller scales		X	X	X	X
Feasible at individual wellheads		X	X		X
Effective at removing chloride		X	X	X	X
Waste is suitable for disposal at WWTP[a]		X	X		X
May require construction of conveyance system for waste flow to WWTP		X	X		X
May require WWTP hydraulic capacity to be increased		X	X		X
Pretreatment required[b]	X	X	X		
Waste may have beneficial reuse	X			X	
Requires waste volume reduction	X			X	
Increases amount of source water pumped		X	X		
Source water quality and level of hardness impact efficiency[c]	X	X	X	X	

[a] *Assuming only hardness removal and no presence of any substances prohibited by the WWTP in the source water.*

[b] *Pretreatment would be needed to achieve optimal removal efficiency if organic materials or other solids are sufficiently present in the raw source water.*

[c] *Presence of other constituents in the source water or higher levels of hardness can either reduce efficiency or increase operation cost to achieve the desired efficiency.*

Source: SEWRPC

Table 3.7
Cost Comparison of Water Treatment Technologies

Technology	Capital Cost	Operating Cost	Limitations
Lime Softening	$$$$$	$$$	Storage of lime; Lime sludge waste; Large footprint
Reverse Osmosis	$$$	$$$	15 to 25 percent loss to concentrate stream
Electrodialysis Reversal	$$$	$$$	15 to 25 percent loss to concentrate stream
Ion-Exchange	$$	$$	Chloride disposal
Distillation	$$$$$	$$$$$	High energy use; Residual disposal

Source: Snyder & Associates and SEWRPC

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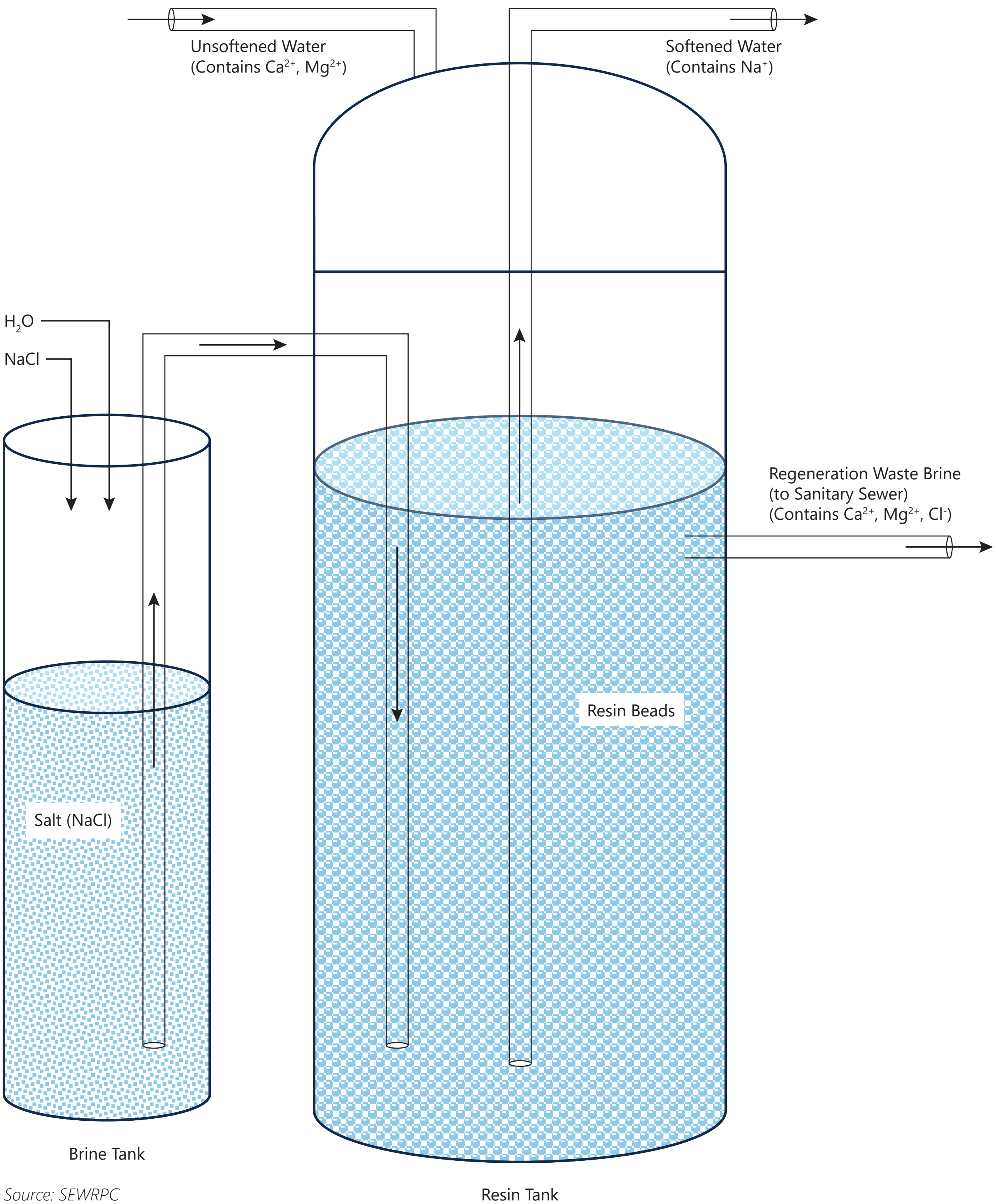
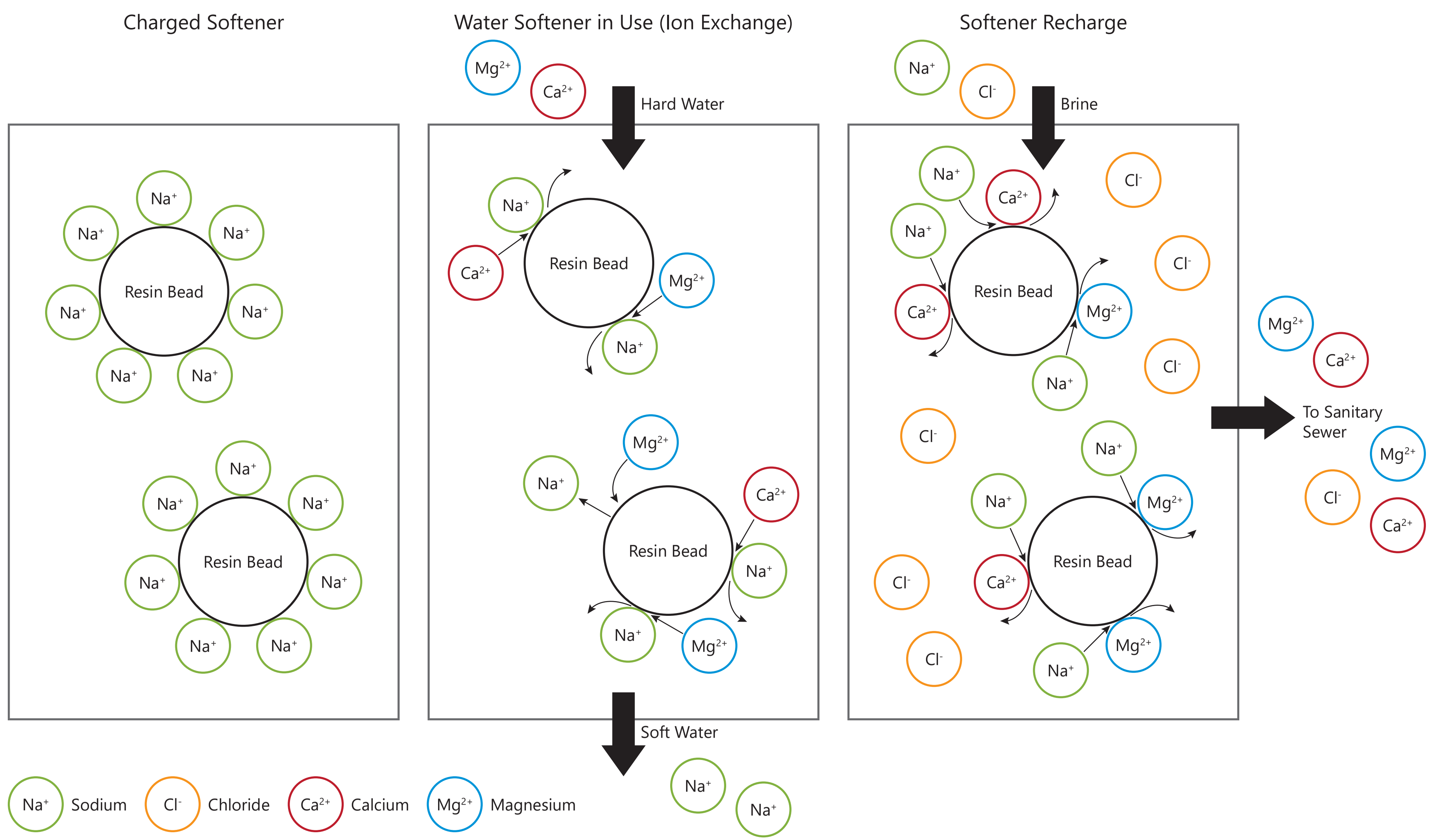
FIGURES

Figure 3.1
Ion-Exchange Water Softening Process



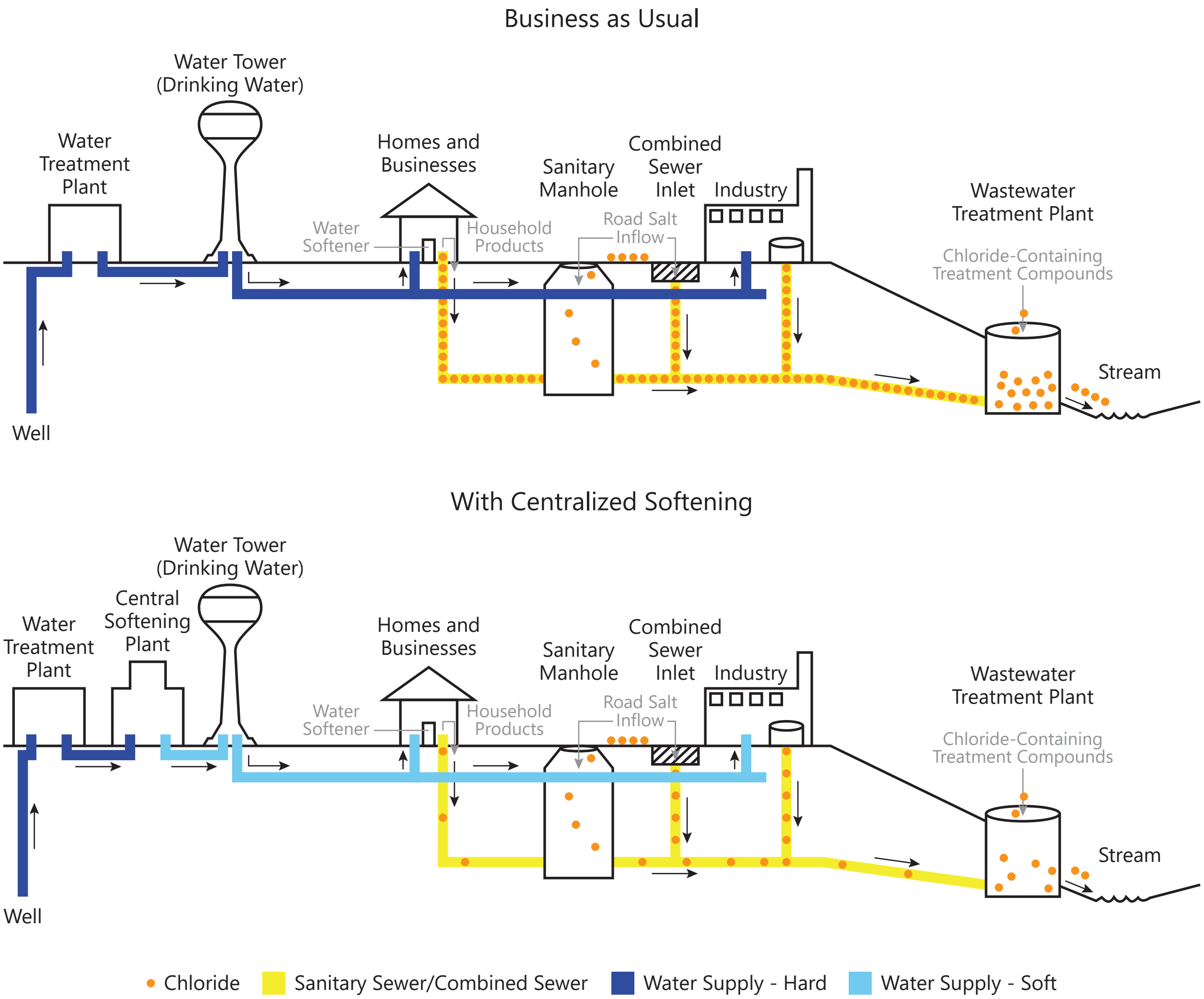
Source: SEWRPC

Figure 3.2
Ion-Exchange Water Softener Use and Regeneration Processes



Source: SEWRPC

Figure 3.3
Chloride Sources to Wastewater Treatment Plants



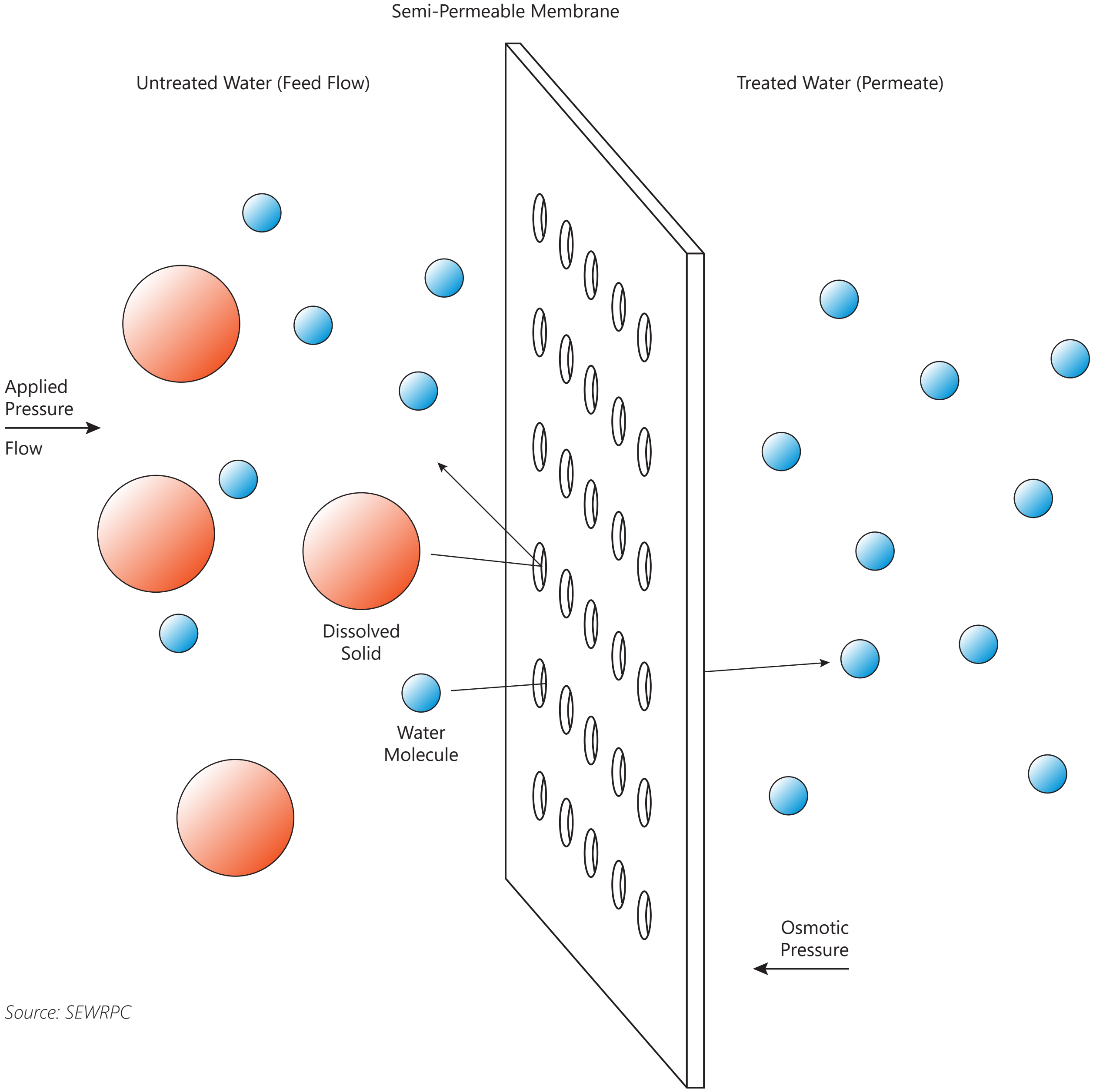
Note: The chloride represented in the diagram is not drawn to scale with respect to comparing the magnitude of chloride produced from one source to another. However, the density of chloride dots is intended to depict changes in chloride production between the two scenarios.

The diagram represents a community with a combined sewer. For communities with separate storm and sanitary sewers, road salt inflow into the sanitary sewer system only occurs via infiltration and inflow through defects at manholes and in the pipes.

Natural levels of background chloride may exist in the water supply and is not represented in the figure.

Source: SEWRPC

Figure 3.4
Reverse Osmosis Process

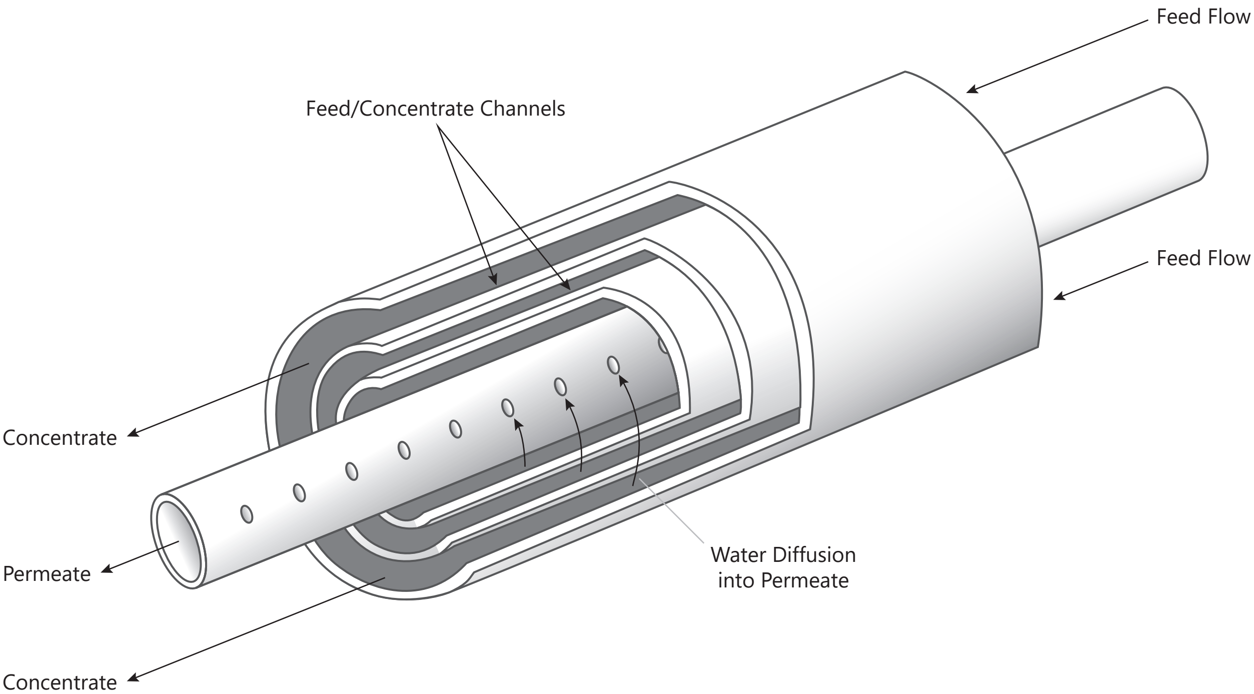


Source: SEWRPC

Figure 3.5
Spiral-Wound Reverse Osmosis Module

Source: Wikimedia User David Shankbone

Figure 3.6
Spiral-Wound Reverse Osmosis Design

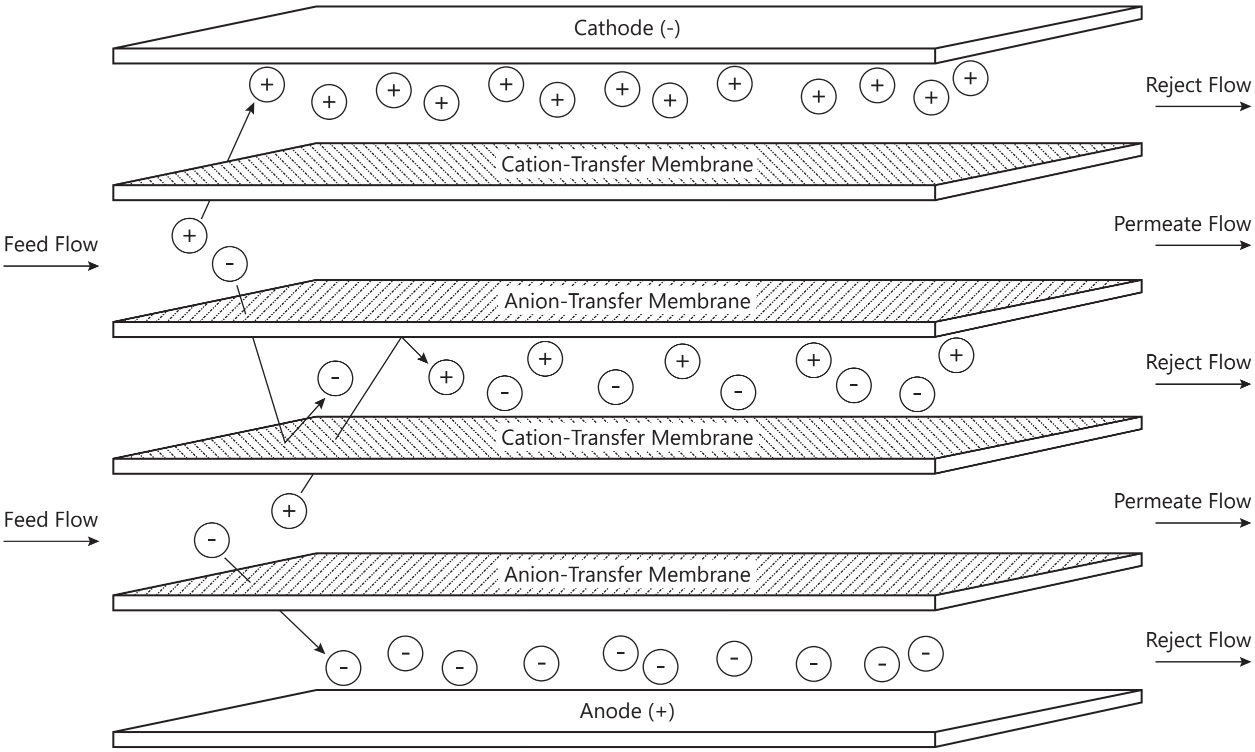


Source: SEWRPC

Figure 3.7
Reverse Osmosis Plant

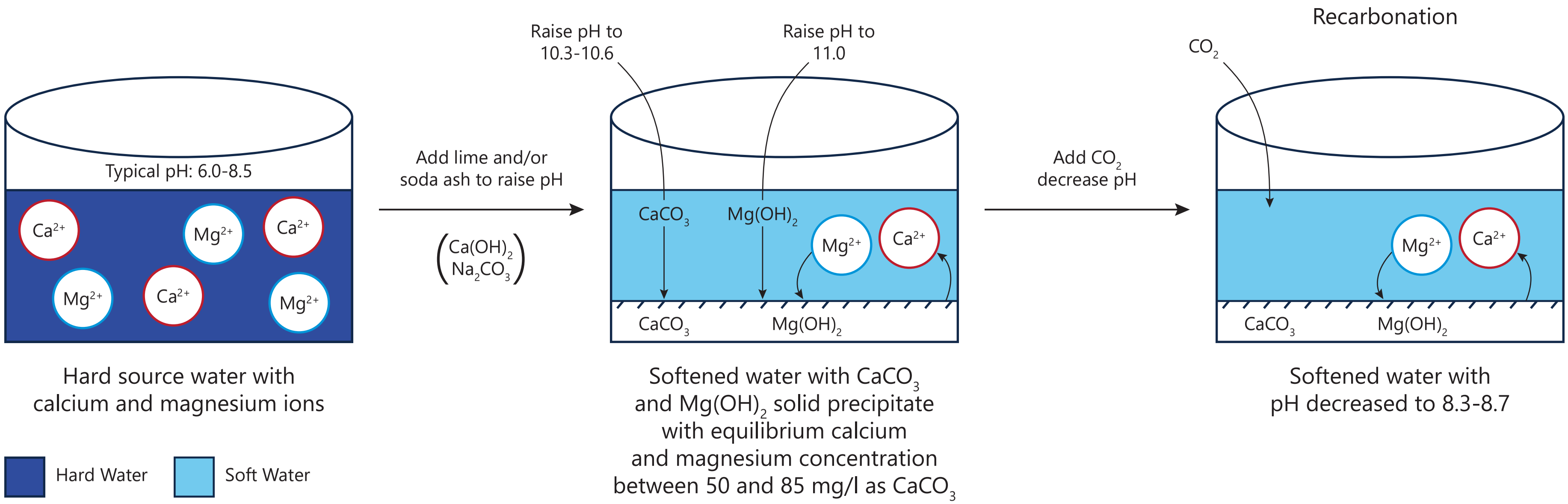
Source: Wikimedia User Z22

Figure 3.8
Electrodialysis Reversal Process



Source: SEWRPC

Figure 3.9
Lime Softening Process



Source: SEWRPC

Figure 3.10
Scale Build-Up in a Water Pipe

Source: Wikimedia User Alexander Yurievich Lebedev

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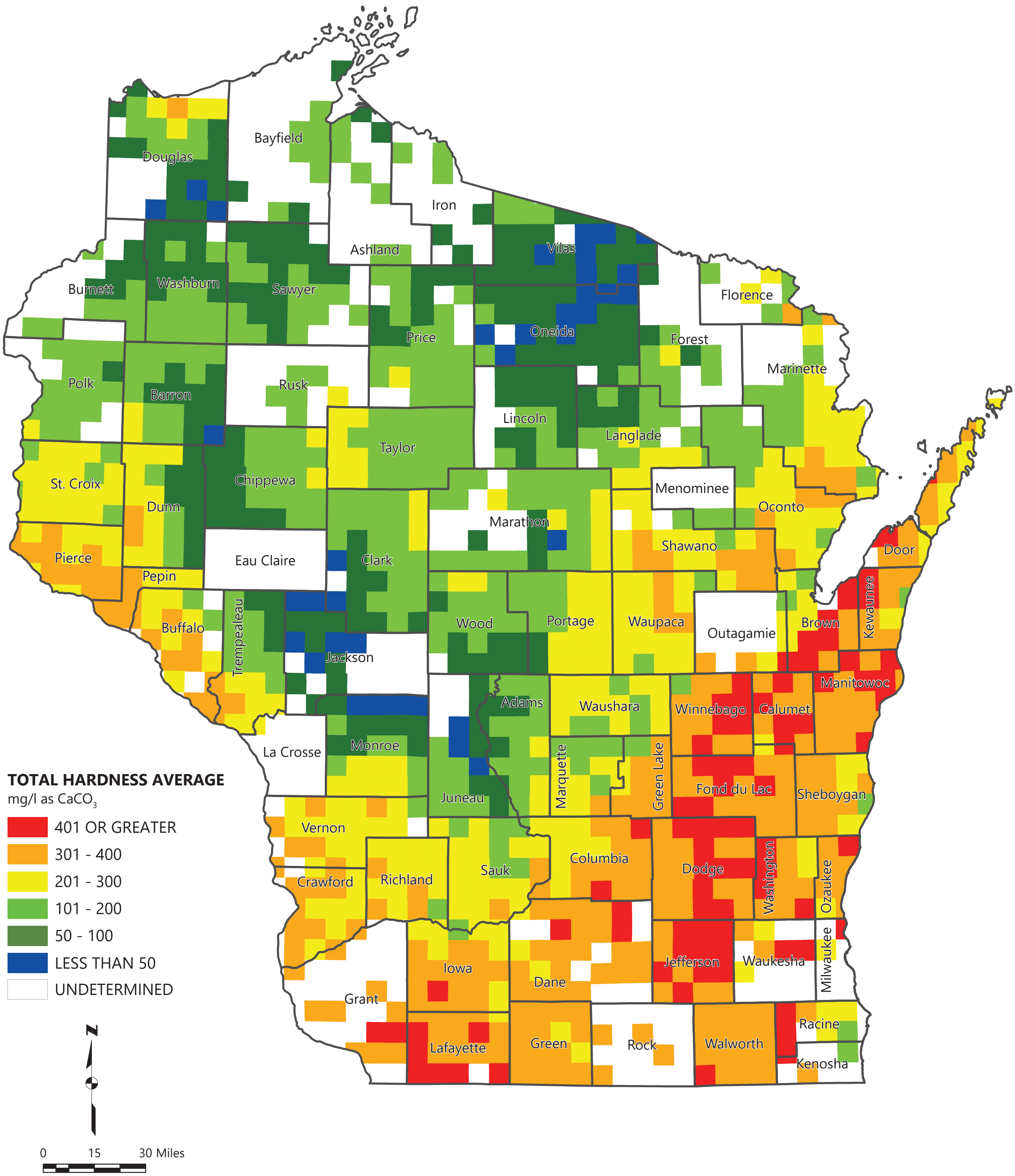
MAPS

Map 3.1
Groundwater Hardness in the State of Wisconsin by Survey Township



Source: U.W. - Stevens Point and SEWRPC