Technical Report No. 66

STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 5

OTHER CHLORIDE SOURCES

5.1 INTRODUCTION

This Chapter explores methods and technologies for reducing chloride loads from agricultural fertilizer, livestock manure, and industrial food processing. Chloride is often a secondary product contained in synthetic fertilizer and livestock manure applied to agricultural fields. For synthetic agricultural fertilizers, potash (specifically in the form of Potassium chloride) is applied to meet the potassium needs of crops, and manure is applied to supply nitrogen and phosphorus to crops. In both cases, chloride is a minority constituent of either synthetic fertilizer or manure, however, chloride is still applied to fields in excess of what crops need. The resulting excess chloride is easily transported by water to either groundwater or surface waters. The Agricultural Fertilizer and Feedlots and Manure Management sections of this Chapter will evaluate alternative synthetic fertilizers as a replacement and organic supplements to potassium chloride, management plans to more effectively apply fertilizer and manure, best management practices for limiting runoff of fertilizers and manure, and precision agriculture technologies to improve the efficiency of fertilizer and manure application.

In industrial dairy, meat, and canning processes, salts containing chloride are often added to food as preservation or taste agents. Chlorides used in the food preservation process also enter the waste stream during cleaning (picks up excess chloride left on equipment) or water softening (ion-exchange). Conventional treatment processes used in food processing plants do not remove chloride from wastewater, resulting in chlorides being discharged in the effluent to the receiving waterbody. The Industrial Food Processes section of this Chapter will evaluate potential sources of chloride in dairy, meat, and canning food processes. Typical in-place wastewater treatment processes at food processing plants or wastewater treatment plants will be described, as well as their inability to remove chloride from wastewater. Finally, dedicated chloride removal processes are described, such as reverse osmosis, brine evaporation pools, forced evaporation, and deepwell injection, as well as their potential use in Southeastern Wisconsin.

5.2 AGRICULTURAL FERTILIZER

Background on Synthetic Fertilizer Use in Wisconsin Agriculture

Much of the Southeastern Wisconsin Region (Region) and the full study area for the Chloride Impact Study is dominated by production agriculture (large-scale, systematic cultivation of crops and livestock for commercial purposes), as shown in Map 5.AreasInAgriculturalLandUsesExistingConditions In 2015, 784,063 acres (41.1 percent of the study area) were used for agricultural activities.[1] In 2022, the most common crops grown in production agriculture fields in the Region include corn, soybeans, and wheat (Table 5.AcresOfCroplandUsedToGrowSelectCrops). The most critical nutrients that crops require include nitrogen (N), phosphorus (P), and potassium (K) to maintain soil fertility, promote crop growth, and increase crop yields as shown in Table 5.TotalNutrientUptakeOfSelectedCrops.[2] Chloride is included in Table 5.TotalNutrientUptakeOfSelectedCrops as a comparison to macronutrients used by crops. It should be noted that the chloride uptake values reported are from laboratory and/or field studies where extreme amounts of chloride were applied to fields to elicit results. Across all studies, it was common to see that as more chloride fertilizer was applied, more was utilized by the crop and stored in the plant matter. Thus, it is likely that uptake values reported in Table 5.TotalNutrientUptakeOfSelectedCrops likely exceed typical crop uptake values, depending on the amount of chloride applied to Wisconsin agricultural fields. Fertilizers are often applied to agricultural fields to supply the additional nutrients needed for crop growth. Potassium which is an important nutrient to maintain healthy crop growth, is applied in the form of "potash."

Potassium plays a vital role in regulating the movement of water, nutrients, and carbohydrates in plant tissue. It affects protein, starch, and adenosine triphosphate (ATP) production, which regulates the rate of photosynthesis.[3] If a plant is deficient in potassium, it stunts plant growth and reduces yield. Potash is the

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[1] *SEWRPC Technical Report No. 61, Field Monitoring and Data Collection for the Chloride Impact Study, Table 2.5: Existing Land Use Within the Study Area, September 2023.*

[2] *E. Logan, J. Lee, E. Landis, S. Custer, A. Bennett, J. Fulton, K. Port, and E. Hawkins, "Fertilizer Removal by Crop Mobile App," May 25, 2018. ohioline.osu.edu/factsheet/fabe-5502. (date accessed: November 18, 2024)*

[3] *D.E. Kaiser and C.J. Rosen, "Potassium for crop production," Last modified 2018. extension.umn.edu/phosphorus-and-potassium/potassium-crop-production#soybean-603412. (date accessed: October 15, 2024)*

common name given to a group of minerals that contain potassium (K) but is produced mostly in the form of potassium chloride (KCl), also known as muriate of potash (MOP). Potassium chloride represents about 95 percent of the potash used in the United States.[4]

While fertilizers like potassium chloride are critical for agricultural production, their widespread use has raised environmental concerns, particularly related to the chloride ion (Cl^-) contained in KCl. While potassium is considered a macronutrient (meaning plants uptake large quantities of it during their life cycle), chloride is considered a micronutrient, meaning less of it is needed by the plant. Chloride constitutes about 47 percent of the weight of potassium chloride, meaning much of it is left unused by the plant when potassium chloride is applied. For example, in a study done in Minnesota on corn plants, corn grain uptakes 3.7 to 4.8 pounds of chloride per acre, and the corn stover took up 6.4 to 28.1 pounds of chloride per acre. While chloride taken up in the corn grain is harvested and removed from the field, chloride in corn stover remains in the field after harvest, leaving the ultimate fate of that chloride to persist in the field after the stover decomposes. With an application rate of 100 pounds of potassium chloride per acre, 78 pounds of chloride were applied per acre. At maximum, 32.9 pounds of chloride per acre (4.8 from grain and 28.1 from stover) were taken up by the corn crop. However, only 4.8 pounds per acre were ultimately removed from the field during harvest of corn grain, leaving around 94 percent of the chloride remaining in the field after harvest in the form of stover or in the soil/water.[5] It should also be noted that there was no significant yield increase or decrease in corn plants with changes in potash application. Based on county-level data compiled by the National Agricultural Statistics Service and provided to the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP), about 20.3 million pounds of chloride are applied to agricultural fields as potash fertilizer in the seven county Southeastern Wisconsin Region annually.[6] Excess chloride that

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[4] *D.L. Armstrong, and K.P. Griffin, "Production and Use of Potassium,"* Better Crops with Plant Food, *82(3):6-8, 1998; S.M. Jasinki, D.A. Kramer, J.A. Ober, and J.P. Searls,* Fertilizers – Sustaining Global Food Supplies, *U.S. Geological Survey Fact Sheet No. 99-155, 1999; J.P. Searls, Potash, U.S. Geological Survey Commodity Statistics and Information, 2000; California Fertilizer Foundation,* Plant Nutrients, *2011.*

[5] *C.J. Rosen, "Chloride Cycling in Agricultural Cropping Systems"* 2025 Salt Symposium. *August 2025.*

[6] *Wisconsin Department of Agriculture, Trade, and Consumer Protection, "Agricultural Chemical Use,"* Wisconsin Farm Reporter, *20(9):3-4, May 22, 2019; Wisconsin Department of Agriculture, Trade, and Consumer Protection, "Agricultural Chemical Use: Barley,"* Wisconsin Farm Reporter, *20(9):4, May 12, 2020; Wisconsin Department of Agriculture, Trade, and Consumer Protection, "Agricultural Chemical Use: Soybeans,"* Wisconsin Farm Reporter, *21(10):3-4, June 1, 2021; U.S. Department of Agriculture National Agricultural Service,* 2017 Census of Agriculture: Wisconsin State and County Data, *April 2019.*

remains in the soil as a by-product of potassium fertilizer application has the potential to make its way into the environment via surface runoff or infiltration.

Excess chloride has an impact on soils, sediments, groundwater, and surface waters. Once in the soil and water systems, chloride tends to move with the water, affecting chemical and biological functions. In soil, chloride can weaken soil structures and enable the movement of heavy metals in the soil profile. In groundwater systems, chloride can directly contaminate drinking water sources and surface waters via baseflow. In surface water systems, chloride can change the properties of water (i.e., freezing point) and can be toxic to aquatic organisms. More information on how chloride affects natural systems can be found in SEWRPC Technical Report No. 62.[7]

Potash

To address the negative impacts of excess chloride originating from potash fertilizer application on the environment, researchers and agricultural experts are increasingly interested in developing and adopting practices that can reduce the release of chloride ions from agricultural fields where fertilizers, such as potash, are applied. There are a variety of methods to reduce chloride exports: from reduction through smarter fertilizer application practices, alternatives to potash, precision application of fertilizer, and conservation practices.

Soil Testing

Soil testing is the only practical way of directly measuring where certain nutrients are needed in a field and is an important part of Nutrient Management Plans. Soil testing results drive Nutrient Management Plans (NMPs) and help determine fertilization needs for a specific crop and field. Generally, soil testing involves taking soil cores from a field and then sending those samples to a lab for analysis. DATCP recommends that soil samples are collected at a minimum of every five acres of a field at an interval of every four years.[8] More stringent (more frequent sampling and closer spacing) soil testing in agricultural fields improves the effectiveness of NMPs by providing precise data of soil nutrient levels, including potassium. For the purposes of smarter potash application, soil testing highlights areas with natural potassium sufficiency (where little application of potash would be needed) or can detect patterns of nutrient distribution throughout a field, enabling more targeted applications (more details will be provided in the Precision

[7] *SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024*.

[8] *Wisconsin Department of Agriculture, Trade, and Consumer Protection,* Nutrient Management Brochure: Implementing Nutrient Management in Wisconsin, *Wisconsin Department of Agriculture, Trade, and Consumer Protection, 2024*.

Agriculture Technologies section later in this Chapter). With accurate and frequent soil tests, farmers can better match fertilizer application rates to the actual nutrient needs of their crops, avoiding unnecessary or over-application of potassium chloride and minimizing excess chloride in the soil.

Soil test potassium levels can be classified to predict the likelihood of a crop yield increase to added potash fertilizer. A summary of optimum potassium levels from soil tests in southeast Wisconsin, and their level classifications (relative to the crop and soil type) are shown in Table 5.OptimumSoilTestLevels.[9] Only soil fertility groups A (high P content, medium K content) and C (low P, high K) are shown in the table because they are the most prevalent in southeast Wisconsin. Interpretations of soil test potassium results are shown in Table 5.SoilTestInterpretation. Together, regular and detailed soil testing and Nutrient Management Plans help refine nutrient applications, supporting both crop health and environmental protection by minimizing the risk of chloride contamination in groundwater and surface water.

Alternative Fertilizers

While potassium chloride is the most common potash fertilizer used in the United States and Wisconsin, there are alternative synthetic and organic fertilizers as summarized in Table 5.AlternativeKFertilizers. From the perspective of limiting chloride exports from agricultural fields, alternative fertilizers to potassium chloride have the advantage of containing little or no chlorides. There are two main disadvantages with alternative fertilizers; their potassium ion is less readily available to the plant (measured as approximate K_2O in Table 5.AlternativeKFertilizers), and their cost is usually higher because they are more difficult to source. K_2O (Potassium oxide) is used in industry as the standard way to express the amount of potassium in a substance or fertilizer, even though K_2O itself usually is not present. K_2O is used as a consistent conversion factor to compare the relative potassium content of different fertilizer formulas. The salt index (SI) is used to measure the increase in osmotic pressure (ability to draw water out of a soil) of a given fertilizer compared to a standard of sodium nitrate (SI = 100). Fertilizers with a SI exceeding 100 draw out more water than sodium nitrate, impacting the water that is available to a plant, and in some cases, can draw water out of the plant tissue itself, which is referred to as 'fertilizer burn'. This is another environmental impact from fertilizers that is worth considering when discussing alternative potassium fertilizers. For crops with a low salt tolerance (such as soybeans and some corn), a fertilizer with a low SI is preferred. In discussion with County Conservationists throughout the Region, many of the synthetic alternative potassium chloride fertilizers discussed in the succeeding pages are not being used. The primary barriers to use are that they

[9] *K.A. Kelling, L.G. Bundy, S.M. Combs, and J.B. Peters. "A3030 Optimum soil test levels for Wisconsin," 1999. University of Wisconsin-Extension.*

are not financially competitive with potassium chloride, not widely available, and/or a lack of education and awareness regarding them.[10]

Potassium Sulfate

Potassium sulfate, also known as sulfate of potash (SOP), is a potassium fertilizer that provides both potassium and sulfur to plants. It is commonly used when cultivating chloride sensitive crops like potatoes, fruits, and vegetables (e.g., broccoli, cauliflower, garlic), and for sulfur demanding crops (e.g., canola, rice, oilseed crops).[11] The key advantage of using potassium sulfate over potassium chloride is its lack of chloride content, which lowers the risk for salt stress in sensitive crops and salinity prone soils. In addition, potassium sulfate has two critical macronutrients (potassium and sulfur) that are used in large quantities by plants.

The main disadvantage of SOP fertilizer is that it is more expensive than potassium chloride (see Table 5.AlternativeKFertilizers) which could limit its use on a large scale. It also has a lower solubility and therefore is not ideal to be used in fertigation systems (injecting water soluble fertilizer into irrigation systems to supply nutrients and water to crops simultaneously), and typically requires multiple applications.[12] SOP also typically requires an incorporation fertilizer application (fertilizer is mixed into the top layer of the soil through tillage or injection) as opposed to a conventional broadcast fertilizer application (fertilizer is spread across the surface of the soil). The former requires specialized equipment and takes longer, adding costs for producers.

Recent research has shown that SOP fertilizer can accomplish similar crop yield results as more conventional fertilizers (urea, ammoniated superphosphate, granulated KCl).[13] In addition, use of SOP fertilizer has been

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[10] *Email correspondence between Racine County (C. Sampson), Waukesha County (A. Barrows), and Ozaukee County (K. Vogeler) staff, and Commission staff (L. Herrick & C. Klaubauf), December 4 & 5, 2025.*

[11] *International Plant Nutrition Institute (Canada), "Potassium Sulfate". cropnutrition.com/resource-library/potassium-sulfate/. (date accessed: October 15, 2024); A. Blaylock, "Potassium Fertilizers: Muriate of Potash or Sulfate of Potash?" Last modified: June 19, 2020. nutrien-ekonomics.com/news/potassium-fertilizers-muriate-of-potash-or-sulfate-of-potash/. (date accessed: October 29, 2024).*

[12] *Wisconsin Department of Agriculture, Trade, and Consumer, 2023,* op. cit.

[13] *V.Y. Prushak, G.V. Pirogovskaya, V.V. Lapa, L.K. Ostrovskiy, V.V. Shevchuck, and D.G. Myslivets, "Efficiency of complex NPK fertilizers obtained from conversion alkaline solution at potassium sulphate production."* Proceeding of the National Academy of Science of Belarus*, 57(4): 286 – 296, 2019.*

found to significantly increase the dry weight of the harvested corn crop and nutrient uptake of the in-field corn crops when compared to potassium chloride.[14]

Potassium Nitrate

Potassium nitrate, also known as nitrate of potash, provides both potassium and nitrogen in readily available forms, making it ideal for high value crops like potatoes, tomatoes, leaf greens, citrus fruits, and other tree fruits.[15] It is also highly soluble, making it commonly used in liquid fertilization practices such as fertigation and foliar application (applying liquid fertilizer to the leaves of a plant). This fertilizer option also contains nitrogen in the form of nitrate, which is another macronutrient important to crop growth, making it possible to supply two key plant macronutrients at once. Applications of potassium nitrate do come with environmental concerns however, as excess application can result in nitrate runoff, which is a driver of harmful algae blooms. Potassium nitrate does not contain chlorides, meaning it does not contribute to chloride runoff from fields. However, potential prohibitive barriers for using potassium nitrate are its high cost (see Table 5.AlternativeKFertilizers) and inconsistencies in supply availability.[16]

Some research shows that incorporating potassium nitrate with chitosan (sugar from the outer skeleton of shellfish) and montmorillonite clay microparticles, creates a fertilizer that can extend the release of potassium nitrate over several weeks.[17] Extending the release of potassium nitrate is beneficial for both the soil and crops because more nutrients are available over a longer period, which leads to less overall fertilizer needing to be applied, thereby reducing the potential negative environmental impacts.

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[14] *M.M. Taj-Aldeen, I.K. Mohammed, and F.K. Ahmed, "Performance of maize under magnetized water and K-sulfate and Chloride."* Iraqi Journal of Agricultural Science, *40(5): 37 – 44, 2009.*

[15] *D. Napier, "Balanced nutrition of potatoes: Potassium nitrate applications for potatoes,". sqmnutrition.com/en/essays/balanced-nutrition-potatoes-potassium-nitrate-applications/ ; D.E. Kaiser and C.J. Rosen, "Potassium for crop production," Last modified 2018. extension.umn.edu/phosphorus-and-potassium/potassium-crop-production#soybean-603412. (date accessed: October 15, 2024)*

[16] *Zion Market Research "Potassium Nitrate Market Size, Share, Growth and Forecast 2030," Last modified 2021. zionmarketresearch.com/report/potassium-nitrate-market. (date accessed: November 1, 2024)*

[17] *L.L. Messa, C.F. Souza, and R. Faze, "Spray-dried potassium nitrate-containing chitosan/montmorillonite microparticles as potential enhanced efficiency fertilizer."* Polymer Testing, *81, January 2020. doi.org/10.1016/j.polymertesting.2019.106196*

Potassium-Magnesium Sulfate

Another fertilizer that does not contain chloride is potassium-magnesium sulfate, commonly known as K-mag or Sul-Po-Mag. K-mag is a double salt that can crystallize into the minerals langebeinite ($K_2Mg_2(SO_4)_3$), leonite ($K_2Mg(SO_4)_2 \bullet H_2O$), and picromerite ($K_2Mg(SO_4)_2 \bullet 6H_2O$). Langbeinite and leonite are commonly used for organic agricultural practices. Magnesium is considered a macronutrient in crops; thus, the application of K-mag fertilizer is most productive in areas where soils have a magnesium deficiency or when growing crops that require increased levels of magnesium (e.g., cabbage, alfalfa, peas, soybeans).[18]

There are some barriers to using K-mag in production agriculture fields. First, it is slightly more expensive on a per ton basis than potassium chloride. Second, it has less available K_2O than KCl, meaning more of it must be applied to achieve the same levels of potassium in the soil (see Table 5.AlternativeKFertilizers). Lastly, due to the complicated chemical nature of the potassium-magnesium sulfate salt, it takes significantly longer to dissolve in water (although it is completely dissolvable) than other potassium fertilizers, KCl and KNO_3 in particular. This makes it difficult to use in fertigation practices. Because of the economics of its use and the low availability of potassium, K-mag is used most appropriately as a fertilizer when there is a need for magnesium and sulfur.[19]

Potassium Thiosulfate

Potassium thiosulfate (KTS) offers a combination of potassium and sulfur in a soluble form, making it compatible (and common) with fertigation and foliar application systems. The advantage of the foliar application is that fertilizer is applied directly to the plant (rather than to the soil, after which it must be taken up by the roots), which sometimes means that less of it can be applied. KTS also contains no chloride, so it does not contribute chloride to the environment. However, more research is needed to fully assess other environmental impacts KTS may have compared to KCl.[20]

There are several barriers to use for potassium thiosulfate. First, KTS has low K_2O compared to KCl and higher cost per metric ton, resulting in a higher cost to achieve the same amount of potassium in the soil.

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[18] *D.E. Kaiser and C.J. Rosen, "Magnesium for crop production," Last modified 2023. extension.umn.edu/micro-and-secondary-macronutrients/magnesium-crop-production. (date accessed: October 29, 2024)*

[19] *International Plant Nutrition Institute (IPNI) Canda,* Potassium Magnesium Sulfate: Langbeinite, *IPNI Nutrition Source Specifics No. 6, 2019.*

[20] *Z. Cai, S. Gao, M. Xu, and B.D. Hanson, "Evaluation of potassium thiosulfate as a nitrification inhibitor to reduce nitrous oxide emissions."* Science of The Total Environment, *618(15): 243 – 249, March 15, 2019.*

It can also be phytotoxic (toxic to plants) if used in low soil moisture conditions and can evaporate during foliar applications if the air temperature is above 90 degrees Fahrenheit. It also can be corrosive to metal, which complicates storage and handling logistics.[21]

Potassium Feldspar

Potassium feldspar (K-feldspar or K-spar) is a commonly occurring framework silica which accounts for approximately 10 percent of the weight in soils[22] and is a common material in Wisconsin soils.[23] Ground K-spar, also known as stonemeal, has been discussed as a potential substitute for traditional potassium fertilizers; however the slow leaching of potassium ions from K-spar is a commonly cited limitation.[24] In some settings, particularly in organic and sustainable farming where perennial crops can thrive on the slow release of potassium, this can be advantageous. However, its effectiveness is limited for short season or high potassium demand crops as its release of potassium is considered slow. There is some recent research that suggests that the leaching rate of K ions from syenite (a form of potassium feldspar) may be faster than previously thought at the temporal and spatial scales that plant roots experience nutrient uptake.[25] These results indicate that silicate minerals may be more viable as an alternative potassium fertilizer than previously thought. The advantage of potassium feldspar over potassium chloride is that it contains only trace amounts of chloride, thus it does not contribute additional chlorides to the natural environment. Potassium feldspar is also cheaper per metric ton than potassium chloride but more expensive to apply an equivalent K_2O as KCl (Table 5.AlternativeKFertilizers), because of its lower comparative K content.

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[21] *J. Allan, "Making a Case for In-Season Potassium Applications | Progressive Crop Consultant," Last modified June 7, 2024. progressivecrop.com/2024/06/07/making-a-case-for-in-season-potassium-applications/. (date accessed: November 1, 2024).*

[22] *P.M. Huang,* Chemical Processes in Soils: 227 - 292, *Madison, WI: Soil Science Society of America, 2005.*

[23] *Wisconsin Geological and Natural History Survey, "Potassium Feldspar," Last modified: May 17, 2021. home.wgnhs.wisc.edu/minerals/potassium-feldspar/. (date accessed: October 16, 2024).*

[24] *A.E. Blum and L.L. Stillings, "Feldspar dissolution kinetics."* Reviews in Mineralogy and Geochemistry, *31(1): 291 – 351, January 1995.; D.A.C Manning, "Mineral sources of potassium for plant nutrition. A review."* Agronomy for Sustainable Development, *30(2): 291 – 294, July 30, 2012; T. Skorina and A. Allanore, "Aqueous alteration of potassium-bearing aluminosilicate minerals: from mechanism to processing."* Green Chemistry, *17(4): 2123 – 2136. doi.org/10.1039/c4gc02084g*

[25] *D. Ciceri and A. Allanore, "Microfludidic Leaching of Soil Minerals: Release of K^+ from K Feldspar."* PLoS ONE, *10(10), October 20, 2015.*

Potassium feldspar is highly available as a mineral as it is one of the most abundant minerals in the crust of the Earth.

Compost

Compost is created from decomposed organic materials (grass clippings, leaves, food scraps, etc.) and is used in organic and conventional agriculture due to its ability to improve soil health and fertility.[26] Organic matter in compost enhances soil structures and helps soils retain moisture and nutrients more effectively, improving crop health and yield. Compost provides small amounts of nutrients, such as potassium, but is not considered a good primary source. Studies have shown that 40 pounds of potash fertilizer provides the same amount of potassium as 280 pounds of compost or 800 pounds of cow manure.[27] Thus, compost should be used more as an amendment to soil that improves soil structure, moisture retention, and microbial activity, rather than a complete replacement for nutrient fertilizers, particularly in production agriculture settings. Compost is used in the Region as a soil amendment by some agricultural operators in Waukesha County. Some operators in Walworth County use chicken manure as an alternative fertilizer in a similar manner to compost.[28]

Compost does have the advantage of containing little to no chlorides (depending on the source material used to create it), meaning it will likely not contribute to chlorides in the soil. One benefit of adding compost to the soil is that it may indirectly lead to less chloride exports from agricultural fields. This is because the improvements to the soil structure that come from adding compost may promote better nutrient retention, thus requiring less application of synthetic fertilizer in subsequent growing seasons.[29] While compost works great as a soil amendment, there are some barriers to its use within production agriculture. The quality of compost can vary greatly depending on its source materials, making it difficult to fully predict its nutritional content and effectiveness. While commercial compost costs shown in Table 5.AlternativeKFertilizers are

[26] *M. Ozores-Hampton, P.A. Stansly, and T.P. Salame, "Soil Chemical, Physical, and Biological Properties of a Sandy Soil Subjected to Long-Term Organic Amendment."* Journal of Sustainable Agriculture, *35(3): 243 – 259, March 21, 2011.*

[27] *P. Pugliese, "Compost enriches soil – but doesn't replace fertilizer," Last modified March 18, 2022. newswire.caes.uga.edu/story/8896/compost-and-fertilizer.html*

[28] *Email correspondence between Waukesha County (A. Barrows) and Walworth County (M. Bonneville) staff, and Commission staff (L. Herrick & C. Klaubauf), December 3 & 4, 2025.*

[29] *D.C. Weindorf, J.P. Muir, C. Landeros-Sánchez, W.B. Campbell, and S. Lopez Ortiz, "Organic Compost and Manufactured Fertilizers: Economics and Ecology,"* Integrating Agriculture, Conservation and Ecotourism: Examples from the Field, *27 – 53. Dordrecht:: Springer Netherlands, 2011.*

cheaper compared to potassium chloride per metric ton, around seven times as much compost is needed to supply the amount of potassium as KCl. Thus, it might be more cost and space effective to use compost as a soil supplemental additive, using already available materials on farms such as animal manure, crop residue, and bedding materials. Creating compost on site requires significant investment from producers in time, land, and machinery before any benefits are realized, however it does have significant benefits for soil health.

Biochar

Biochar is a form of carbon rich material produced from the thermal decomposition of organic matter in low oxygen conditions, similar to the process that creates charcoal. When applied to soil, biochar has proven effective at improving soil structure, increasing water holding capacity, and enhancing nutrient retention[30]. Working as a binding agent, biochar reduces nutrient leaching, making it an advantageous soil amendment in nutrient rich locations such as fields growing leafy green vegetables or high value fruits. Biochar is also associated with longer term carbon sequestration in soil, offering environmental benefits by capturing carbon and enhancing soil microbial biodiversity[31]. In agriculture, biochar can be combined with compost and synthetic fertilizers to maximize nutrient availability, and over time, reduce the need for synthetic fertilizers. Biochar combined with other fertilizers would be best for soil reclamation projects or sustainable farming practices. Biochar does not contribute chlorides to the soil, so it is safe for chloride sensitive crops. However, the potassium release from biochar is slow and may not suffice for crops with immediate high potassium demands. Other barriers to the use of biochar include the need for specialized equipment and specialized expertise, making it expensive for smaller operations.[32] Biochar is also cheaper than synthetic potassium fertilizers (on a per metric ton basis) as shown in Table 5.AlternativeKFertilizers, however it may not even be able to supply potassium in a meaningful manner for production agricultural crop fields. Thus, it is best used as a soil supplement to improve soil health and indirectly help reduce chloride exports from fields by reducing the need for synthetic fertilizers over time.

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[30] *K. Jindo, Y. Audette, F.S. Higashikawa, C.A. Silva, K. Akashi, G. Mastrolanardo, M.A. Sánchez-Monedero, and C. Mondini, "Role of biochar in promoting circular economy in the agriculture sector. Part 1: A review of biochar roles in soil N, P, and K cycles." Chemical and Biological Technologies in Agriculture, July, 14, 2020.*

[31] *W. Widowati and A. Ansah, "Biochar Can Enhance Fertilization Efficiency and Economic Feasibility of Maize Cultivation."* Journal of Agricultural Science, *6(2), January 15, 2014.*

[32] *D. Pierson, N. Anderson, J. Brewen, N. Clark, M.C. Hardy, D. McCollum, F.H. McCormick, J. Morisette, T. Nicosia, D. Page-Dumroe, C. Rodriguez-Franco, and J. Tirocke, "Beyond the basics: a perspective on barriers and opportunities for scaling up biochar production from forest slash."* Biochar, *6(1), January 2, 2024.*

Glauconite

Glauconite, also known as greensand, is a mineral used in agriculture that is valued as a natural source of potassium.[33] Once applied, nutrients are slowly released into the soil making it suitable for crops that benefit from steady, long term nutrient availability rather than immediate, high dose fertilizer applications. Glauconite has been shown to enhance soil health by supplying potassium without the risk of chloride buildup, making it a desirable alternative to potassium chloride, particularly for chloride sensitive crops such as fruits, potatoes, and tobacco. Its gradual release of potassium and micronutrients like iron, magnesium, and silica are particularly beneficial for soils deficient in these elements. Conversely, the slow nutrient release rate of glauconite may not be sufficient for crops with high and immediate potassium demands. For this reason, glauconite is often used as part of a comprehensive soil amendment strategy. Additionally, the effectiveness of glauconite depends on soil pH and microbial activity, as it relies on natural soil processes to release nutrients over time. Greensand is also cheaper than synthetic potassium fertilizers on a per metric ton basis, however it may not be able to supply potassium at the rate needed for production ag crop fields. Thus, it is likely best used as a soil supplement for continuous slow potassium release and soil health.

Precision Agriculture Technologies

Precision agriculture is a relatively new approach in farming that employs advanced technologies and methodologies to enhance agricultural efficiency and productivity, while minimizing impacts on the environment. It centers around the collection and analysis of data from various sources, including soil sensors, satellite imaging, and unmanned aerial vehicles, to facilitate informed decision making regarding agricultural practices. The primary objective of precision agriculture is to optimize field level management of crops by considering the variability of soil and crop characteristics throughout a field. This approach allows for site specific management of irrigation, fertilizers, and pesticides, ultimately leading to improved crop yields, reduced environmental impact, and increased profitability for farmers. By harnessing technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), and the Internet of Things (IoT) (a network of physical objects, such as sensors, connected to the internet and able to communicate with other devices), precision agriculture provides a systematic framework for managing agricultural operations more effectively and sustainably. An example of how precision agriculture works for an irrigation system is shown in Figure 5.PrecisionAgDiagram. For the purpose of limiting chloride exports from agricultural fields, precision agriculture can provide a pathway for smarter application of synthetic

[33] *S. Rakesh, R. Juttu, K. Jogula, B. Raju, "Glauconite: An Indigenous and Alternative Source of Potassium Fertilizer for Sustainable Agriculture."* International Journal of Bioresource Science, *7(1): 17 – 19, June 2020. doi.org/ 10.30954/2347-9655.01.2020.4*

fertilizer (i.e., using it only where and when it is necessary), and thus less potential for chlorides to be lost from the field to groundwater or surface water.

Real Time Monitoring and Data Analysis

Continuous monitoring of soil nutrient levels and crop conditions can be achieved through integrated sensor systems that measure parameters like soil moisture, pH, and electrical conductivity. This real time data allows farmers to make informed decisions about fertilizer application rates and timing, helping to synchronize nutrient supply with crop needs. Taken a step further, cutting edge data analysis using machine learning algorithms and artificial intelligence (AI) can analyze patterns and predict the optimal application strategies for fertilizers, including those that contain chlorides.

Variable Rate Technology

Variable Rate Technology (VRT) is a precision agriculture method that allows farmers to apply fertilizers at varying rates across a field, rather than uniformly This technique is guided by detailed soils data (either from soil testing or by sensors), which helps identify zones that require different nutrient levels. Agricultural fields are mapped by drones or satellites, and zones of high and low nutrient content are identified. Mapped information is fed to a processor and controller on a piece of machinery. The controller then tells the variable-rate drive on the machinery where and when to apply more or less fertilizer based upon the mapped pre-existing nutrient content. By adjusting the amount of fertilizer applied based on soil conditions and crop requirements, farmers can minimize nutrient runoff, maintain soil health, and save money.[34] VRT can help with the precise application of potash fertilizers, thereby reducing excess chloride that would eventually infiltrate to groundwater or enter waterways as runoff.

Farmers can encounter several challenges when trying to implement VRT technology. The high initial costs needed for VRT which include software, sensors, specialized mechanical technology, GPS, and/or GIS systems may deter producers from adopting VRT, especially for small or medium sized operations.[35] In addition, a large amount of data management is required to incorporate VRT appropriately into an

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[34] *C.S. Singh, A. Raj, A.K. Singh, A.K. Singh, and S.K. Singh, "Nutrient expert assisted site-specific nutrient-management: An alternative precision fertilization technology more maize production in Chota-nagpur plateau region of Jharkhand."* Journal of Pharmacognosy and Phytochemistry, *7: 760 – 764, 2018.*

[35] *S.A. O'Shaughnessy, S.R. Evett, P.D. Colaizzi, M.A. Andrade, T.H. Marek, D.M. Haeeren, F.R. Lamm, and J.L. LaRue, "Identifying Advantages and Disadvantages of Variable Rate Irrigation: An Updated Review."* Applied Engineering in Agriculture, *35(6): 837 – 852, 2019.*

agricultural operation. Often, this requires significant training which may be prohibitive for some farms.[36] Thus, it is critical for farmers to collaborate with experts for successful adoption of precision agriculture technologies.

Remote Sensing

Remote sensing involves collecting data from satellite images or aerial surveys to analyze soil conditions and crop health. [37] This information can inform decisions about when and where to apply potash fertilizers. By understanding spatial variations in crop nutrient needs, farmers can optimize fertilizer applications, ensuring that they use only what is necessary, thereby reducing the risk of chloride infiltration and runoff into nearby water bodies.

GIS and GPS Integration

Geographic Information Systems (GIS) and Global Positioning Systems (GPS) are integrated into precision agriculture to facilitate spatial analysis of the many variables within fields. GIS can assist agricultural operations by mapping characteristics such as soil types, humidity levels, and nutrient concentrations. GPS provides accurate positioning data for precise fertilizer applications (see Figure 5.AgGIS&GPS). This combination allows farmers to create site specific management zones based on the data collected, thereby ensuring that fertilizers are applied accurately and efficiently across varying field conditions.[38] GPS technology also enables monitoring of equipment application routes to prevent overlap and minimize excess application.

Unmanned Aerial Vehicles (UAVs)

UAVs equipped with sensors can collect real time data on crop conditions and soil health over large areas. These UAVs can be used to monitor plant health through multispectral imaging (using non-visible light with visible light to make decisions about plant health), enabling the detection of nutrient deficiency or excesses.

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[36] *A.Y. Adewuyi, B. Anyibama, K.B. Adebayo, J.M. Kalinzi, S.A. Adeniyi, and I. Wada, "Precision agriculture: Leveraging data science for sustainable farming."* International Journal of Science and Research Archive, *12(2): 1122 – 1129, 2024.* doi.org/10.30574/ijsra.2024.12.2.1371.

[37] *C. Sangeetha, V. Moond, G.M. Rajesh, J.S. Damor, S.K. Pandey, P. Kumar, and B. Singh, "Remote Sensing and Geographic Information Systems for Precision Agriculture: A Review."* International Journal of Environment and Climate Change, *14(2): 287 – 309, 2024.* doi.org/10.9734/ijecc/2024/v14i23945.

[38] *S.R. Vernekar and J.S. Parab, "Soil Urea Estimation using Embedded Systems."* International Journal of Recent Technology and Engineering, *8(4): 11296 – 11299.* doi.org/10.35940/ijrte.D9565.118419.

After identifying areas requiring intervention, UAVs can also facilitate targeted application of fertilizers (see Figure 5.AgUAVs.), thus ensuring optimal use of resources while minimizing the risk of excess fertilizer (including chloride) from entering water systems.[39]

Conservation Practices

Agricultural conservation practices are aimed at either preventing chloride from being transported from fields by runoff or detaining the runoff containing chloride prior to it entering a waterway. Conservation practices are an essential tool for mitigating water pollution and protecting aquatic ecosystems. These can include best management practices (BMPs) to reduce or control fertilizer applications, soil management practices, and policy and education. Each of these play a part in reducing the environmental impacts of chloride pollution.

Best Management Practices

In the context of this section, Best Management Practices (BMPs) can be defined as practices designed to reduce runoff from agricultural fields containing chloride ions. Vegetative filter and buffer strips are an example of a BMP that treats and/or detains runoff. Typically, vegetative filter strips are used as a stormwater management and pollutant removal method in urban areas while buffer strips and used along waterways as a method of habitat protection and water quality improvement. However, the difference between these practices is minute, and the terms can be used interchangeably. Buffer and filter strips are areas of permanent vegetation located within and between agricultural fields and the watercourses they drain to (see Figure 5.AgBufferStripsPhoto).[40] They are intended to intercept and slow runoff, thereby providing water quality benefits. In addition, in many settings filter and buffer strips are intended to intercept shallow groundwater moving through the root zone below the buffer. The vegetation in the buffer strips can uptake significant quantities of nutrients such as phosphorus and nitrogen as the runoff passes through, reducing the nutrient load to waterbodies.[41] However, chloride is a micronutrient, thus the small uptake by vegetation

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[39] *S.M. Shamsi, H.B. Abdullah, and L. Bakar, "Development of Integrated EC and pH Sensor for Low-Cost Fertigation System"* IOP Conference Series: Earth and Environmental Science, *515, June 2020.* doi.org/10.1088/1755-1315/515/1/012016.

[40] *M.J. Helmers, T. Isenhart, M. Dosskey, S. Dabney, and J. Strock,* Buffers and Vegetative Filter Strips, *Iowa State University, Department of Agricultural and Biosystems Engineering, 2015.*

[41] *J.W. Faulkner, W. Zhang, L.D. Geohring, and T.S. Steenhuis, "Tracer movement through paired vegetative treatment areas receiving silage bunker runoff."* Journal of Soil and Water Conservation, *66(1): 18 – 28, 2011.* doi.org/10.2489/jswc.66.1.18; *C. Karnatz, J.R. Thompson, and S. Logsdon, "Capture of stormwater runoff and pollutants*

would be a side effect of the buffer and filter strips, rather than the designed purpose of filter strips. Thus, buffer and filter strips would have a minimal impact overall on reducing chloride loads to receiving waters or groundwater.

Another example of a BMP used to reduce fertilizer runoff from agricultural fields are cover crops. Cover crops are grown to cover the bare soil during the non-growing season or between row crops (such as corn) during the growing season (see Figure 5.CoverCrops). Common cover crops and their characteristics and features are shown in Appendix Table 5.CoverCropCharacteristics. By providing ground cover, cover crops help to control soil erosion, stabilizing the soil surface and slowing down water movement. Cover crops minimize the amount of soil and associated nutrients that can be carried off by precipitation and wind.[42] Additionally, the root systems of cover crops improve deeper soil structure, further enhancing porosity and infiltration. This increased water permeability reduces surface runoff volume and prevents contaminants from easily entering nearby streams and lakes.

In addition to runoff reduction, cover crops actively absorb nutrients, including chlorides (although minimally), from the soil, further decreasing the likelihood of nutrient runoff or leaching during heavy rain.[43] Different types of cover crops cater to distinct agricultural field needs. For example, legumes like clover and vetch offer the dual benefit of erosion control and nitrogen fixation, reducing the need for synthetic fertilizers.[44] Grasses such as rye and barley can establish quickly to provide immediate soil stabilization, which is especially valuable during rainy periods.[45]

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by three types of urban best management practices." Journal of Soil and Water Conservation, *74(5): 487 – 499, September 2019.* doi.org/10.2489/jswc.74.5.487.

[42] *R. Egozi and E. Gil, "Cover crops impact on excess rainfall and soil erosion rates in orchards and potato fields, Israel."* European Geoscience Union General Assembly, *17, 2015.*

[43] *M. Skidmore, "The impact of extreme precipitation on nutrient runoff."* Journal of the Agricultural and Applied Economics Association, *2(4): 760 – 785, November 27, 2023.*

[44] *M.S. Smith and J.J. Varco, "Abatement of Nitrate Pollution in Groundwater and Surface Runoff from Cropland Using Legume Cover Crops with No-Till Corn."* Kentucky Water Research Institute Research Reports, *163, July 1986.*

[45] *J.W. Faulkner, W. Zhang, L.D. Geohring, and T.S. Steenhuis, 2011*, op cit.

Cover crops also contribute to long term soil health by adding organic matter and supporting microbial activity, which can increase soil productivity over time.[46] Economically, cover crops can lower costs related to fertilizer applications and erosion control measures, potentially boosting farm profitability.[47] Moreover, by reducing the concentration of chlorides and other nutrients in runoff, cover crops improve water quality in streams, lakes, and groundwater aquifers, benefitting aquatic ecosystems downstream from agricultural operations.[48]

Controlled Release Fertilizer Application

Controlled release fertilizers (CRFs) (see Figure 5.CRFDiagram) offer an innovative approach to reducing chloride runoff from agricultural fields, with benefits to both crop productivity and environmental sustainability. A meta-analysis of 220 studies on the application of CRFs on maize showed the CRFs increased crop yield by 6.46 percent, nitrogen use efficiency by 33.23 percent, soil organic carbon by 4.07 percent, and soil pH by 1.01 percent, and decreased nitrous oxide and ammonia volatilization by 3.61 percent and 54.08 percent respectively.[49] Designed to release nutrients gradually, CRFs synchronize nutrient availability with plant uptake.[50] This slow release mechanism reduces leaching, particularly during rainfall, as nutrients are less available to be washed away from the fertilizer pellet as opposed to traditional fertilizer crystals. As a result, CRFs enhance nutrient use efficiency and reduce the need for repeated applications, which often contribute to excess chloride levels in the soil and water.[51] Additionally, the use of CRFs supports

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[46] *L. Starr, C. Stewart, N. Nelson, D. Presley, G. Kluitenberg, K. Roozeboom, and P. Tomlinson, "Cover crops and P-fertilizer management affect microbial activity in a US Midwest corn and soybean rotation."* Agronomy Journal, *November 1, 2024.*

[47] *A.E. Anderson, "The Impact of Cover Crops on Farm Finance and Risk: Insights from Indiana Farma Data using Econometric and Stochastic Methods," MS Thesis, Purdue University, West Lafayette, Indiana, USA, 2019.*

[48] *M.A. Bourns, N.O. Nelson, R.E. Carver, K. Roozeboom, G. Kluitenberg, P. Tomlinson, Q. Kang, and G.M. Hettierachchchi, "Cover crops impact phosphorus cycling and environmental efficiency in a corn-soybean system."* Agronomy Journal, *116(1): 109 – 120, October 26, 2023.*

[49] *Y. Qiao, G. Yue, X. Mo, L. Zhang, S.Sun, "Controlled-release urea derived from various coating materials on the impacts of maize production: A meta-analysis."* Industrial Crops and Products, *225, March 2025.*

[50] *K. Mikula, G. Izydorczyk, D. Skrzyczak, M. Mironiuk, K. Moustaka, A. Witek-Krowiak, and K. Chojnacka, "Controlled release micronutrient fertilizers for precision agriculture – A review."* Science of The Total Environment, *712, April 10, 2020.*

[51] *M.H. Rahman, K.M. Shamsul Hasque, and M.Z. Hossain Khan, "A review on application of controlled released fertilizers influencing the sustainable agricultural production: A Clean production process."* Environmental Technology & Innovation, *23, August 2021.*

climate smart agricultural practices by preventing direct exposure of the fertilizer granule to the soil, preventing the loss of nutrients, and by being less affected by changes in the environment; allowing CRFs to persist longer in the soil than traditional fertilizers. In total, these factors leave more nutrients available to the plant and less nutrients able to leave the rooting zone, contributing to soil health, ecosystem resilience, and overall sustainability on agricultural systems.[52]

Several CRF technologies, such as polymer coated and starch-based formulations are specifically designed to reduce nutrient loss and minimize chloride runoff. Polymer coatings allow nutrients to diffuse slowly, providing extended availability. Starch based coatings offer a biodegradable and effective alternative for controlled nutrient release.[53] A list of CRF materials, coating techniques, and research findings are shown in Table5.CRFCoatingMaterials. A drawback of CRFs is that they are more expensive on a per acre basis than traditional soluble fertilizers. One study found that CRFs were 2.3 to 3.7 times more expensive than a range of soluble fertilizer programs.[54]

Controlled release fertilizers are currently being used in the Region, primarily in the form of Environmentally Smart Nitrogen (ESN) slow-release nitrogen (encapsulated Urea).[55] Nitrogen is particularly well advantaged to being used as slow-release fertilizer because excess nitrogen is prone to volatilization (process of a chemical transforming into a gas) and controlled released reduces this risk. Slow-release nitrogen fertilizer is typically applied to corn crops in the Region and applied in formulations of 46-0-0, 44-0-0, 28-0-0, 32-0-0, and 28-0-0-5 (Nitrogen-Phosphorus-Potassium-Sulfur).[56] The cost of controlled release nitrogen fertilizers is around 1.5 times as expensive per ton as typical urea fertilizer. Controlled release potassium

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[52] *E. Vermoesen, S. Bodè, G. Brosen, P. Boeckx, and S. Van Vlierberghe, "Chemical strategies towards controlled release in agriculture."* Reviews in Chemical Engineering, *40(2): 247 – 277, February 2024.* doi.org/10.1515/revce-2022-0057.

[53] *D. Lawrencia, S.K. Wong, D. Yi Sern Low, B. Hing Goh, J. Kheng Goh, U.R. Ruktanonchai, A. Soottitantawat, L.H. Lee, and S.Y. Ting, "Controlled Released Fertilizers: A Review on Coating Materials and Mechanism of Release."* Plants, 10(2): 238, 2021.; *M. Salimi, B. Channab, A. El Idrissi, M. Zahouily, and E. Motamedi, "A comprehensive review on starch: Structure, modification, and applications in slow/controlled- release fertilizers in agriculture."* Carbohydrate Polymers, *322(15), December 2023.*

[54] *C.M. Hutchinson and E.H. Simonne, "Controlled-Release Fertilizer Opportunities and Costs for Potato Production in Florida."* University of Florida Institute of Food and Agricultural Sciences Extension, *July 2003.*

[55] *Email correspondence between Racine County (C. Sampson) and Ozaukee County (K. Vogeler) staff and Commission staff (L. Herrick & C. Klaubauf), December 4 & 5, 2025.*

[56] *K. Vogeler, 2025,* Ibid.

fertilizers are not widely used in the Region, either due to a lack of availability, being cost prohibitive, or a lack of knowledge on their use among agricultural operators.[57]
Integration of CRFs with previously discussed practices such as soil testing, precise application timing, buffer strips, and cover cropping can further optimize nutrient management and runoff reduction.[58]

Policy, Extension, and Outreach

An improved policy framework can be instrumental in promoting sustainable farming practices that reduce chloride runoff. Effective policies can include regulations that control the type and amounts of fertilizers used, particularly those high in chloride.[59] Policies could also set minimum buffer distances from water bodies for fertilizer application, reducing the risk of overall runoff contamination. Additionally, financial incentives or subsidies for BMPs such as cover cropping, or reduced fertilization practices from precision agriculture and controlled release fertilizer can encourage farmers to adopt practices that minimize chloride leaching. Establishing comprehensive water quality monitoring programs is also essential to track chloride levels in surface waters, allowing policymakers to adjust nutrient management guidelines as needed.

University extension services are crucial in making research accessible to farmers by providing hands-on technical assistance. Extension professionals can offer guidance on timing and methods for fertilizer application to reduce runoff and chloride export. Through demonstration programs, farmers can observe BMPs in action, such as buffer strips and cover crops, which may increase their willingness to adopt these practices. Additionally, extension services can play a key role in disseminating research findings, ensuring that agricultural producers stay informed about sustainable practices and the impacts of fertilizers with chloride.

University extension outreach initiatives and farmer education further support the adoption of chloride reducing practices. Public awareness campaigns can educate both farmers and the public about the

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[57] *Email correspondence between Racine County (C. Sampson), Ozaukee County (K. Vogeler), Waukesha County (A. Barrows), and Walworth County (M. Bonneville) staff, and Commission staff (L. Herrick & C. Klaubauf), December 4 & 5, 2025.*

[58] *S. Moradi, A. Babpoorm S. Ghanbarlou, M.Y. Kalashgarani, I. Salahshoori, and A. Seyfaee, "Toward a new generation of fertilizers with the approach of controlled-release fertilizers: a review."* Journal of Coatings Technology and Research, *21: 31- 54, 2024.*

[59] *J.R. Coad, "Managing phosphorous in intensive pastures soils to improve the long-term environmental sustainability of the Dairy Industry," MS thesis, University of Tasmania, Hobart, Australia, 2024.*

environmental impact of chloride on water systems, building support for sustainable practices. Collaborative projects involving producer led groups or community groups can foster collective action and commitment to reducing chloride sources. Workshops and seminars provide platforms for farmers to learn about nutrient management and sustainable practices, enhancing their ability to make informed decisions. Farmer education programs can also cover nutrient management planning, use of precision agriculture technologies, and soil health, all of which contribute to a more targeted and efficient use of fertilizers.

Drain Tiles and Drainage Control Systems

Drain tiles are a commonly employed water management technique used in agricultural fields to increase crop yield, particularly in regions with high soil saturation near the surface. In Wisconsin, drain tiles are typically installed 3 to 6 feet below the surface, spaced 30 to 100 feet from each other.[60] The tiles, typically perforated polymer pipes, remove water from upper depths of the soil profile and lower the water table to enable root growth, plant uptake of nutrients, enhancing crop productivity.[61]

In Midwestern soils (i.e., typically well-drained soils), drain tiles alter the hydrologic cycle by shortening water transport pathways, reducing water retention of the land surface and soil profile, and enabling more rapid flow routing to streams.[62] Site-specific studies of drain tiled agricultural watersheds in North America concluded that tile drainage can account for approximately 50 percent of the annual discharge from a rural watershed.[63] Thus, in the context of chloride, whose transport is driven by the movement of water throughout a field, there is the concern that in fields with drain tile, chloride applied to fields has a quick

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[60] *J.C. Panuska, "The Basics of Agricultural Tile Drainage: Basic Engineering Principles 2,"* Biological Systems Engineering Department, UW-Madison, *(2017).*

[61] *C.A. Poole, R.W. Skaggs, G.M. Cheschier, M.A. Youssef, and C.R. Crozier, "Effects of drainage water management on crop yields in North Carolina,"* Journal of Soil and Water Conservation: 68(6), 429 – 437, *(2013); R. Singh, M. Helmers, W.G. Crumpton, and D.W. Lemke, "Predicting effects of drainage water management in Iowa's subsurface drained landscapes,"* Agricultural Water Management: 92(3), 162 – 170, *(2007).*

[62] *K.L. Blann, J.L. Anderson, G.R. Sands, and B. Vondracek, "Effects of Agricultural Drainage on Aquatic Ecosystems: A Review."* Critical Reviews in Environmental Science and Technology: 39(11), *(2009).*

[63] *K.W. King N.R. Fausey, and M.R. Williams, "Effect of subsurface drainage on streamflow in an agricultural headwater watershed,"* Journal of Hydrology: 519(A), 438 – 445, *(2014); M.L. Macrae, M.C. English, S.L. Schiff, and M. Stone, "Intra-annual variability in the contribution of tile drains to basin discharge and phosphorus export in a first-order agricultural catchment,"* Agricultural Water Management: 92(3), 171 – 182, *(2007); M.R. Williams, K.W. King, and N.R. Fausey, "Contribution of tile drains to basin discharge and nitrogen export in a headwater agricultural watershed,"* Agricultural Water Management: 158, 42 – 50, *(2015).*

pathway to surface waters. During portions of the growing season when potash fertilizer is applied, this could result in high chloride loadings to surface water during a short period of time. This line of thought is supported by a 2016 study for agricultural watersheds where the riverine chloride response to chloride inputs from agricultural fertilizer was rapid, due to tile drainage.[64]

Another study found that in drier years when more irrigation is needed, more chloride was lost from the soil (120 to 480 pounds Cl per acre per year during dry year vs. 20 to 285 pounds Cl per acre per year during wet year) because of the concentration of chloride in irrigation water.[65] The additional chloride added to the field from an increased volume of irrigation water can also be transported by drain tiles to surface water. Thus, there is interest in controlling the discharge of water to and from drain tiles to surface water during certain periods of time, which in turn spreads out the loading of chloride.

Controlled drainage systems regulate flow from drain tiles in agricultural fields, primarily to maintain water levels for plants. Water control structures are installed or retrofitted at the outlet of drainage tile networks. The control structure manages flows by controlling water levels, which is based on agronomic, ecologic, and farming needs. Two types of tile control structures are commonly used. The first are open-ditch flashboard riser structures. Flashboards made of treated wood, aluminum, or plastic are added or removed from the riser to control the water level at the outlet. More boards raise the level of the water at the structure, reducing outflow from the drain tile system. The other structure is an inline control system that is attached directly to the subsurface drain tiles. These structures operate on the same premise as the riser structure but can control the flow from individual or groups of pipes, rather than the whole system.[66]

These drain tile control systems could be used to slow down the export of chlorides from agricultural fields through drain tiles. By placing flashboards in riser structures in anticipation of rainfall events or during potash application, runoff containing chloride would not have a direct conduit to surface waters and the chloride load could be more spread out over time, rather than all at once, see Figure 5.ControlledDrainage. These control systems in conjunction with buffer strips provide a better opportunity for plants within the buffer strips to uptake some chloride, but more likely, macronutrients like nitrogen and phosphorus.

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[64] *M.B. David, C.A. Mitchell, L.E. Gentry, and R.K. Salemme, "Chloride Sources and Losses in Two-Tile Drained Agricultural Watersheds,"* Journal of Environmental Quality: 45(1), 341 – 348, *(2016).*

[65] *C.J. Rosen, (2025). Op cit.*

[66] *C. Poole, M. Burchell, and M. Youssef, "Controlled Drainage – An Important Practice to Protect Water Quality That Can Enhance Crop Yields,"* North Carolina State University Extension, *(2023).*

Concluding Remarks and Future Work

Production agriculture can contribute chloride to the environment through the application of synthetic fertilizer (mainly potassium chloride) onto crop fields. While potassium is a macronutrient that is used by plants in large quantities, chloride is used minimally, and thus most of it remains in the field. The excess chloride either remains in the soil, percolates down to groundwater aquifers, or runs off with rainfall into surface water bodies. Chloride ions negatively affect soil structure, reduce the quality of groundwater (used both for drinking and irrigation) and surface water, and are toxic to both plants and biota.

The most effective way to reduce production agriculture chloride inputs into the environment is to minimize excess chloride ions being spread onto fields in the first place (i.e., not over-applying in areas where potash fertilizer is not needed). Traditional edge of field best management practices like filter strips are likely to be largely ineffective in reducing chloride exports from a field. This is because chloride is not needed in large quantities by the BMP plants. Rather, practices like nutrient management plans, soil testing, application of alternative fertilizers, precision fertilizer application, and the use of controlled release fertilizers are more effective in reducing the chloride impacts from synthetic fertilizers.

Soil testing works with nutrient management planning (discussed in Section 5.4) to better inform farmers how much fertilizer is needed and where in the field it is necessary. By doing this, excess applications of fertilizer are reduced. Alternative fertilizers to potassium chloride are available, however most are more expensive and may be cost prohibitive to many agricultural operations. Alternative fertilizers that apply two macronutrients (such as potassium sulfate) may be the most efficient type of alternative fertilizer because it does not contain chloride and supplies two necessary macronutrients to the plant.[67]

In the same vein as nutrient management plans and soil testing, precision agriculture and controlled release fertilizers reduce the excess chloride left in the field. Precision agriculture application of fertilizer centers around the idea of applying fertilizer only where it is needed through informed decision-making using UAVs, remote sensing, and GIS/GPS systems. Controlled release fertilizers use slow-release pellets to increase the exposure of the plant root to fertilizer nutrients. This improves the efficiency of the fertilizer, thus reducing the amount of fertilizer that needs to be applied, which minimizes the excess chloride present in the soil.

[67] *C.M. Geiflus, "Chloride in Soil: From Nutrient to Soil Pollutant and Plant Toxicant"* 2024 Salt Symposium.

More research is needed on ways to reduce excess chloride exports from agricultural fields. While minimizing the sources of chloride currently appears to be the best pathway forward, methods of removing it from the field or from runoff are currently limited. Alternative methods that can remove chloride in large quantities from runoff or shallow groundwater are needed. Regenerative best management practices such as cover crops, compost, and/or biochar show potential by improving soil health, improving nutrient retention from year to year, and thus reducing the need for fertilizer applications in subsequent planting seasons.

5.3 FEEDLOTS AND MANURE MANAGEMENT

Sodium chloride, as well as other less prevalent micronutrients containing chloride, are commonly found in animal feed. Chloride consumed by livestock is excreted in manure which is stored and then applied to permitted agricultural fields. The amount of chloride present in manure varies by animal. More information on animal manure chloride concentrations can be found in SEWRPC Technical Report No. 65, Chapter 3, Table 3.7.[68] Livestock waste is considered a small source of chloride to the environment (0.75 percent of annual chloride loading) when compared to local, state, and private road and parking lot deicing (58.7 percent of annual chloride loading), see SEWRPC Technical Report No. 65, Chapter 4, Figure 4.1.[69]

In Wisconsin, a livestock operation with 1,000 animal units (AU) or more is defined as a Concentrated Animal Feeding Operation (CAFOs). Under state and federal law, CAFOs must have a WDNR-issued Wisconsin Pollutant Discharge Elimination System (WPDES) permit because of the potential for more harmful damage to ground and surface waters from excessive runoff and animal waste, when compared to smaller animal feeding operations. CAFOs are required to have a minimum 180-day manure storage capacity to provide adequate manure storage throughout the winter season and prevent manure spreading on frozen or snow-covered ground.

As part of their WPDES permit, CAFOs are required to have nutrient management plans to guide the spreading of their livestock manure. In addition to nutrient management plans, similar soil testing practices and precision agriculture technologies as described in the prior Agricultural Fertilizer section can be used to apply manure in a more efficient manner that results in less runoff. By limiting runoff of manure to surface water, the impact of the chloride present in the manure can be minimized.

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[68] *SEWRPC Technical Report No. 65,* Mass Balance Analysis for Chloride in Southeastern Wisconsin, *October 2025*

[69] *Ibid.*

Nutrient Management Plans

Nutrient management plans (NMPs) are a practice used to guide the use of manure and other fertilizers to meet crop nutrient needs, while minimizing the potential for excess nutrients to run off fields to lakes, streams, and groundwater.[70] NMPs help farmers apply the right amount of nutrients to their crops, at the optimal time and location they are needed. This benefits farmers by improving crop yields and reducing costs (through needing to apply less nutrients) and benefits the environment by minimizing the application of excess nutrients on fields. In Wisconsin, NMPs must meet requirements in Wisconsin Statute ATCP 50: *Soil and Water Resource Management Program*, Wisconsin Statute NR 151: *Runoff Management*, and Natural Resources Conservation Service (NRCS) Conservation Practice Standard (CPS) 590: *Nutrient Management*. Agricultural operations require NMPs if they fall into one of the following categories:[71]

- Participate in the Farmland Preservation Program
- Offered cost-sharing to develop a plan
- Accept cost-sharing for manure storage systems
- Large livestock operations (greater than 1,000 animal units) that require a WPDES permit
- Regulated under a local ordinance for manure storage or livestock siting

Currently, more than one-third of the 9 million cropland acres in Wisconsin are managed under NMPs. Farmers who are not required to use NMPs but wish to participate may be eligible for financial assistance.[72] WDNR approved nutrient management plans have the following items, at minimum:

[70] *Wisconsin Department of Agriculture, Trade and Consumer Protection, "Nutrient Management," Last modified 2023. datcp.wi.gov/Pages/Programs_Services/NutrientManagement.aspx. (date accessed: October 15, 2024)*

[71] *Wisconsin Department of Agriculture, Trade, and Consumer Protection, 2023,* op. cit.

[72] *Wisconsin Department of Agriculture, Trade, and Consumer Protection provides information on NMP financial assistance and training for farmers, agronomists, and agricultural educators at* datcp.wi.gov/Pages/Programs_Services/NutrientManagement.aspx.

- NRCS 590: Nutrient Management Checklist and DNR Form 3400-25BA narrative containing information on farm operations including animal units and manure/wastewater amounts and disposal methods

- Maps showing restricted spreading areas

- SnapPlus Assessment Report, Nutrient Mass Balance Report, Crop Report, and Soil Test Summary Report

- Manure Analysis

- Information regarding headland stacking (practice of piling solid manure on field edges prior to being field spread)

- Information regarding manure/process wastewater irrigation

- NR 151 Silurian Bedrock Targeted Performance Standards

More information regarding Nutrient Management Plan requirements can be found on the WDNR Nutrient Manage Planning webpage.

The Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) provides a list of available nutrient management planners in each county on their Nutrient Management webpage. Other useful nutrient planning information available to farmers include the *Runoff Risk Advisory Forecast,*[73], University of Wisconsin-Extension Publication A2809: *Nutrient Application Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin*, and NMP Partner agencies with DATCP, including:

- Wisconsin Department of Natural Resources

- University of Wisconsin Extension: Nutrient and Pest Management

- U.S. Department of Agriculture – Natural Resources Conservation Service (Wisconsin office)

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[73] *Available at manureadvisorysystem.wi.gov/runoffrisk/index.*

- Wisconsin Discovery Farms

Regulations Regarding Smaller Animal Feeding Operations

Medium CAFOs are defined as an animal feeding operation with 300 to 999 animal units. Manure spreading for medium CAFOs is not regulated unless they cause a Category I discharge to navigable waters or the operation has caused fecal contamination of water in a groundwater well constructed in accordance with NR 811 or 812.[74] A Category I discharge is defined as an unacceptable practice identified as a point source discharge of pollutants to navigable waters typically through man-made devices (ex: pipes, ditches, etc.). If a small animal feeding operation has less than 300 animal units, it may not be designated as a CAFO based on the above discharge criteria unless the operation had a Category I discharge to navigable waters that is determined to contribute a significant amount of pollutants to navigable waters. If an animal operation under 1,000 animal units has been determined to have committed a Category I discharge, it must complete a WPDES permit and take actions to permanently eliminate or significantly reduce the discharge that was the basis of the designation.

WPDES permit terms and conditions for medium or small CAFOs include the following:

1. Comply with livestock performance standards and prohibitions, regardless of the availability of cost sharing.

2. Address manure, process wastewater and contaminated runoff from the production area in a manner that is consistent with accepted management practices and that treats or contains all manure, process wastewater, and contaminated runoff for storm events up to and including a 25-year, 24-hour storm event.

3. Control all discharges from the production area in a manner that does not cause exceedances of groundwater or surface water quality or impair wetland function values.

4. Develop and implement a nutrient management plan in accordance with NR 243.14 for the land application of manure and process wastewater.

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[74] *Wisconsin Department of Natural Resources, "Wisconsin Administrative Code Chapter 243: Animal Feeding Operations". NR 243.26(1), 243.26(2)(a)2.b.*

5. Comply with the requirements in NR 243.13 (5) (b) and (6) to (8) and 243.142 (5).

6. Conduct periodic inspections of the production area and land application equipment at a frequency specified in the WPDES permit.

7. Conduction manure, process wastewater and soil sampling in accordance with WPDES permit conditions.

8. Maintain and submit reports to the WDNR in accordance with WPDES permit conditions.

Other Manure Management Methods

The aforementioned conservation practices of vegetative/buffer strips and cover crops, precision agriculture techniques, and university extension/outreach that were discussed in the Agricultural Fertilizer section of this Chapter also apply to Manure Management. Vegetative/buffer strips and cover crops detain runoff and uptake nutrients contained in manure such as nitrogen and phosphorus. Precision agriculture technologies can work in tandem with nutrient management plans to optimize nutrient applications by using sensors, GPS, and variable rate applications. This ensures that manure is applied at the correct rate for the specific needs of crops in each part of the field, preventing excess nutrients as well as chlorides from being washed away. University extension/outreach can provide information on cutting edge technology to farmers to better manage and apply manure. Manure incorporation, a technique for reducing manure runoff that was not discussed in the Agricultural Fertilizer section is discussed below.

Manure Incorporation

There are several manure application techniques for both solid and liquid manures, each presenting advantages and disadvantages for nutrient and/or soil loss, ease of application, cost, and equipment needed. Broadcast application of solid and liquid manure is easy, cheap, and can be done regardless of soil conditions (i.e., frozen soil). When done on no-till soil, soil losses are reduced when compared to tilled up soil.[75] However, with broadcast application on no-till soil, from a nutrient standpoint, nitrogen can be lost rapidly due to volatilization, and phosphorus and chloride can easily runoff during rain or snowmelt events.[76] By mixing or incorporating manure that is broadcast applied, the potential for ammonia (nitrogen)

[75] *Minnesota Pollution Control Agency, "Runoff Reductions with Incorporated Manure", May 2018.*

[76] *University of Minnesota Extension, "Manure application methods and nitrogen losses", 2021. extension.umn.edu/manure-management/manure-application-methods-and-nitrogen-losses.*

volatilization is reduced, as well as runoff volume and phosphorus losses. However, if manure is incorporated into the soil in a manner that significantly disturbs the top layer of soil, soil losses during runoff events are increased when compared to no-till broadcast application. Thus, it is important to incorporate manure into the soil in a manner that does not significantly disturb the soil structure.

The following field application methods only work for liquid manure, as they involve the injection of the manure into the sub-surface of the soil. It is generally thought that injection practices reduce odors, ammonia gas loss, nutrient loss, and soil loss. In addition, manure is injected into the soil where the rooting zone of the crop will eventually be, potentially increasing the amount of nutrients available to the crop. However, injection methods are considered more expensive than broadcast applications, as they require specific implements, take longer to perform, and require more tractor horsepower and fuel. The following manure injection methods are available:

- Knife injection involves using vertical shanks, shaped like knives, pulled through the soil, creating a thin vertical slot for manure to be placed. This method reduces nutrient loss by concentrating manure into small, vertical strips in the soil. However, there is the concern that manure in these vertical strips is not optimal for plant growth.

- Sweep injection involves creating a broad horizontal band of manure below the soil surface, improving the access of plant roots to the manure when compared to knife injection. This is done by inserting the blade beneath soil surface prior to tilling. Once the blade is inserted into the ground, it is pulled, creating a furrow beneath the soil surface that manure is injected into. By doing this, manure is delivered to the plant root zone without significantly disturbing the soil surface. Sweep injection does require a tractor with more horsepower to pull the implement through the soil.

- Disk or coulter injection systems use a rolling disk, or wavy disk, called a coulter, to open a vertical slot in the soil for manure. This method requires less horsepower than knife or sweep injections but if manure is applied at too high of a rate, it may still end up on the surface if the slots overflow.

Anaerobic Digestion

Another manure management method to deal with excess agricultural livestock manure is anaerobic digestion. Anaerobic digestion is a process through which bacteria break down organic matter, such as animal manure, wastewater biosolids, and food wastes in the absence of oxygen.[77] Anaerobic digestion takes place in a sealed vessel called a reactor. Reactors contain microbes that digest (break down) waste and produce biogas and digestate.

Anaerobic digestion biogas is composed of methane, carbon dioxide, hydrogen sulfide, water vapor, and other trace gases. The energy in bigas can be used like conventional natural has to provide heat, generate electricity, and power cooling systems. The digestate material is the residual organic material left after digestion. The digestate material has a solid and liquid fraction, which can be used in many ways, but most relevant to manure management is as a fertilizer for agricultural fields. Using digestate as manure can improve soil health by converting the nutrients in manure to a more accessible form for plants to use, destroying pathogens already present in manure, and help protect local water resources by reducing nutrient runoff.

Concluding Remarks

Nutrient Management Plans (NMPs) guide the timing, location, and quantity of manure and fertilizer applications to match crop needs, minimizing excess nutrients and chlorides that could reach surface or groundwater. Smaller animal feeding operations may also be required to obtain WPDES permits if they discharge pollutants to navigable waters. Additional practices such as buffer strips, cover crops, precision agriculture, and manure incorporation or injection can further reduce nutrient and chloride losses and runoff volume. Technologies like anaerobic digestion also help manage manure sustainably by producing energy and converting nutrients into more plant-available forms while reducing pathogens and runoff risk.

Overall, these agricultural practices can be viewed as proactive in nature, as they focus on preventing contamination of surface and groundwater before it occurs by controlling manure application, storage, and treatment. With respect to smaller animal feeding operations, these practices can be reactive, as action is typically not required until a violation takes place. This emphasizes a need for a broader framework of regulation and extension for farmers that focuses on prevention of manure violations through planning, improving management, and adoption of BMPs that reduce runoff and nutrient loss at the source.

[77] *U.S. Environmental Protection Agency, "AgSTAR: Biogas Recovery in the Agriculture Sector" 2024. epa.gov/agstar.*

5.4 INDUSTRIAL FOOD PROCESSES

Background, Typical Wastewater Contaminants, and Sources of Chloride

This section discusses major industrial food sources of chloride to the environment. In the Region, major industrial food sources include dairy processing, meat processing, and canning of fruits and vegetables. This section will discuss how these industries come to have chlorides in their wastewater streams, the typical chloride and chemical levels observed, and methods for removal of chlorides from the wastewater stream at the industrial site, as well as the ability from these methods to be implemented in the Region.

Dairy Processing

The dairy food production and processing industry is generally described as the transformation of raw milk into the following, but not limited to, products: pasteurized and sour milk, yogurt, hard cheese, soft cheese, and cottage cheese, cream and butter products, ice cream, milk and whey powders, lactose, condensed milk, as well as various types of desserts.[78] In Wisconsin, in 2022, the dairy industry accounted for $52.8 billion in industrial revenue (6.5 percent of the state total) and supported 120,700 jobs (3.3 percent of the total state employment).[79] This included $1.6 billion in revenue (0.6 percent of all regional revenue) and around 3,000 jobs (0.2 percent of the jobs) in the Region. There are 35 dairy processing plants in the Region licensed by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP). Nine of the dairy procession plants in the Region are Grade B (milk used in the production of cheese, butter, or nonfat dry milk) processing plants producing more than one million pounds of product per year, 23 are Grade B plants processing less than or equal to one million pounds per year, and six are Grade A (milk that qualifies for beverage consumption) processing plants or receiving stations.[80] Some plants process both Grade A and Grade B milk.

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[78] *T.J. Britz, C. van Schalkwyk, and Y. Hung, "Treatment of Dairy Processing Wastewater"* Handbook of Industrial and Hazardous Wastes Treatment, *2nd Edition, 2004)*; *F. Carvalho, A.R. Prazeres, and J. Rivas, "Cheese whey wastewater: Characterization and treatment"* Science of The Total Environment*, 445-446: 385 – 396, 2013; D. Karadag, O.E. Köroğlu, B. Ozkaya, and M. Cakmakci, "A review on anaerobic biofilm reactors for the treatment of dairy industry wastewater,"* Process Biochemistry, *50(2): 262-271, 2015; M.H. Nadais, M.I. Capela, L.M. Arroja, Y. Hung, "Anaerobic Treatment of Milk Processing Wastewater",* Environmental Bioengineering, *11, 555-627, 2010.*

[79] *S. Deller, J. Hadachek, and L. Polzin, "The Contribution of Dairy to the Wisconsin Economy,"* University of Wisconsin-Extension, *2024.*

[80] *State of Wisconsin Department of Agriculture, Trade and Consumer Protection, "Dairy Plant Resources", datcp.wi.gov/Pages/Programs_Services/DairyProcessors.aspx*

Water requirements in dairy processing are considerable, as it is used in every step of the process, including cleaning, washing, disinfecting, heating, and cooling. While the amount and characteristics of dairy plant wastewater largely depend on the factory size, applied technology, effectiveness and complexity of clean-in-place methods, and good manufacturing practices, the designed volumetric load of wastewater effluent is one cubic meter per metric ton (2,204.6 pounds) of manufactured milk .[81] The large range of dairy products produced results in a large range of wastewater characteristics. The range of typical contaminants in untreated wastewater for selected dairy products is shown in Table 5.DairyProductsUntreatedWWCharacteristics.

Similar to other contaminants in dairy wastewater, chloride concentrations in wastewater range depending on the products created, and the processes utilized. Literature reports concentrations of chloride ions in untreated wastewater from milk and dairy products factories at 616 mg/l, 80 to 1,000 mg/l (average of 150 to 200 mg/l), and 46 to 1,930 mg/l (average of 483 mg/l).[82] Conventionally treated (using a sequence of physical, chemical, and biological processes to remove organic matter, suspended solids, and nutrients from wastewater before discharge) dairy processing wastewater had a chloride concentration range from 24.8 to 92.9 mg/l.[83] Chloride is considered a "conservative pollutant" in wastewater, meaning it is not subject to significant reduction in conventional biological treatment found in most wastewater treatment systems; Appreciable reduction of chloride would require advanced treatment such as reverse osmosis or ion exchange.[84] The largest source of chloride in wastewater from dairy plants is the brine used to salt the cheese during processing, while other chloride sources are water softeners, cooling liquors, and the baseline concentration in source water and milk.[85]

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[81] *A.K. Slavov, "General Characteristic and Treatment Possibilities of Dairy Wastewater - A Review,"* Food Technology and Biotechnology, *55(1): 14-28, 2017.*

[82] *C. Onet, "Characteristics of the Untreated Wastewater Produced by the Food Industry,"* Annals of the University of Oradea, Fascicle: Protection of the Environment, *15: 709 -714, 2010; United States Environmental Protection Agency, "Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Dairy Product Processing Point Source Category," 1974; Slavov, 2017, Ibid.*

[83] *A. Tikariha and O. Sahu, "Study of Characteristics and Treatment of Dairy Industry Waste Water,"* Journal of Applied & Environmental Microbiology, *2(1): 16 – 22, 2014.*

[84] *U.S. Environmental Protection Agency, 1974,* op cit.

[85] *State of Wisconsin Department of Natural Resource, "Waste Management Issues for Dairy Processers," 1998; Slavov, 2017,* op cit.

Meat Processing

Meat processing is defined as a facility that produces meat and/or poultry products (MPP) by performing one or more of the following operations:

- Slaughter livestock (e.g., cattle, calves, hogs, sheep, and lambs), poultry (e.g., chickens, turkeys, and small game such as rabbits), or both.
- Further processing of meat, poultry, or both.
- Render waste from slaughter and further processing operations (e.g., bones, feathers, and fat).

Slaughter facilities, also called first processing or harvesting facilities, receive and hold live animals, slaughter them, and produce a raw dressed product, either in whole or in parts. These products are then further processed (either onsite or after transport to a different further processing facility) or sold to distributors, retailers, or consumers. Further processing facilities use whole carcasses or cut up meat or poultry parts to create consumable products. A facility that performs both first and further processing activities under the same roof is known as an integrated facility.[86]

Meat processing generates wastewater during the carcass washing process, during hide and hair removing (e.g., scalding), evisceration, and the cleaning and sanitation of equipment and facilities. Typically, slaughter operations use more water than further processing activities. The main sources of waste entering the waste stream are from materials such as blood, internal organs, soft tissues, bones, manure (urine and feces), dirt from hides and hooves, and cleaning/sanitizing chemicals. Further processing and hide treatment operations can add additional pollutants from fats, soft tissues, brine, cooking oils, and tanning agents. Table 5.IntegratedMeatProcessingFaciltiesWWContaminants outlines the typical pollutants found in untreated meat processing wastewater from integrated facilities.

In poultry processing, the majority of wastewater is produced during scalding for feather removal, bird washing before and after evisceration, chilling, and cleaning and sanitizing of equipment and facilities. Poultry first processing facilities typically generate more wastewater than meat first processing plants, primarily due to continuous overflow from scalding tanks and immersion of carcasses in ice bath chillers.

[86] *U.S. Environmental Protection Agency, "Technical Development Document for Proposed Effluent Limitations Guidelines and Standards for the Meat and Poultry Products Point Source Category," 2023.*

Common waste materials from poultry processing include blood, feathers, internal organs, soft tissue, manure, bones, dirt from feathers, and a variety of cleaning and sanitizing chemicals. Further processing can also contribute fats, soft tissue residues, pickling brine, and cooking oils to the waste stream. Table 5.PoultryFaciltiesWWContaminants outlines the main pollutants from untreated wastewater from poultry processing operations.

Meat rendering plants convert the remainder fatty wastes from slaughter and processing facilities into useable products like lard and tallow. The majority of wastewater from rendering operations is produced during raw material receiving, condensing cooking vapors, drying, facility cleanup, and truck and barrel washing. The characteristics of the wastewater generated by rendering facilities are influenced by multiple variables, including the type of final product (e.g., edible vs. inedible) and the composition of the raw materials. Operational parameters such as cooking rate, agitation speed, cooker loading conditions, foams, and the presence (or absence) of grease traps contribute to significant variability in both wastewater volume and composition across facilities. In some operations, solids recovered from dissolved air flotation (DAF) (see *Typical In-Place Wastewater Treatment Processes* for more information about DAF) are recycled into the rendering process. Table 5.RenderingFacilityWWContaminants shows the average pollutant concentrations in untreated wastewater from independent (i.e., facilities not under the same roof as slaughter or processing facilities) rendering facilities.

In the meat and poultry processing industry, high chloride wastewater is defined as a specific type of processing wastewater generated from the hide processing, kosher slaughter, curing, smoking, pickling, and marinating processes. Certain meat processing plant wastewaters containing elevated chloride concentrations can be segregated at the point of generation. Excessive salt levels in wastewater pose significant challenges for downstream water use, including undesirable taste, increased water treatment cost, staining, corrosion of infrastructure, scaling within plumbing systems, and limitations on reuse for agricultural irrigation. Traditional meat curing and brining operations employ formulations with a salt-to-water ration of one cup per gallon, corresponding to salt concentrations ranging from 7 to 10 percent by weight (approximately 70,000 – 100,000 mg/l).[87] This concentration range aligns with the optimal water binding capacity of proteins in meat products. Although the reuse of brine solutions is technically feasible,

[87] *U.S. Environmental Protection Agency, 2023,* op cit.

it typically results in further elevated salt concentrations, which is not suitable for all subsequent processing steps.[88] Consequently, spent brine is often discharged as wastewater.

Kosher processes for meat and poultry commonly utilize chloride-based compounds. However, opportunities exist to lower the chloride concentration in the resulting wastewater. A study conducted at a kosher poultry processing facility demonstrated that implementing a dry tumbling system to isolate the high chloride waste stream from the rest of the waste stream can result in an 80 to 85 percent reduction in the total dissolved solids (TDS) and chloride concentrations in the discharged effluent. At this facility, the segregated high chloride waste stream had chloride levels of approximately 24,000 mg/l.[89]

In the hide curing process, a substantial amount of salt (containing chlorides) is utilized to preserve raw hides. Raw bovine hides are typically preserved with salt levels equating to approximately 50 percent of the hide weight or in a 95 percent saturated brine solution. During the soaking process, approximately 75 percent of the applied salt is released into the effluent. One study reported that salt may constitute up to 40 percent of the total solids in tannery wastewater.[90]

Most meat and poultry processing facilities rely on potable water sources, either from municipal supplies or on-site wells, for all process water requirements. These facilities frequently implement water softening systems to prevent scale formation and maintain compliance with food grade production standards.[91] Ion exchange is the most common method for water softening at these facilities, which involves the use of sodium chloride brine solutions to remove water hardness from the waste stream. The sodium chloride brine can contain chlorides at concentrations ranging from 8 to 20 percent (80,000 to 200,000 mg/l). Post

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[88] *L. Du, G.-H. Zhou, X.-L. Xu, and C.-B. Li, "Study on kinetics of mass transfer in water-boiled salted duck during wet-curing,"* Journal of Food Engineering: 100(4), 578 – 584, *(2010).*

[89] *U.S. Environmental Protection Agency, "Summary of High Chlorides Wastewater,"* DCN MP00305, *(2023).*

[90] *M. Sarker, W. Long, and C.-K. Liu, "Preservation of Bovine Hide Using Less Salt with Low Concentration of Antiseptic, Part I: Effectiveness of Developed Formulation,"* Journal of American Leather Chemists Association: 113(1), 12 – 18, *(2018).*

[91] *U.S. Environmental Protection Agency, "Abbyland Foods Abbotsford, WI Site Visit Report (July),"* DCN MP00276, *(2022)*; *U.S. Environmental Protection Agency, "Swift Beef Company, Hyrum Plant Site Visit Report (August),"* DCN MP00138, *(2022).*

softening, the spent brine is typically discharged with wastewater, introducing a concentrated load of chlorides into the wastestream.[92]

Fruit/Vegetable Canning

The fruit and vegetable canning industry is primarily processing facilities that engage in manufacturing canned, pickled, and brined fruits and vegetables. Examples of products made in these establishments are canned juices; canned jams and jellies; canned tomato-based sauces, such as ketchup, salsa, chili sauce, spaghetti sauce, barbeque sauce, and tomato paste; and pickles, relishes, and sauerkraut.[93]

A typical flow diagram for the vegetable canning process is shown in Figure 5.VegetableCanningProcessDiagram. The primary objective of the canning process is to destroy any microorganisms in the food and prevent recontamination by microorganisms. Heat is the most common agent to destroy microorganisms, but removal of oxygen can be used in conjunction with other methods to prevent the growth of aerobic microorganisms.[94]

Like the previously discussed dairy and meat processing wastewater, high levels of organic matter and suspended solids are the main contaminants of concern in vegetable canning wastewater.[95] While the amount and characteristics of wastewater produced varies by the vegetable(s) processed, Table 5.VegtablesWWCharacteristics shows wastewater volume and characteristics of selected vegetables.

Chlorides and salts are introduced to the process during the 'wash' and 'can filler' stage, where a brine solution is added to the vegetables in the can. Brine solution is added to cans, at a salt concentration of 1.5

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[92] *Z. Liu, M. Haddad, S. Sauve, and B. Barbeau, "Alleviating the Burden of Ion Exchange Brine in Water Treatment: From Operation Strategies to Brine Management,"* Water Research: 205, *(2021)*.

[93] *U.S. Department of Commerce, International Trade Administration, "U.S. Industrial Outlook 1992—Food and Beverages, (1992); North American Industry Classification, "2022 Census of Manufacturers – 311421 Fruit and Vegetable Canning", (2022).*

[94] *B.S. Luh and J.G. Woodroof, ed., "Commercial Vegetable Processing" 2nd edition, (1988); J.L. Jones, M.C.T. Kuo, P.E. Kyle, S.B. Radding, K.T. Semrau, and L.P. Somogyi, "Overview Of Environmental Control Measures and Problems In The Food Processing Industries"*, Industrial and Environmental Research Laboratory, Food and Wood Products Branch, *(1979); N.W. Deroiser, "The Technology Of Food Preservation", 3rd edition, (1970).*

[95] *U.S. Environmental Protection Agency, "Liquid Wastes From Canning And Freezing Fruits and Vegetables",* National Canners Association Western Research Laboratory, (*1971).*

to 8 percent (15,000 to 80,000 mg/l), depending on the vegetable and intended product.[96] The purpose of the brine solution is to maintain the flavor of the vegetables during the canning process.

Typical In-Place Wastewater Treatment Processes

The USEPA identifies four categories of wastewater dischargers: direct dischargers (facilities discharging to surface water), indirect dischargers (facilities discharging to a public wastewater treatment plant (WWTP)), direct and indirect dischargers (facilities with both direct and indirect discharge), and zero dischargers (facilities that generate wastewater but do not discharge it to a WWTP or surface waters). One option for facilities to achieve zero discharge is through land application of their treated wastewater, either on or off site. Other options to achieve zero discharge are through complete reuse, subsurface injection (not in Wisconsin), or the use of septic tanks. The following sections describe end-of-pipe wastewater treatment practices and technologies for process wastewater treatment that may be on-site for direct dischargers and zero dischargers (prior to final disposal). Not all facilities have all forms of treatment on-site (i.e., primary treatment, biological treatment, phosphorus removal, etc.), but most facilities perform at least preliminary treatment before discharging, as well as adhering to local water quality standards. It should also be noted that these treatment processes are not specifically designed to remove chlorides from the waste stream and thus achieve poor removal efficiency of chlorides. Processes with the potential to perform meaningful chloride reduction from waste streams are discussed separately in the *Potential Chloride Removal Processes* section.

Preliminary Treatment

At most industrial facilities, the initial stage of wastewater treatment is preliminary treatment, also referred to as pretreatment. This stage consists of a screen or similar device to remove large debris from the wastewater stream, such as feathers, offal, bones, and cartilage chunks. Effective removal of large debris, such as feathers, offal, bone trimmings, cartilage (meat), and large fruit/vegetable scraps (canning) is critical. These materials can impair downstream treatment processes, damage mechanical components, or reduce overall system efficiency. For facilities that discharge their effluent to a WWTP, the preliminary treatment unit may be the sole treatment stage within the facility. For facilities that treat their wastewater onsite, preliminary treatment is typically followed by primary treatment.

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[96] *S. Featherstone, "A Complete Course in Canning and Related Processes: Volume 1 Fundamental Information on Canning,"* Woodhead Publishing Series in Food Science, Technology and Nutrition, *(2015).*

Primary Treatment

Primary treatment removes particulates that can be settled out as well as floating solids. This is typically accomplished with sedimentation basins and skimming, respectively. Chemicals can be added to facilitate coagulation and flocculation[97] to aggregate the solids, making them easier to remove. Table 5.PreliminaryandPrimaryTreatmentUnits outlines common types of preliminary and primary treatment processes employed in the food processing industry, including dissolved air flotation systems; mechanical separators; catch basins for the effective removal of oil, grease, and suspended solids; flow equalization basins; and chemical addition. After primary treatment, the wastewater typically gets routed to secondary, or biological, treatment.

Biological Treatment

Following primary treatment, biological treatment is employed to further reduce wastewater pollutant loads. This stage utilizes microbial processes to decrease biochemical oxygen demand (BOD) and chemical oxygen demand (COD) through the degradation and assimilation of organic matter by microorganisms during respiration and biomass synthesis. In addition to organic matter removal, biological treatment also facilitates nitrogen removal through the nitrification and denitrification processes.

Nitrification is an aerobic, two-step process. In the first step, *Nitrosomonas* bacteria oxidizes ammonia (NH_3) to nitrite (NO_2^-). In the second step, *Nitrobacter* bacteria further oxidizes nitrite to nitrate (NO_3^-), Effective nitrification requires adequate oxygen levels, sufficient microbial biomass, and adequate hydraulic retention time to ensure complete conversion of ammonia to nitrate.[98] Denitrification is an anoxic process in which heterotrophic bacteria convert nitrate and nitrite into gaseous forms such as nitrous oxide (N_2O) and nitrogen (N_2), effectively removing nitrogen from the wastewater stream. This step occurs under low oxygen conditions and requires a suitable carbon source to support bacterial metabolism. Common biological treatment systems used in facilities to achieve nitrification/denitrification are summarized in Table 5.BiologicalTreatmentUnits.

Phosphorus Removal

In addition to nitrogen removal, some facilities incorporate phosphorus removal techniques as a part of their biological treatment systems. Biological phosphorus removal is achievable because microorganisms

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[97] *Flocculation is the process of aggregating organic matter into larger masses that can be removed mechanically or by settling.*

[98] *Metcalf & Eddy, Inc., "Wastewater Engineering: Treatment, Disposal, and Reuse. 4th ed.,"* DCN MP00334, *(2003).*

involved in wastewater treatment require phosphorus for cellular synthesis and energy transfer processes. Under certain conditions, specific microbial populations, known as phosphate-accumulating organisms (PAOs), can be enriched to uptake and store excess phosphorus within their cells.

Biological treatment systems such as sequencing batch reactors (SBRs), Bardenpho, and modified Bardenpho configurations are commonly employed to facilitate the simultaneous removal of nitrogen and phosphorus. These systems create alternating anaerobic and anoxic zones that promote the growth and activity of PAOs alongside nitrifying and denitrifying bacteria. While effective, biological phosphorus removal general achieves moderate levels of phosphorus reduction and may not reach the lower discharge limits required in some regulatory frameworks.

For more advanced or stringent phosphorus limits, facilities may utilize chemical precipitation or other tertiary treatment methods, as outlined in Table 5.PhosphorusRemovalUnits. These processes typically provide a higher degree of phosphorus removal compared to biological processes alone.

Disinfection

Following biological treatment, facilities may implement additional treatment steps to achieve the removal or inactivation of pathogenic microorganisms. Disinfection is a critical component of the treatment process, particularly for facilities that discharge treated effluent directly to surface waters. It ensures compliance with public health standards and environmental discharge permits.

In meat processing, disinfection is more commonly applied at first processing facilities, where the volume and biological load of wastewater are typically higher, compared to further processing facilities. Table 5.DisinfectionTreatmentUnits outlines commonly used disinfection methods.

Solids Handling

Solids (also known as biosolids or sludge) are typically generated from the primary treatment and biological treatment processes. In order to properly dispose of the solids, further treatment is required before disposal through land applications such as fertilizer for agricultural fields, off-site landfilling, off-site composting, or incineration. Sludge that is disposed of in a landfill must meet the specifications of the facility, such as allowable water content. Most solids must be dewatered before land application. Dewatering is practice of removing water from the solids using a centrifuge (a long drum that spins). The solids enter one end of the centrifuge and then using centrifugal forces, are pulled to the outside of the drum while the water drains through the center. The remaining water is then returned into the liquid stream of a treatment plant to undergo continued treatment.[99] Solids are dewatered prior to land application to reduce volume and weight, which reduces transportation and disposal costs. A lower liquid fraction in the waste also reduces the potential for runoff from the waste. The EPA and WDNR require the contents of biosolids to be periodically tested prior to land application. These test results identify potentially hazardous metals present in the solids, as well as inform the application rate of the solids to the fields (in a similar way to Nutrient Management Plans do for manure/fertilizer). In addition to testing, biosolid applications must meet standards listed in WI Administrative Code NR 204 and USEPA Code of Federal Regulations 40. Part 503. Site criteria for land application can be found in Table B of NR 204.[100] Techniques for the treatment of sludge are listed in Table 5.SolidsHandlingTreatmentUnits.

Chloride Removal Alternatives

Most facilities that generate wastewater streams with high chloride concentrations collect and combine these streams with other wastewater flows. This practice results in dilution of the high chloride concentration prior to treatment, however it does not reduce the overall amount of chlorides in the waste stream. The combined wastewater is subsequently conveyed to the existing end-of-pipe treatment system prior to discharge, either to surface waters and/or a WWTP. Conventional wastewater treatment systems do not remove chloride, thus, chloride ions remain untreated and are ultimately discharged into the environment. Some facilities separate their high chloride concentration waste stream using dedicated floor drains, separate process piping, or isolated buildings. This allows for separate management of the high chloride concentration wastewater, facilitating the potential for targeted treatment or alternative disposal methods.

Reverse Osmosis

Reverse osmosis (RO) is the process of using pressure to push water through a semipermeable membrane, leaving chloride and other dissolved solids and larger compounds on the feed water side of the membrane as reject flow. Figure 3.4 in Chapter 3 of this Report conceptually shows this process. RO systems can have a recovery rate of 70 to 80 percent,[101] which is defined as the amount of feed water that passes through the

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[99] *City of Fond Du Lac Wastewater Treatment & Resource Recovery Facility, "Biosolids Management," 2018. fdl.wi.gov/wastewater/biosolids-management/*

[100] *Wisconsin Department of Natural Resources, "Wisconsin Administrative Code Chapter 204: Domestic Sewage Sludge Management," 1996.*

[101] *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.*

membrane to become permeate[102]. Chapter 3 of this Report contains further details on chloride removal with reverse osmosis systems. RO can achieve a high removal efficiency of chloride and other dissolved solids of up to 98 percent.[103] In Wisconsin, a reverse osmosis system was installed at a seasonal vegetable canning facility in response to regulatory pressure from the city to reduce the chloride load in its wastewater going to the WWTP. The facility wastewater treatment process was upgraded to include a reverse osmosis system upstream of the water softeners, decreasing the frequency of the water softener regeneration cycles, reducing the production of sodium chloride brine. Resulting chloride loads in wastewater dropped from 12,656 mg/l in 2009 to 2,442 mg/l in 2010. An RO system was installed upstream of the water softeners removing hardness prior to the water softeners. Water softeners were then used to remove any remaining hardness issues after RO processing. The reduction in load on the water softeners reduced the need to recharge the water softeners with NaCl brine, thus reducing the chloride added to the water. The RO system also reduced soft water demand by 29 percent and wastewater production by 250,000 gallons per year. Annually, this resulted in $11,000 savings (2010 cost) from reduced water softener use and city and sewer maintenance.[104]

Drawbacks for reverse osmosis systems include high energy consumption during operation and membrane fouling that requires continuous chemical cleaning.[105] Specific energy requirements for high salinity water can reach 4 kilowatts per cubic meter of water.[106] This high energy requirement can present a significant

[102] *Permeate is the treated water that has passed through the RO membrane.*

[103] *Y. Li, Z. Yang, K. Yang, J. Wei, Z. Li, C. Ma, X. Yang, T. Wang, G. Zeng, Z. Yu, and C. Zhang, "Removal of chloride from water and wastewater: Removal mechanisms and recent trends",* Science of the Total Environment: 821, *(2022). 10.1016/j.scitotenv.2022.153174*

[104] *Veolia Water Technologies, "Canning Facility reduces chloride discharge by 80%, meeting tightening city regulations", (2022). watertechnologies.com/case-study/canning-facility-reduces-chloride-discharge-80-meeting-tightening-city-regulations*

[105] *S.M. Shalabay, S.W. Sharshir, A.E. Kabeel, A.W. Kandeal, H.F. Abosheiasha, M. Abdelgaied, M.H. Hamed, and N. Yang, "Reverse osmosis desalination systems powered by solar energy: Preheating techniques and brine disposal challenges – A detailed review*," Energy Conversion and Management: 1, *(2022).* doi.org/10.1016/j.enconman.2021.114971

[106] *L.F. Greenlee, D.F. Lawler, B.D. Freeman, B. Marrot, and P. Moulin, "Reverse osmosis desalination: Water sources, technology, and today's challenges",* Water Research: 43(9), 2317 – 2348, *2009.* doi.org/10.1016/j.watres.2009.03.010; *R.F. Service, "Desalination Freshens Up",* Science: 313(5790), 1088 – 1090, *2006.* doi.org/10.1126/science.313.5790.1088

obstacle for some facilities. However, integration with renewable energy sources such as solar, wind, geothermal, and biomass present opportunities for offsetting the significant energy requirements.[107]

RO systems can create finished water that is nearly free of chloride and many other substances that can be discharged to surface waters. However, the waste brine material from RO systems used to remove chloride requires disposal. The brine reject would contain high levels of chloride as well as other pollutants such as metals, nutrients (ammonia, nitrate and phosphorus), organic chemicals (endocrine disruptors and pesticides), effluent organic matter (particularly in the food processing industry), and pathogens, potentially at elevated concentrations.[108] Chapter 3 of this Report discusses brine disposal handling and considerations in further detail.

Other less common methods for chloride discharge reduction that are in use at food processing facilities are discussed below, including brine evaporation ponds, mechanical evaporation systems, and deepwell injection.

Brine Evaporation Ponds

Brine evaporation ponds are a method of disposing of salt-laden wastewater, common to areas of arid and semi-arid climates.[109] Specifically, these lagoons require climates with net evaporation conditions (i.e., more evaporation than precipitation). Shown in Figure 5.EvaporationPond, evaporation pounds work by

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[107] *M. Faegh and M.B. Shafii, "Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes",* Desalination: 409, 128 – 135, *(2017). doi.org/10.1016/j.desal.2017.01.023; B. Wu, A. Maleki, F. Pourfayazm and M.A. Rosen, "Optimal design of stand-alone reverse osmosis desalination driven by a photovoltaic and diesel generator hybrid system",* Solar Energy: 163, 91 – 103, *(2018). doi.org/10.1016/j.solener.2018.01.016; P.A. Davies, "Wave-powered desalination: resource assessment and review of technology",* Desalination: 186(1 – 3), 97 – 109, *(2005). doi.org/10.1016/j.desal.2005.03.093; E. Tzen and R. Morris, "Renewable energy sources for desalination",* Solar Energy: 75(5), 375 – 379, *(2003). doi.org/10.1016/j.solener.2003.07.010; M.A. Abdelkareem, M.E.H. Assad, E.T. Sayed, and B. Soudan, "Recent progress in the use of renewable energy sources to power water desalination plant",* Desalination: 435, 97 – 113, *(2018). doi.org/10.1016/j.desal.2017.11.018; H. Tanaka, "Thermal distillation system utilizing biomass energy burned in stove by means of heat pipe".* Alexandria Engineering Journal: 55(3), 2203 – 2208, *(2016).* doi.org/10.1016/j.aej.2016.06.008

[108] *D. Ghernaout, "Brine Recycling: Toward Membrane Processes as the Best Available Technology,"* Applied Engineering: 3(2), 71 – 84, *(2019).*

[109] *M. Ahmed, W.H. Shayya, D. Hoey, A. Mahendran, R. Morris, and J. Al-Handaly, "Use of evaporation ponds for brine disposal in desalination plants,"* Desalination: 130(2), 155 – 168, *(2000).*

evaporating chloride-free water into the atmosphere from high-chloride wastewater in the pond, leaving behind salt deposits. Advantages of brine evaporation ponds include ease of construction, low maintenance, and minimal operator attention, as compared to mechanical evaporation systems. Disadvantages include the requirement of large areas of land where the evaporation rate is high and the need for an impervious layer below the pond to protect groundwater from potential contamination. Southeast Wisconsin has a humid continental climate, characterized by having cold winters, warm summers, and most of the rain falling during the growing season.[110] This climate is not conducive to effective brine evaporation pond operation, and thus this method would not be effective in the Region.

Mechanical Evaporation Systems

Facilities can also use mechanical evaporation systems to remove chlorides. Mechanical evaporation systems actively force evaporation rather than rely on passive evaporation as occurs in brine evaporation ponds These systems have smaller physical footprints compared to evaporation ponds and can be used in any climate. These systems promote evaporation of high chloride concentration wastewater, leaving behind salt crystals and producing clean steam.[111] One example of a mechanical evaporation technology is a submerged combustion evaporator, which uses a heat exchanger to evaporate water by combusting fuel and releasing the heat directly into the water. An advantage of these systems is their effectiveness in evaporating water from solutions that have a high likelihood to foul or scale, such as brine.[112] Saltwater solutions can be concentrated, and the insoluble salts are precipitated out. The main disadvantage of submerged evaporation is that cooling water is needed for larger systems to prevent heat damage.

More often, facilities use mechanical evaporation for high chloride waste streams using forced circulation evaporators, which use steam with a heat exchanger and condenser to evaporate water and recover solids, a process diagram is shown in Figure 5.MechanicalEvaporatorDiagram. High chloride wastewater is fed into a feed or surge tank, where flow and concentration fluctuations are controlled to ensure consistent chloride loading and to prevent damage to downstream equipment. From the surge tank, wastewater is circulated at a high velocity by a forced circulation pump through a heat exchanger, where it is heated using steam to

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[110] *Wisconsin State Climatology Office: University of Wisconsin-Madison, "Historic Climate Data", climatology.nelson.wisc.edu/wisconsin-climate-divisions/climate-normals/*

[111] *B.K. Pramanik, L. Shu, and V. Jehatheesan, "A review of the management and treatment of brine solutions,"* environmental Science" Water Resources Technology: 3, 625 – 658, *(2017).*

[112] *J.L. Bagley, "Consider Submerged Combustion for Hot Water Production,"* Heat Transfer, *(2002).*

a temperature close to its boiling point.[113] The heated brine liquor then enters a lower pressure flash/separator vessel, where a portion of water instantaneously evaporates. This phase change produces a water vapor steam containing little to no chlorides and a liquid brine with an increased chloride concentration (chloride concentration increases not because of chloride removal, but because of water removal from the waste stream). The water vapor steam is routed to a condenser, where it is condensed into a low chloride distillate. The concentrated brine from the separator is not immediately discharged but is continuously recirculated back to the forced-circulation pump, inducing repeated evaporation cycles in which water is progressively removed, and the chloride concentration incrementally increases. The chloride concentration in the recirculating brine is monitored until the desired concentration is achieved. Once the target concentration is reached, a blowdown stream is withdrawn to prevent excessive salt buildup. The removed high chloride blowdown is directed to a handling unit such as a crystallizer for salt recovery, an evaporation pond, hazardous waste disposal, or a zero-liquid discharge system.

Overall, mechanical evaporation systems present a viable alternative for the recovery of salts from industrial waste streams, with nearly zero liquid discharge and smaller physical footprints than brine evaporation ponds. However, the systems are costly and energy intensive, have a high carbon footprint, and may not be feasible on a larger industrial scale.[114]

Deepwell Injection

Facilities may dispose of their high chloride wastewater using deepwell injection via Class I wells. Class I wells are used to inject hazardous and nonhazardous waste into deep, confined rock formations, typically thousands of feet below the lowermost local drinking water wells. However, in Wisconsin, per NR 815.06 (1), construction of Class I injections wells or use of a well as a Class I injection well is prohibited. Also prohibited is the use of a well to place a hazardous waste underground (NR 665.0430), use of a well to place

[113] *Boiling is intentionally avoided within the heat exchanger to minimize scaling and fouling by chloride salts.*

[114] *A. H. P. Swift, H. Lu, B. Humberto, "Zero discharge waste brine management for desalination plants,"* Desalination, Research and Development Program Report No. 89, US Department of the Interior Bureau of Reclamation Technical Service Center, Water Treatment Engineering and Research Group, Denver, Colorado, *(2002).*

municipal or domestic wastewater underground (NR 206.07 (2) (d)), and use of a well to place a pollutant underground (NR 214.04 (3)).[115]

Deepwell injection may be an appropriate method of disposing of high chloride waste streams in areas inland, away from coastlines, low seismic activity, and away from geological fault lines.[116] Given the proximity of the Region to Lake Michigan and Wisconsin law prohibiting the use of deepwell injection, it is not a suitable method for disposing of high chloride waste streams in southeast Wisconsin.

Concluding Remarks

Traditional wastewater treatment systems used in food processing facilities, including primary, biological, and nutrient removal processes, are not designed to remove chloride. Consequently, chloride ions remain in wastewater and can be discharged to surface water or downstream WWTP, contributing to damage to human infrastructure and the environment. Some industrial facilities use reverse osmosis (RO), a pressure driven membrane separation process, capable of achieving rejection rates of up to 98 percent. However, RO systems face technical challenges such as membrane fouling and high energy consumption, which could necessitate integration with renewable energy sources in the future. Additionally, RO generates a high pollutant reject brine concentrate that not only contains chlorides, but other pollutants rejected by the membrane, which require separate management and disposal.

Given the limitations of RO brine management, alternative disposal methods were reviewed. Brine evaporation ponds, which passively evaporate water and leave behind salt residue, are unsuitable for southeast Wisconsin due to the humid continental climate and insufficient net evaporation. Mechanical evaporation systems offer a more climate-independent option with smaller physical footprints and the potential for near-zero liquid discharge (i.e., the steam that evaporates leaves through a stack). These systems evaporate water from high chloride waste streams and produce salt solids for off-site disposal however, they can be capital and energy intensive at the industrial scale. Deepwell injection is used elsewhere but prohibited in Wisconsin. Viable chloride management strategies in the Region should focus

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[115] *Wisconsin Department of Natural Resources (WDNR), "Chapter NR 815 Injection Wells," (2004); WDNR, "Chatper NR 665 Interim License Waste Treatment, Storage and Disposal Facility Standard," (2006); WDNR, "Chapter NR 206 Land Disposal of Municipal and Domestic Wastewaters," (1985); WNDR "Chapter NR 214 Land Treatment of Industrial Liquid Wastes, By-Product Solids and Sludges," (1990).*

[116] *J. Glater and Y. Cohen, "Brine disposal from land based membrane desalination plants: A critical assessment,"* Draft Prepared for the Metropolitan Water District of Southern California, Polymer and Separations Research Laboratory, University of California, Los Angeles, *(2003).*

on source segregation of high chloride streams, implementation of targeted treatment technologies like RO or mechanical evaporation, and innovative brine handling approaches that comply with local, state, and federal regulatory constraints.

5.5 CHAPTER SUMMARY

A summary of state-of-the-art practices to minimize chlorides for agricultural fertilizers and industrial food processing are listed below.

Agricultural Chloride Sources

- Use of synthetic potash fertilizers (predominately KCl) contribute chloride to the environment, where it can remain in the soil, percolate to groundwater, or run off into surface water.

- Alternative potassium fertilizers to KCl exist but are expensive, not widely available to producers, and/or there is a lack of knowledge about them among agricultural producers.

- The most effective way to reduce chloride inputs from synthetic fertilizers is to minimize the excess fertilizer spread onto the fields.

- More research is needed on potential methods to remove chloride from agricultural fields after fertilizers are applied.

- Manure and runoff from feedlots are not a major source of chlorides when compared to human deicing activities, but still represent an opportunity to reduce chloride exports into the environment, as well as reducing more prevalent nutrients and pathogens already in animal waste.

- Nutrient management plans for animal waste guide the timing, location, and quantity of applications to match crop needs, minimizing excess nutrient and chloride runoff.

Industrial Food Processing Chloride Sources

- Food processing systems often contain large amounts of organic matter and nutrients, but chlorides also enter the processing waste stream through different processes with respect to each food processing industry.

- Traditional wastewater treatment systems utilized in food processing facilities are not designed to remove chloride from wastewater, thus, it remains in the wastewater and is transported either to the environment or to a public wastewater treatment plant.

- Reverse osmosis is an existing technology used to remove chlorides from some industrial waste streams, achieving chloride removal rates of up to 98 percent. RO systems face challenges for widespread use, such as membrane fouling, high energy consumption, and the generation of a high pollutant reject brine which requires separate management and disposal.

- Other industrial food processing chloride removal technologies include brine evaporation ponds, mechanical forced evaporation, and deepwell injection. Brine evaporation ponds are unsuitable for the Region due to our humid continental climate, and deepwell injection wells are banned in Wisconsin. Thus, mechanical forced evaporation systems represent a pathway forward to remove chlorides from wastewater.

Technical Report No. 66

STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 5

OTHER CHLORIDE SOURCES

TABLES

Table 5.AcresOfCroplandUsedToGrowSelectCrops
Acres of Cropland Dedicated to Select Crops in Southeastern Wisconsin: 2022

	Cropland 2022 (acres)					
Counties	Barley	Corn for Grain	Oats	Rye for Grain	Soybeans	Wheat
Kenosha	0	22,185	39	(D)	18,464	3,490
Milwaukee	0	979	0	0	1,297	215
Ozaukee	0	7,184	282	20	10,569	2,745
Racine	0	31,327	396	363	32,578	6,706
Walworth	(D)	64,506	54	272	40,969	3,459
Washinton	34	26,273	1,399	294	26,014	4,886
Waukesha	0	18,031	96	244	15,776	1,580
Total	34	170,485	2,266	1,193	145,667	23,081

Note: "(D)" means that data is withheld to avoid disclosing data for individual farmers.

Source: NASS

Table 5.TotalNutrientUptakeOfSelectedCrops
Total Nutrient Uptake of Selected Crops

	Crop Nutrient Removal (lbs/bushel)					
Nutrients	Barley	Corn for Grain	Oats	Rye for Grain	Soybeans	Wheat (spring)
N	1.39	1.12	1.08	2.20	4.35	2.19
P_2O_5	0.56	0.51	0.44	0.67	0.97	0.73
K_2O	1.52	1.35	1.13	1.81	2.20	1.53
Cl[a]	0.21	0.61	0.16	1.46	0.56	0.45

Note: Nitrogen, phosphorus, and potassium are considered macronutrients and are included to compare chloride uptake to macronutrients.

[a] *Chloride uptake values are not widely reported in pounds per bushel, literature was consulted to find plant matter chloride contents and were converted to estimated uptake values. Uptake values reported are from the average of plant matter content values reported in literature. Assumptions and sources for each respective crop are listed below:*

Barley: E. Tavakkoli, F. Fatehi, S. Coventry, P. Rengasamy, and G.K. McDonald, "Additive effects of Na^+ *and* Cl^- *ions on barley growth under salinity stress."* Journal of Experimental Botany, *Volume 62(6), p. 2189-2203, March 2011. Assumed 48 pounds of barley per bushel.*

Corn for grain: M.B. Paker, T.P. Gaines, and G.J. Gascho, "Chloride effects on corn." Communications in Soil Science and Plants Analysis, *Volume 16. 1985. Assumed 56 pounds of corn per bushel.*

Oats: P.E. Gaspar, "Response of Oat to Chloride Fertilization." South Dakota State University Open Public Research Access Institutional Repository and Information Exchange, *1988. Assumed 34 pounds of oats per bushel.*

Rye: L.E. Francois, T.J. Donovan, K. Lorenz, and E.V. Maas, "Salinity Effects on Rye Grain Yield, Quality, Vegetative Growth, and Emergence." Agronomy Journal, *Volume 81(5), 1989. Assumed 60 pounds of rye per bushel.*

Soybeans: M.B. Paker, T.P. Gaines, and G.J. Gascho, "Chloride Toxicity of Soybeans on Atlantic Flatwood Soils." Agronomy Journal, *Volume 75(3), p. 439-443. May 1983. Assumed 60 pounds of soybeans per bushel.*

Wheat: W.K. Schumacher, "Residual Effects of Chloride Fertilization on Selected Plant and Soil Parameters." South Dakota State University Open Public Research Access Institutional Repository and Information Exchange, *1988. Assumed 60 pounds of wheat per bushel.*

Sources: The Ohio State University, Raygeln Commodities, Inc

Table 5.OptimumSoilTestLevels
Test Levels for Wisconsin (Subsoil Fertility Groups A and C)

			Soil Test Category			
Subsoil Fertility Group	Very Low (VL)	Low (L)	Optimum (Opt.)	High (H)	Very High (VH)	Excessively High (EH)
			Soil Test K (ppm)			
Demand Level 1 (corn)						
A	<60	60-80	81-100	101-140	--	>140
C	<60	60-70	71-100	101-140	--	>140
Demand Level 2 (soybeans and low-demand field crops)						
A	<50	50-80	81-100	101-120	121-140	>140
C	<40	40-70	71-90	91-110	111-130	>130
Demand Level 3 (alfalfa, irrigated field crops, low-demand vegetable crops, and wheat)						
A	<70	70-90	91-120	121-151	151-170	>170
C	<55	55-70	71-100	101-130	131-150	>150
Demand Level 4 (red clover and medium-demand field crops)						
A	<55	55-70	71-100	101-120	121-150	>150
C	<50	50-65	66-90	91-110	111-130	>130
Demand Level 5 (high-demand vegetable crops)						
A	<60	60-120	121-180	181-200	201-220	>220
C	<50	50-110	111-160	161-180	181-200	>200
Demand Level 6 (potato)						
A	<80	80-120	121-160	161-180	181-210	>210
C	<70	70-100	101-150	151-170	171-190	>190

Source: University of Wisconsin-Extension

Table 5.SoilTestInterpretation
Codes and Descriptions of Soil Test Interpretation Categories

Category			Probability of Yield Increase[a] (%)
Name	Symbol	Description	
Very Low	VL	Substantial quantities of nutrients are required to optimize crop yield. Buildup should occur over a 5- to 8-year period. Response to secondary or micronutrients is likely or possible for high or medium demanding crops, respectively.	>90
Low	L	Somewhat more nutrients than those removed by crop harvest are required. Response to secondary or micronutrients is possible for high demanding crops, but unlikely for medium or low demanding crops.	60-90
Optimum	Opt.	This is economically and environmentally the most desirable soil test category. Yields are optimized at nutrient additions approximately equal to the amounts removed in the harvest portion of the crop. Response to secondary or micronutrients is unlikely regardless of crop demand level.	30-60
High	H	Some nutrients are required, and returns are optimized at rates equal to about one-half of the nutrient removal by the crop.	5-30
Very High	VH	Used only for potassium. Soil tests are above the optimum range and gradual draw-down is recommended. Approximately one-fourth of nutrient removal is recommended.	5
Excessively High	EH	No fertilizer is recommended for most soils since the soil test level will remain in the non-responsive range for at least two to three years. On medium- and fine-textured soils, a small amount of starter fertilizer is advised for row crops.	<2

[a] *Percentage of fields that can be expected to show a profitable yield increase when recommended nutrients are applied.*

Source: University of Wisconsin-Extension

Table 5.AlternativeKFertilizers
Alternative Potassium Fertilizers

Material	Chemical Formula	Approximate K_2O (%)	Salt Index[a]	Cost ($/metric ton)	Cost to Apply Equivalent K_2O as KCl ($/metric ton)
Potassium Chloride	KCl	60 to 62	116.2	300 to 400	--
Potassium Sulfate	K_2SO_4	50	43.4	720 to 820	1,440 to 1,640
Potassium Nitrate	KNO_3	44	69.5	1,000 to 1,200	2,270 to 2,730
Potassium-Magnesium Sulfate (langbeinite)	$K_2SO_4 \cdot 2MgSO_4$	20	43.4	300 to 520	1,500 to 2,600
Potassium Thiosulfate	$K_2S_2O_3$	17	68.0	800 to 1,000	4,700 to 5,880
Potassium Feldspar	$KAlSi_3O_8$	17	--	100 to 200	590 to 1,180
Compost	--	~ 8 to 14	--	30 to 70	210 to 490
Biochar	--	Varies	--	131	--
Glauconite	--	Varies	--	91	--

Note: All costs are the cost of the item in October 2023, or in terms of October 2023 monies according to U.S. Bureau of Labor Statistic's Consumer Price Index Inflation Calculator.

[a] *Salt index is used to measure the increase in osmotic pressure (ability to draw water out of a soil) of a given fertilizer compared to a standard of sodium nitrate (SI = 100).*

Sources: USGS, University of Minnesota-Extension, New Mexico Bureau of Geology and Mineral Resources, A&L Canada Laboratories, Inc., Y Charts, Intratec, Solinc, Homeguide.com, and SEWRPC

Table 5.CRFCoatingMaterials
Controlled Release Fertilizers Coating Materials

Material	Modifier	Research Findings	Release Duration[a]
Sulfur-Based			
Gypsum	Sulfur/paraffin; ground magnesium lime/polyol	Addition of hydrophobic sealant slows down release but still faster than commercial CRF.	Not Available
Phospho-Gypsum	Paraffin wax/Span-80	Addition of emulsifier significantly reduces the release rate due to enhanced paraffin adhesion.	10 days
Mineral-Based			
Hydroxyapatite (HA)	Lignocellulosic biomass	Urea adsorption due to chemical bond with HA results in slow release. It can be further enhanced with the addition of hydrophobic filler.	5 min-3 days
Zeolite	Corn and potato starch, bentonite, white cement, acrylic polymer	Suitable binder type can slow down the release rate.	8 Hours (>8 hours for acrylic polymer)[b]
Bentonite	Starch, hydroxypropyl methylcellulose (HPMC); hydrophilic polymer (polyacrylamide); hydrophobic polymer (polycaprolactone)	Nanocomposite provides a superior controlled release. The urea release rate is affected by binder type and slowed down due to adsorption by bentonite.	2 Days
Attapulgite (APT)	Ethyl cellulose (EC) and sodium carboxymethyl cellulose/hydroxyethyl cellulose hydrogel	Urea release slowed down due to adsorption by APT. Optimum. Carboxymethyl cellulose and hydroxymethyl cellulose (CMC/HEC) and crosslinker content are also important factors.	5 Days
Synthetic Polymer-Based			
Polystyrene	Wax, Polyurethane	Wax is brittle and cannot prevent water penetration into the coating. Increasing size slows down release and reduces coating material required.	70 Days
Polyurethane (PU)	Mesoporous silica; Hydroxypropyl-terminated Polydimethylsiloxane (HP-PDMS)	Filler morphology affects the release rate. Implementation of hydrophobic gradient layer increases urea diffusion resistance.	55-70 Days
Polyether Sulfone	Fe_2O_3 nanoparticles (NPs)	A new class of CRF. Fe_2O_3 NP increases coating thickness and reduces release rate. It also allows the carrier to be recovered and recycled.	Not Available
Biodegradable Synthetic Polymer-Based			
Aliphatic Polyester	None	The increasing size of CRF but using smaller urea crystals slows down degradability and release rate.	1 Day
Bio-based Epoxy	Different ratio of liquified bagasse (LB) to bisphenol-A diglycidyl ether (BDE)	Optimum BDE amount increases compactness and hydrophobicity and retards release rate.	10-30 Days
Polyvinyl Alcohol	PEG and Na_2SO_4; biochar	High water swelling rate and only 15-20% release on the first day. Improves water retention in soil and can adsorb Fe(III) ions which reduces toxicity to plants. Biochar improves mechanical strength, degradability and slows down release rate.	> 30 Days[b]

Table continued on next page.

Table 5.CRFCoatingMaterials (Continued)

Material	Modifier	Research Findings	Release Duration[a]
		Natural Polymer-Based	
Biobased Polyurethane (PU)	Isocyanate, acrylonitrile modification, superabsorbent from chicken feather meal; nano fumed silica	Double layer polymer coating significantly retards the release rate. Castor oil-based PU has better adherence as the coating material. Nano fumed silica reduces porosity and pore size. Isocyanate affects the structure of PU which affects the release rate.	14-77 Days
Bio-based Modified Alkyd Resin	Cassava starch	Using castor oil reduces coating requirement compared to rubber oil.	Not Available
Polysulfone (SO_2 and eugenol based)	None	Increasing M_w of polymer reduces the rate of degradation, slowing down the release.	3-30 Days
Latex	None	Urea content affects swelling degree which greatly affects the release rate.	30 Days
Natural Rubber	Cassava starch; attapulgite/NR and NR-g-Polyacrylic acid	Hydrophobic NR can retard release rate with enhanced hydrophilicity through grafting. Multicoated CRF with NR and hydrogel shows great controlled release.	> 24 Hours[b]
Starch	Bentonite; cellulose nanofibril from bagasse; natural char NP; bagasse, melamine, polyvinylacetate; EC	Urea can act as a plasticizer. Modification of starch to increase hydrophobicity and the use of reinforcing agent can improve controlled release. Starch-based hydrogel shows excellent water holding capacity and retention in soil. Using an appropriate filler creates interactions which slow down the release.	6-30 Days
Cellulose	Silica NP, bentonite, montmorillonite (MMT)	Incorporation of filler into cellulose-based coating material promotes tortuous path and compactness which slows down diffusion.	6 Days-30 Days; >30 Days (w/MMT)[c]
Lignin	Alkenyl succinic anhydride	Water-repelling properties shows great potential to retard nutrient release.	10-30 Min
Alginate	K-Carrageenan/celite superabsorbent; MMT; biogenic silica	Incorporation of filler increases porosity which improves water absorption and slows down the release.	18-50 Days; >60 Days (w/MMT)
Chitosan	Humic substances; starch+allicin; salicylaldehyde; magnesium+natural rubber	Smaller urea crystals can be better encapsulated in the matrix for slow release. Chitosan does not provide strong effects but incorporation with other materials may promote interactions that retard release.	7-13 Days
		Other Organic Materials	
Biochar	Bentonite, sepiolite	Good urea sorption capability by biochar and mineral binder to slow down the release.	30 Days
Rosin Adduct	Maleic anhydride	The effective barrier for urea release due to the covalent bond between maleic anhydride and urea. Works effectively under different soil texture.	4 Days[d]

[a] *Time required to reach 75 percent release.*

[b] *Release experiment only conducted until 40 percent release.*

[c] *Release experiment only conducted until 60.8 percent release.*

[d] *Time required to release 45 percent and reached plateau.*

Source: D. Lawrencia, S.K. Wong, D.Y.S. Low, B.H. Goh, J.K. Goh, U.R. Ruktanonchai, A. Soottitantawat, L.H. Lee, and S.Y. Tang, "Controlled Release Fertilizers: A Review on Coating Materials and Mechanism of Release", Plants, *10(2), 2021*

Table 5.DairyProductsUntreatedWWCharacteristics
Characteristics of Untreated Wastewater from Selected Dairy Products

Milk Processing Effluent Source	Active Reaction pH	Contaminants (mg/l)						
		BOD_5	COD	FOG	TS	TSS	TN	TP
Fluid Milk	5-9.5	500-1,300	950-2,400	--	--	90-450	--	20-30
Yogurt	4.53	--	6,500	--	--	--	--	--
Butter	12.08	220-2,650	8,930	2,880	--	700-5,070	--	--
Ice Cream	5.1-6.96	2,450	5,200	--	3,900	3,100	--	14
Cheese	3.38-9.5	590-5,000	1,000-63,300	330-2,600	1,920-53,200	190-2,500	18-830	5-280
Cottage Cheese	7.83	2,600	17,650	950	--	3,380	--	--
Washing Wastewater	10.37	3,470	14,640	3,110	--	3,820	--	--

Note: BOD_5 = biological oxygen demand for 5 days, COD = chemical oxygen demand, FOG = fat, oil and grease, TS = total solids, TSS = total suspended solids, TN = total nitrogen, TP = total phosphorus

Source: A.K. Slavov, "General Characteristics and Treatment Possibilities of Dairy Wastewater – A Review," Food Technology and Biotechnology. 55(1): 12 – 28, *2017*

Table 5.IntegratedMeatProcessingFacilitiesWWContaminants Average Pollutant Concentration in Untreated Wastewater from Integrated Meat Processing Facilities

Unit	Pollutant	Average Concentration
Mg/l	Aluminum	0.564
	Ammonia	61.7
	Barium	0.0984
	Biochemical Oxygen Demand (BOD)	3,870
	Bromide	1.99
	Calcium	87.9
	Carbonaceous Biochemical Oxygen Demand (cBOD)	3,620
	Chemical Oxygen Demand (COD)	5,720
	Chloride	675
MPN/100ml	*E. coli*	9,540,000
	Enterococci	6,260,000
	Fecal Coliform	3,730,000
Mg/l	Fluoride	23.9
	Iron	35.1
	Magnesium	36.4
	Manganese	0.257
	Molybdenum	0.0262
	(Total) Nitrogen	195
	Oil and Grease	1,420
	(Total) Phosphorus	36.1
	Sodium	512
	Titanium	0.0831
	Total Dissolved Solids (TDS)	2,970
	Total Organic Carbon	545
	Total Suspended Solids (TSS)	2,160
	Vanadium	0.0738
	Zinc	0.504

Note: Mg/l = milligram per liter, MPN/100ml = most probable number per 100 milliliters.

Source: USEPA

Table 5.PoultryFaciltiesWWContaminants
Average Pollutant Concentration in Untreated Wastewater from Poultry First and Integrated Poultry Processing Facilities

Unit	Pollutant	Average Concentration
Mg/l	Aluminum	0.576
	Ammonia	88.1
	Biochemical Oxygen Demand (BOD)	4,660
	Bromide	0.0580
	Calcium	24.2
	Carbonaceous Biochemical Oxygen Demand (cBOD)	1,280
	Chemical Oxygen Demand (COD)	3,020
	Chloride	98.8
MPN/100ml	E. *coli*	396,000
	Enterococci	319,000
	Fecal Coliform	169,000
Mg/l	Fluoride	15.8
	Magnesium	10.2
	(Total) Nitrogen	122
	Oil and Grease	177
	Phosphorus, Ortho-P	14.5
	(Total) Phosphorus	17.3
	Sodium	148
	Sulfate	56.6
	Total Dissolved Solids (TDS)	4,680
	Total Organic Carbon	406
	Total Suspended Solids (TSS)	6,520
	Zinc	0.156

Note: Mg/l = milligram per liter, MPN/100ml = most probable number per 100 milliliters.

Source: USEPA

Table 5.RenderingFacilityWWContaminants
Average Pollutant Concentration in Untreated Wastewater from Independent Rendering Facilities

Unit	Pollutant	Average Concentration
Mg/l	Aluminum	2.35
	Ammonia	103
	Barium	0.0974
	Biochemical Oxygen Demand (BOD)	8,630
	Calcium	89.5
	Carbonaceous Biochemical Oxygen Demand (cBOD)	8,270
	Chemical Oxygen Demand (COD)	21,400
	Chloride	467
	Copper	0.225
MPN/100ml	*E. coli*	111,000,000
	Enterococci	7,144,000
	Fecal Coliform	29,900,000
Mg/l	Fluoride	89.3
	Iron	7.73
	Lead	0.0164
	Magnesium	39.8
	Manganese	0.266
	(Total) Nitrogen	257
	Oil and Grease	1,110
	(Total) Phosphorus	93.3
	Sodium	365
	Sulfate	56.0
	Total Dissolved Solids (TDS)	4,530
	Total Organic Carbon	1,660
	Total Suspended Solids (TSS)	4,140
	Zinc	0.814

Note: mg/l = milligram per liter, MPN/100ml = most probable number per 100 milliliters.

Source: USEPA

Table 5.VegtablesWWCharacteristics
Water Use and Wastewater Characteristics for Selected Vegetables

		Water Used[a]		Effluent Load	
Product	**Function**	Gal/ton	Gal/case	Biological Oxygen Demand (BOD) lbs/ton	Suspended Solids (SS) lbs/ton
Beans, green	Wash		25.5		
	Tank and spray	52			
	Flume	108			
Beets	Primary Wash Flume	100		0.8	20.0
Carrots	Primary Wash Flume	90		0.5	2.0
Corn	Spray	13[b]			
	Cool	17[b]			
	Husked Corn Washer	103		2.5	1.0
	Washer and silker	212		15.0	4.0
Peas	Wash and flume	1,200			
	Clipper Mill and Wash	706		12.0	5.5
	Wash	432		4.0	0.5
Potatoes	Spray	2,500		20.0	30.0
	Spray and Soak	640		10.7	21.0
	Peel and wash	468		2.2	2.2
	Slicer-Washer	1,540		40.0	49.7
	Primary Wash Flume	70		0.5	2.0
Tomatoes	Wash	1,320			
	First Wash		1-20	0.4[c]	
	Second Wash		2-4	0.8[c]	
	Rinse after dump	1,186			
	Lye Peel Removal	504			
	Spray		721		
	Lye Peel Rinse		1374		

[a] *Water used is per ton or case of finished product.*

[b] *Units for spraying and cooling water for corn are gallons per minute.*

[c] *BOD is in pounds per case for tomatoes.*

Source: USEPA

Table 5.PreliminaryandPrimaryTreatmentUnits
Preliminary and Primary Treatment Units Used in the Food Processing Industry

Treatment Unit	Description
Preliminary	
Screens	Screening removes large solid particles from wastewater. Different types of screens can be used in wastewater treatment, including static or stationary, rotary drum, brushed, and vibrating. Screens typically have stainless steel wedge wire that removes medium and coarse particles.
Primary	
Dissolved Air Flotation (DAF)	Air is dissolved under pressure and then released at atmospheric pressure in a tank containing wastewater. The released air creates bubbles that adhere to suspended solids, causing the solids to float to the surface where they can be removed by skimming. DAF removes suspended solids (soil and sand), fatty tissues from meat and poultry, oils, grease, and metals. This treatment unit can also be used for biological treatment, as it reduces biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Solids gathered from this treatment unit are often combined with sludge from other treatment units and moved to solid handling.
Separators	Separators remove oils, fatty grease from animals, and suspended solids by skimming and collecting the materials from the surface of the wastewater.
Catch Basin	Catch basins separate grease and finely suspended solids from wastewater by the process of gravity separation. Each basin is equipped with a skimmer and a scraper. The skimmer removes grease and scum on the surface, and the scraper removes sludge that collects at the bottom of the basin.
Flow Equalization	A flow equalization unit is any type of basin, lagoon, tank, or reactor that serves to control a variable flow of wastewater to achieve a near-constant flow into the treatment system. A separate unit for equalization may not be necessary as many treatment units (such as DAF, a catch basin, or an anaerobic lagoon) may provide flow equalization.
Chemical Addition	Facilities may add chemicals for settling, thickening, and/or pH control. These chemicals can be added in the DAF, flow equalization, or other units, or before the wastewater enters these units. Chemicals include polymers, coagulants, and flocculants.

Source: USEPA

Table 5.BiologicalTreatmentUnits
Biological Treatment Units Used in the Food Processing Industry

Treatment Unit	Process	Description
Activated Sludge	Nitrification	Activated sludge systems achieve biological nitrification using microorganisms to convert ammonia to nitrate in an aerobic environment. Wastewater and microorganisms are aerated in a reactor for a specified period. This process creates a sludge that later separates from the water by settling in a clarification unit. This process is typically performed on wastewater through a series of separate tanks.
Sequencing Batch Reactor (SBR)	Nitrification	An alternative setup to the activated sludge setup where the same processes is performed on waste batched sequentially in the same reactor tank, rather than separate tanks.
Attached Growth/Fixed Film Reactors	Nitrification	Another alternative to the activated sludge setup where microbes are attached to a rigid supporting media, rather than floating around in the tank.
Moving Bed Biofilm Reactor (MBBR)	Nitrification	An alternative hybrid suspended growth-fixed film system in which a biocarrier media in the unit provides a place for microorganisms to grow.
Membrane Bioreactor (MBR)	Nitrification	A combination setup that utilizes filtration with a suspended growth bioreactor.
Modified Ludzack-Ettinger (MLE) System	Denitrification	Two-stage system with an anoxic zone followed by an aerobic zone. Nitrate produced by the aeration zone is recycled back to the anoxic zone and is used as an oxygen source for facultative bacteria in the anoxic zone. Capable of removing most BOD and 80% of nitrogen.
Four-Stage Bardenpho	Nitrification/ Denitrification	Anoxic, aerobic, anoxic, and aerobic stages, followed by secondary clarification. Mixed liquor with high levels of nitrate is recycled from the first aerobic stage back to the first anoxic stage. Activated sludge from the clarifier is recycled back to the influent. Nitrification occurs primarily in the second stage (aerobic). Denitrification occurs in the first and third stages (anoxic). The final aeration stage removes nitrogen gas from the system and increases the concentration of dissolved oxygen. The four-stage Bardenpho process achieves higher rates of nitrogen removal compared to the two-stage MLE process.
Modified Bardenpho (Five-stage Bardenpho)	Nitrification/ Denitrification	Anaerobic, anoxic, aerobic, anoxic, and aerobic stages, followed by a secondary clarifier. As in the four-stage Bardenpho process, mixed liquor with high levels of nitrate is recycled from the first aerobic stage back to the first anoxic stage and activated sludge from the clarifier is recycled back to the influent. The Five-Stage Bardenpho process can achieve high rates of denitrification.

Source: USEPA

Table 5.PhosphorusRemovalUnits
Phosphorus Treatment Units in the Food Processing Industry

Treatment Unit	Description
Chemical Precipitation	Chemical precipitation involves adding chemicals that encourage coagulation and promote particle adhesion to form large, visible clumps (i.e., flocculation) which can then settle out of the wastewater. The sludge collected from the treatment unit is moved to the solids handling treatment units. Facilities use chemical precipitation for phosphorus removal through the addition of metal salts, most commonly alum or ferric chloride. Facilities may add chemicals to primary treatment (e.g., DAF), biological treatment, or they may have a separate treatment unit.
Filtration	Filtration is the process of passing treated wastewater through a granular media, (e.g., sand, mixed-media, or a filter cloth). This treatment provides further clarification of wastewater by removing total suspended solids (TSS), nitrogen, and phosphorus. The sludge collected from the filter is moved to solids handling treatment units. Reverse osmosis is another type of filtration system, used to remove ions from water.
Ion Exchange	Ion exchange is a physical-chemical process in which ions swap between a solution phase and a solid resin phase. Selective ion exchange targets specific charged particles. This treatment can be used for nutrient removal and/or disinfection.

Source: USEPA

Table 5.DisinfectionTreatmentUnits
Disinfection Treatment Units in the Food Processing Industry

Treatment Unit	Description
Ion Exchange	Ion exchange is a physical-chemical process in which ions swap between a solution phase and a solid resin phase. Selective ion exchange targets specific charged particles. This treatment can be used for nutrient removal and/or disinfection within the meat and poultry products (MPP) industry.
Chlorination/Dechlorination	Chlorination is the process of adding chlorine to wastewater at a rate that results in residual chlorine, which kills pathogens. Dechlorination is the process of removing residual chlorine from disinfected wastewater prior to discharge into the environment. Dechlorination is achieved by adding sulfur dioxide which reacts with free chlorine. Use of chloride gas for disinfection does add chloride to the wastewater through the process of chloride gas reacting with the water and creating hypochlorous acid (HOCl) and hydrochloric acid (HCl). HCl breaks down further into its hydrogen and chloride ions in water.
Ultraviolet Light (UV)	Ultraviolet light units use a suspended or submerged lamp that produces ultraviolet light radiation. The radiation penetrates the wastewater to oxidize organics and/or disinfect by inactivating pathogenic microorganisms.
Filtration	Filtration is the process of passing treated wastewater through a granular media, (e.g., sand, mixed-media, or a filter cloth). Filtration methods that remove particles as small as 100 nanometers (microfiltration), 10 nanometers (ultrafiltration), or 1 nanometer (nanofiltration) can potentially perform disinfection by filtering pathogens that are too large to pass through, though ultrafiltration and nanofiltration are not typical in the MPP industry.
Ozone	Ozone (O_3) is produced in wastewater treatment plants by imposing a high voltage alternating current across a dielectric discharge gap that contains an oxygen-bearing gas. The ozone produced is a very strong oxidant and disinfectant. When ozone decomposes in water, the free radicals, hydroperoxyl (HO_2) and hydroxyl (OH), that are formed disinfection the water by destroying the cell wall of protoplasmic bacteria.

Source: USEPA

Table 5.SolidsHandlingTreatmemtUnits
Solids Handling Treatment Units in the Food Processing Industry

Treatment Unit	Description
Gravity Thickening	Involves placing the sludge in a tank, often cylindrical, where gravity separates the solids from the liquid.
Air Flotation	Uses air to encourage solids to float to the top of the tank, where they are skimmed off the surface.
Anaerobic Digestion	Uses anaerobic bacteria to stabilize sludge, break down organic compounds into biogas, and reduce pathogens and nutrients in the sludge.
Aerobic Digestion	Uses aerobic bacteria to stabilize sludge, breakdown organic compounds into biogas, and reduce organic compounds and other nutrients in the sludge.
Filter Press	Involves pushing sludge between two continuous belts set one above the other. The sludge passes through three process zones: the drainage zone (dewatering by gravity), the pressure zone (dewatering by pressure applied by rollers on the belts), and the shear zone (final dewatering through shear forces).
Centrifugation	Involves pumping sludge into a cone-shaped drum. The drum is rotated to generate centrifugal forces that concentrate solids and cause them to press to the walls of the drum. These solids are continuously removed by an auger, or screw conveyer.

Source: USEPA

Technical Report No. 66

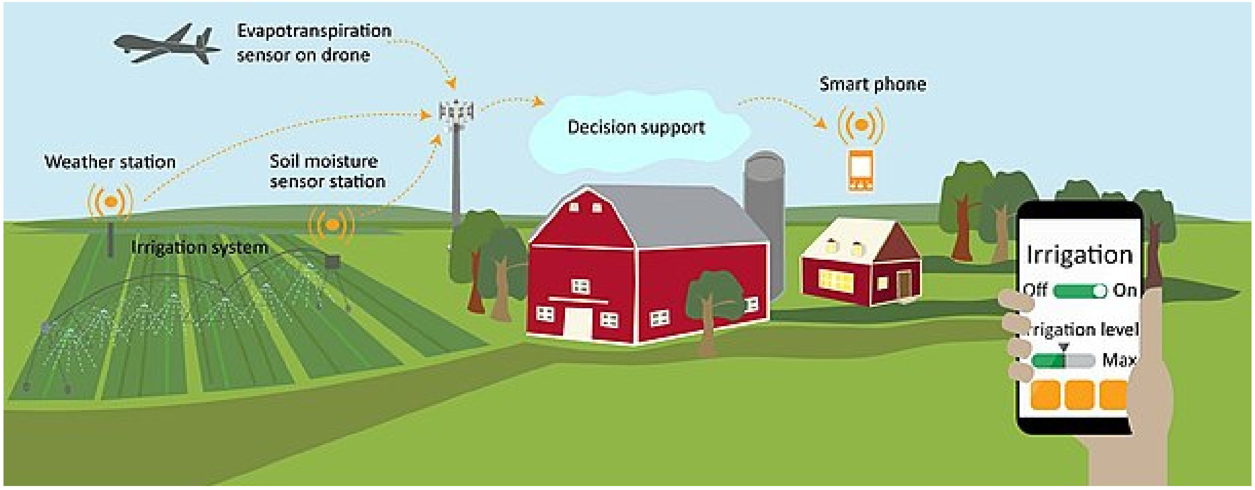
STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 5

OTHER CHLORIDE SOURCES

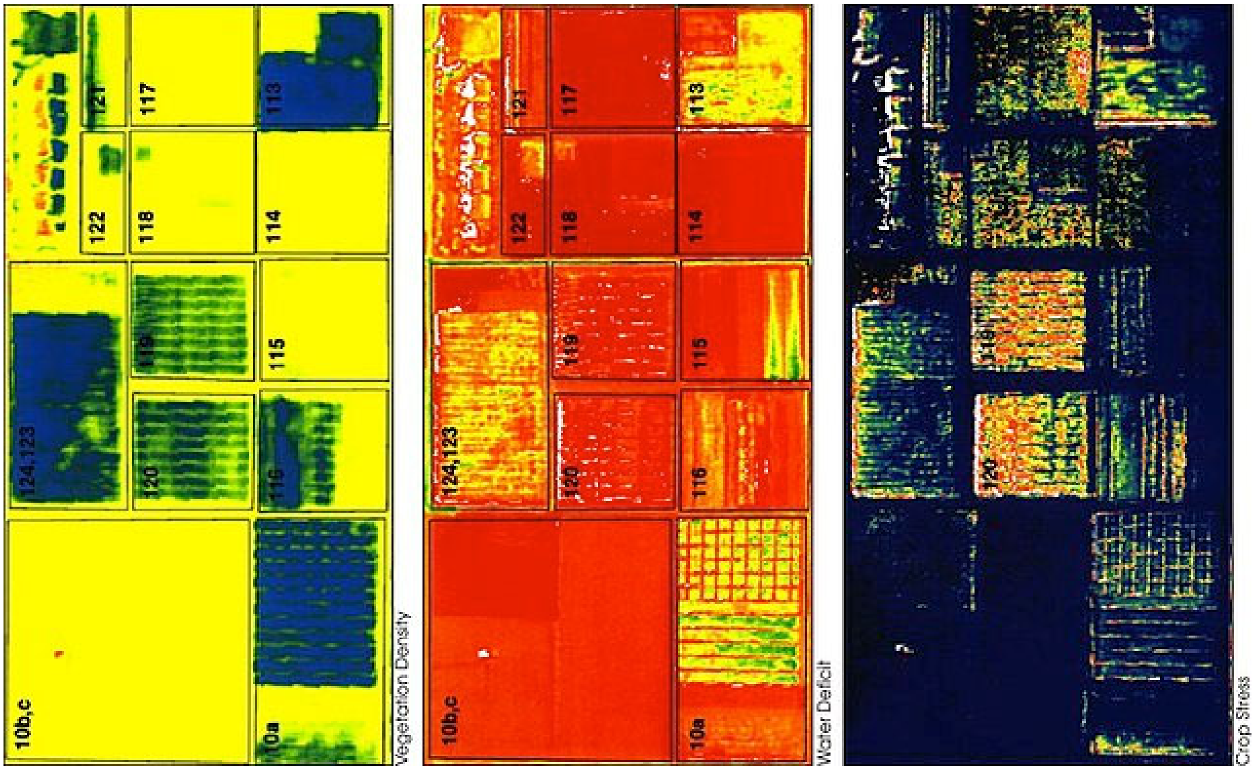
FIGURES

Figure 5.PrecisionAgDiagram
Diagram of Precision Agriculture Methods for Irrigation Systems



Source: U.S. Government Accountability Office and SEWRPC

Figure 5.AgGIS&GPS
GIS/GPS Integration into Remote Sensing in Agriculture



Note: All photos were taken using aerial imagery and converted to maps using GPS/GIS data and relevant indices.

Left image shows vegetation density using Normalized Difference Vegetation Index (NDVI), where dark blue and green indicates lush vegetation and red and yellow shows areas of bare soil.

Middle image shows water deficit, derived from Daedalus' reflectance and temperature measurements. Greens and blues indicae wet soil and reds indicate dry soil.

Right image shows crop stress, where crops under the most stress are shown in red and yellow pixels, while green shows crops under the least stress. Dark blue is bare soil.

Source: United States Department of Agriculture, National Aeronautics and Space Administration, and SEWRPC

Figure 5.AgUAVs
UAVs in Agriculture

Source: Arkansas Agricultural Experiment Station and SEWRPC

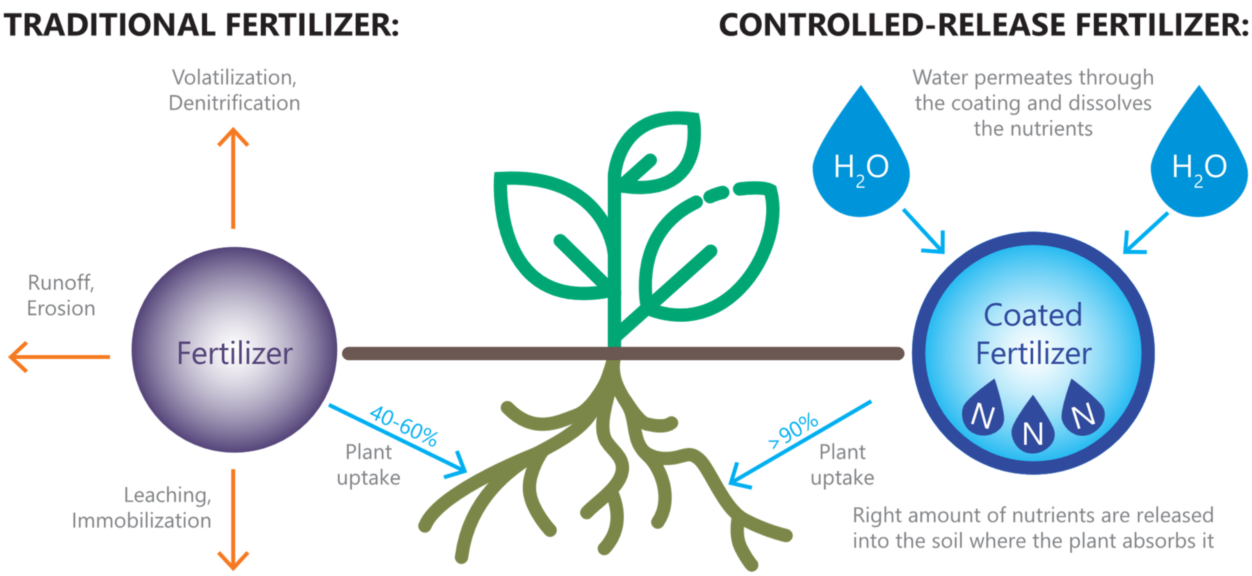
Figure 5.AgBufferStripsPhoto
Agricultural Buffer Strip

Source: USDA and SEWRPC

Figure 5.CoverCrops
Cover Crops Between Rows

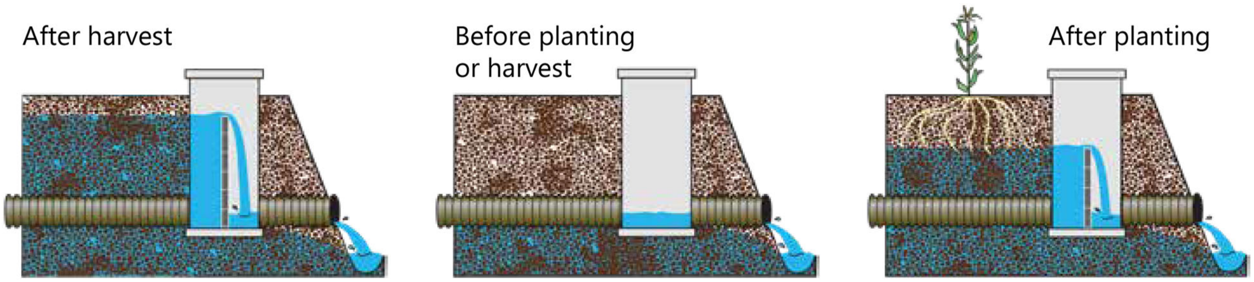
Source: NRCS/Soil and Water Conservation Society and SEWRPC

Figure 5.CRFDiagram
Diagram of Controlled Release Fertilizer



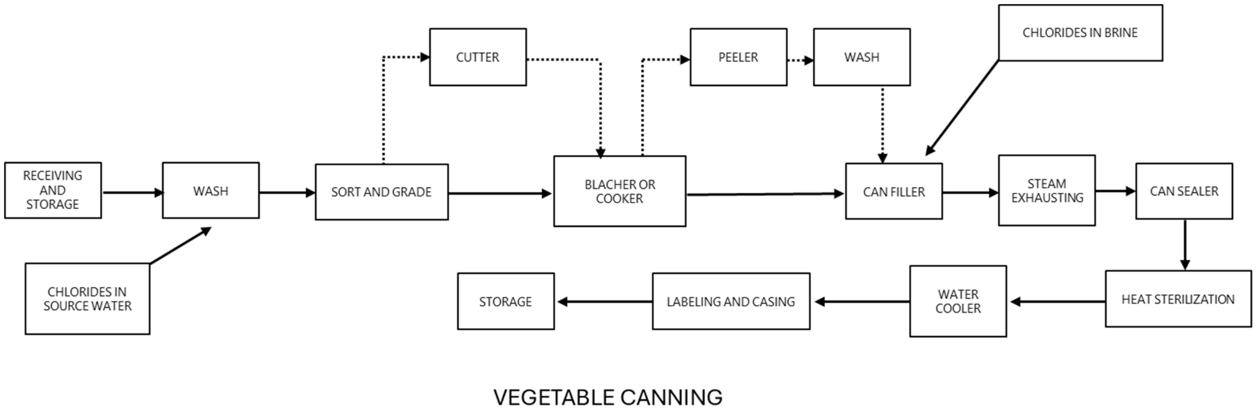
Source: Stamicarbon and SEWRPC

Figure 5.ControlledDrainage
Controlled Drainage Diagram



Source: Purdue University Extension and SEWRPC

Figure 5.VegetableCanningProcessDiagram
Vegetable Canning Process Flow Diagram

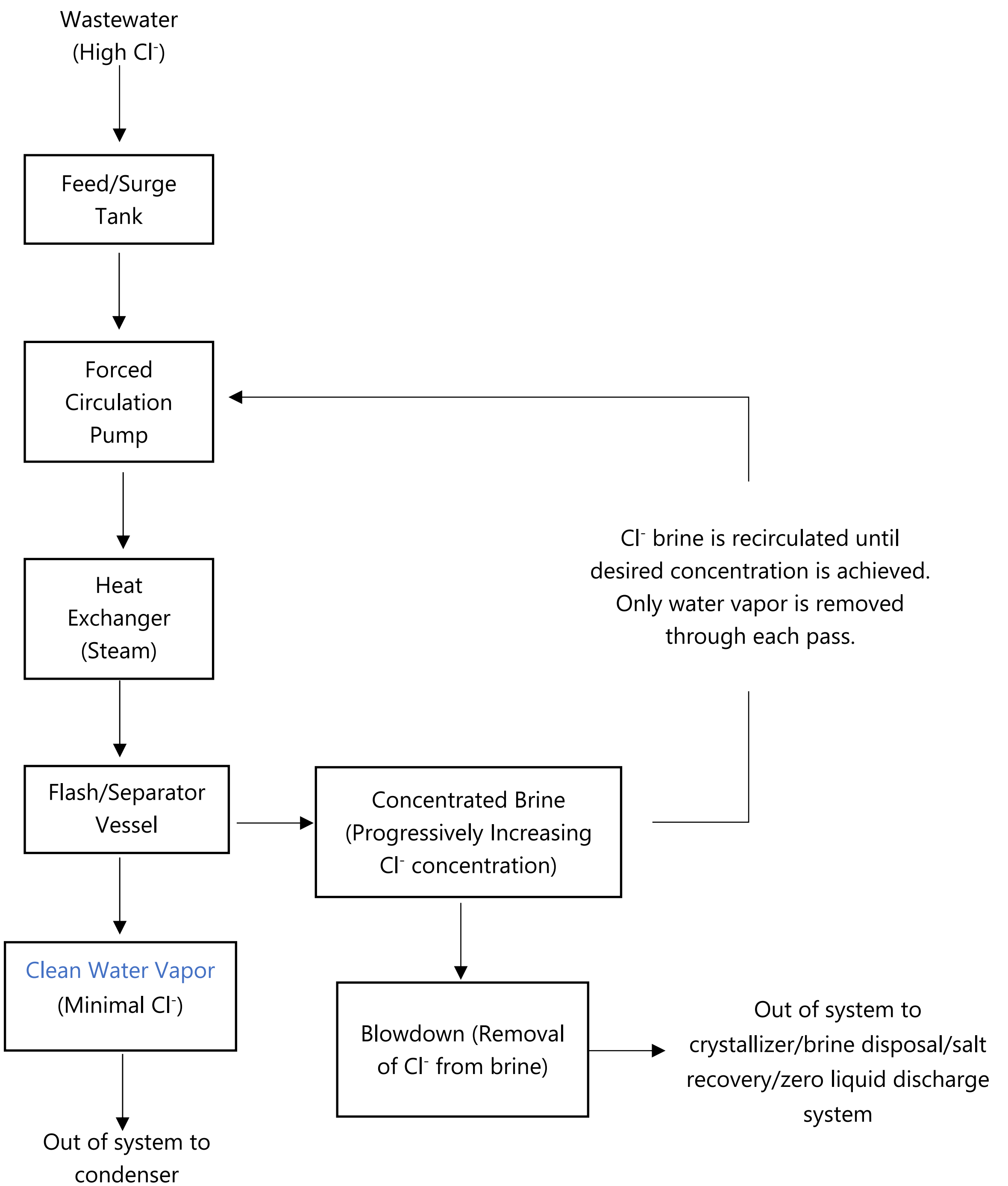


Source: USEPA and SEWRPC

Figure 5.EvaporationPond
Brine Evaporation Pond

Source: M. del Este and SEWRPC

Figure 5.MechanicalEvaportationDiagram
Process Flow Diagram of a Forced Circulation Evaporator System



Source: SEWRPC

Technical Report No. 66

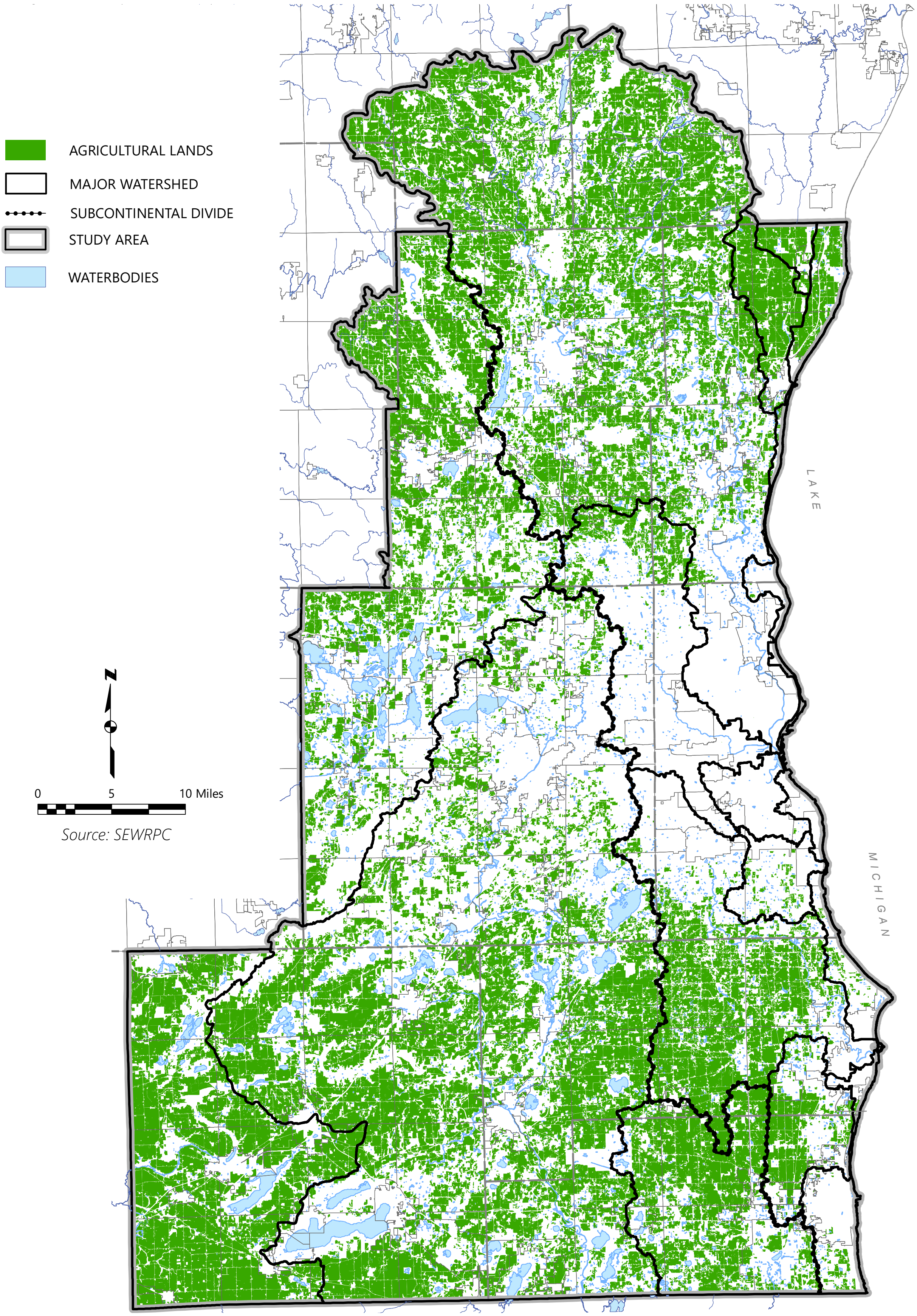
STATE OF THE ART FOR CHLORIDE MANAGEMENT

Chapter 5

OTHER CHLORIDE SOURCES

MAPS

Map 5.AgriculturalLandUses
Areas in Agricultural Land Uses: Existing Conditions



Source: SEWRPC