DEPARTMENT OF TRANSPORTATION

Protection of Precious Waters from Road Salt: Mitigation Through Roadside Ditch Capture

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Center for Transportation Research and Implementation

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Roadway deicers are essential to the functioning of daily life in northern states in winter. After plowing, roadway salting is currently the most practical way of making safe transportation possible in winter. However, road deicer chloride (salt) has a severe negative effect on surrounding watersheds. Yet, currently no methods or procedures have been developed to capture the chloride. The situation is particularly dire where highways cross small receiving streams that are the habitat of endangered and threatened species, such as the Topeka Shiner, because the high concentration of chloride in the highway runoff does not dilute sufficiently to prevent toxicity in the hatching and juvenal rearing areas of the streams. This project developed in-ditch salt capture techniques based on mitigation of chloride migration through absorption and capture in a manufactured backfill media. Chloride mass in drainage water was observed and monitored at a range of concentrations before and after percolation through granular soil mixtures “manufactured” to capture chloride and deployed in flow-through sandbags. Absorbance of chloride was quantified by manufactured soil sandbags in ditch-deployed configurations, allowing optimization of the deployed geometry. Field test installation approaches were designed and tested for chloride capture from actual winter maintenance operations.

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Protection of Precious Waters from Road Salt: Mitigation Through Roadside Ditch Capture

Final Report

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Executive Summary

Roadway deicers are essential to the functioning of daily life in northern states in winter. After plowing, roadway salting is currently the most practical way of making safe transportation possible in winter; amounts in excess of 3 pounds per foot of roadway per winter season are common. However, road deicer chloride (salt) has severe negative effects on surrounding watersheds. Yet, currently no methods or procedures have been developed to capture the chloride. The situation is particularly dire where highways cross small receiving streams that are the habitat of endangered and threatened species, because the high concentration of chloride in the highway runoff does not dilute sufficiently to prevent toxicity in the hatching and juvenal rearing areas of the streams.

This project developed and evaluated in-ditch salt capture techniques based on mitigation of chloride migration through absorption and capture in a manufactured backfill media. Laboratory column studies were done and evaluated for permeability and chloride capture effectiveness by different filter aggregate blends. Hydraulic flow and factors of salt capture related to flow-through, permeable bags of treatment media were evaluated in a 1/8th scale waterway model under conditions including deep frost and frozen media to be expected during a winter installation. An in-ditch treatment approach was developed and prototyped such that hydraulic performance and the performance monitoring approach of the treatment technique could be assessed. Installation and performance of in-ditch treatments, consisting of flow-through berms (or “chevrons”) composed of geotextile bags filled with treatment media mixture were evaluated.

Chapter 1: Introduction

1.1 Background

Snow and ice that fall on roadways cause reduced traction and slippery conditions for cars and trucks. Plowing removes much of the snow and ice, but frequently chloride-based rock salt is applied to lower the melting point of the ice, converting the ice into salty water that leaves the pavement as either runoff or spray (LRRB & MnDOT, 2022). Recent work done for the Minnesota Department of Transportation (Druschel, 2020) showed that an average of 17,000 pounds per lane mile of salt is placed during a typical winter on low-volume state highways, an amount equal to about 3 pounds of salt per every foot of travel lane per winter season.

Northern climate winters bring snow and ice to roadways; deicing with chloride salt is a critical mechanism of being a weather-ready nation (Druschel, 2020). However, roadway deicers, when in the presence of either snow or rain, quickly leave the traveled way as runoff and spray (Druschel, 2017), entering the stormwater systems that are designed to protect natural waters (*Minnesota Stormwater Manual* 2017). Mitigation of chloride from road deicers to stormwater management systems and receiving waters is an emerging concern in northern states (MPCA, 2020) because we know that salts can be deadly in the environment, toxic to aquatic organisms, and lethal to elements of the food chain (Gross, 2022; Corsi, et al, 2010). These effects can be greatly damaging to aquatic organisms in general, with specific behavior-changing and toxicity effects measured on the Topeka shiner, a species of fish listed as a federal endangered species with habitat in Southwestern Minnesota (Bayless, et al, 2003; Mott, et al, 2021).

Unfortunately, stormwater systems are designed to neither stop salt deicers nor mitigate their ecological damage (Decision Tree for Stormwater BMPs, 2011); therefore, chloride is traced to lakes, streams and other receiving waters (Herb, et al, 2017). Chloride in groundwater fed by roadway stormwater runoff has been getting more attention recently; however, there is lack of research on quantifying the mitigation of chloride from deicers to groundwater (Trojan, et al., 2020). While deicers are vital for transportation safety of urban areas as well as rural agriculturally significant roads, the long-term effects of deicers may be overwhelming.

While sodium chloride and rock salt chemistry appear simple and straightforward, the chemistry is actually controlled by ion exchange, diffusion, adsorption, and precipitation processes that can slow release or even remove chloride from water. Mitchell and Soga (2005) describe tests in which chloride migration was slowed by factors including organic content, clay proportion, clay mineralogy, and chloride concentration and the resulting osmotic pressure. Clays of high activity were observed to adsorb chloride, in amounts depending on the permeability and porosity of the soils, the tortuosity of the water flow paths within the soil, and the concentration of the chloride. Absorbing chloride may be the key to reducing the ecological lethality of salt deicers, particularly if we can do it before roadway runoff reaches natural waters such as streams, ponds and rivers.

In an unpublished pilot study (Druschel, 2021), salt capture due to permeation through granular material with clays of various types was observed. For kaolin, illite and the commercial product Tidy Cat kitty litter, capture was about 1:1 salt mass to clay mass. For calcium bentonite and sodium bentonite, the capture was between 10–20:1 salt mass to clay mass. Bentonite clays are well known in the soil geochemistry world for their high activity related to greater surface charge, so this difference in salt capture seems to be appropriate for bentonite clays.

1.2 Proposed Evaluations

Evaluations in this study were done in three settings:

- Column studies in which salt brines were applied in a flow through manufactured treatment media, to determine optimum composition;
- Waterway channel bench-scale (approximately 1/8th scale) studies in which salt brines were applied in a ditch-like configuration for gravity flow with consideration of drainage media, frost and melt out effects to determine optimum configuration; and,
- Field studies involving placement of manufactured treatment media in runoff ditches of low-volume roadways, assessing capture of actual deicer materials as applied over a winter season.

1.3 Previous Work and Literature Study

Description of previous studies regarding deicing and anti-icing performance taken from Druschel (2014):

> Evaluations of deicing and anti-icing performance occur with every winter storm event, with every driver on a given roadway affected by snow or ice. Given the difficulty of driving in winter conditions, it is no wonder this anecdotal evaluation occurs. However, formal studies of performance in the technical literature are few, particularly studies with evaluations of factors rather than comparisons of procedures.
>
> Chollar (1988) summarizes field studies done during the winter of 1986 – 87 comparing the performance of calcium magnesium acetate (CMA) and rock salt at four locations: Wisconsin, Massachusetts, Ontario and California. CMA was found to deice slower than rock salt although eventually reached a similar performance level. CMA was also found to have roadway distribution and persistence issues caused by lower-density particles: (1) particles would spread farther than rock salt (ending off the vehicle lane); and (2) were more susceptible to wind erosion from the roadway. Operational issues were also identified with CMA, including distributor clogging due to material softening with moisture absorbance and increased adherence to vehicle windshields.
>
> Hamilton, et al. (1989) describe field trials of CMA and sodium formate (NaFo) against the performance of sodium chloride done during the winter of 1987 – 88 in Ottawa, Ontario. The purpose of this study was to assess deicer alternatives that were associated with lower

environmental, vegetation and corrosion damage than with sodium chloride. Test sections were designated for the application treatments plus a no-application control using two parallel roadways: a two-lane, low-volume, low-speed city road; and a four-lane, high-volume, moderate-speed regional road (traffic amounts were not provided). This study was the first to use friction testing as a measure of deicer performance. Slower melt times for both alternative deicers and higher application rate needed for equivalent performance of CMA were noted. Cost increases of 33 and 13 times the cost of sodium chloride were noted for CMA and NaFo, respectively.

Raukola et al. (1993) described an anti-icing program evaluation in Finland that used a residual chloride measurement to assess anti-icing persistence on pavement in a medium-duty roadway with 6,100 average daily traffic. Anti-icing was applied in liquid form only for this study. Decreases in surface chloride concentration were found to be associated with roadway moisture most of all. Other factors positively correlated to a decline in surface chloride concentration included traffic, initial application amount, and applicator speed. No difference in the pattern of persistence was noted between sodium chloride and calcium chloride.

Manning and Perchanok (1993) evaluated the use of CMA at two locations in Ontario using a comparison with rock salt for performance measures. The two locations differed greatly in temperature, precipitation and traffic conditions. Four different winter periods were used from 1986 – 87 to 1990 – 91. With heavy traffic and light snow, CMA was generally equivalent to rock salt, although 20 – 70% more CMA was applied in an attempt to match the ionic characteristics of rock salt. Both light-traffic and heavy-snow conditions caused decreases in performance of CMA relative to rock salt.

Stotterud and Reitan (1993) discussed the findings of an anti-icing evaluation in Norway that considered weather factors on ice prevention. Performance was assessed by friction measurements. Anti-icing was negatively affected by snow intensity, lower temperatures and the occurrence of freezing rain. Duration (persistence) of anti-icing materials was found to be reduced by increases in traffic or surface moisture, either as frost or drizzle. Persistence could be as long as 2 or 3 days on the tested roadway if low temperatures and low humidity occurred prior to the storm event. Pavement type and age were discussed as factors in performance, but no clear trend was identified and only differences were discussed.

Woodham (1994) describes a testing program that used a single storm event in 1991 with twelve roadway sections of 0.1 mile each in a single community in Colorado. Four different material preparations were evaluated: (1) magnesium chloride and sand; (2) calcium chloride and sand; (3) sodium chloride (rock salt) and sand; and (4) magnesium chloride, sodium chloride and sand. Salt of any type was limited to 80 pounds per lane mile due to societal constraints. Sand component amount was varied in the blends, as an objective of the study was to find a lower amount of sand in a blend that would achieve expected performance or better.

Prewetting was also evaluated and found to greatly improve deicing time. Magnesium chloride – sand and sodium chloride – sand mixtures were found to perform best.

Blackburn et al. (1994) presented a large and comprehensive study of anti-icing, consisting of liquid, solid and prewet solid anti-icing materials and techniques tested at fourteen locations in nine states (CA, CO, MD, MN, MO, NV, NY, OH and WA) during the winters of 1991 – 92 and 1992 – 93. Materials and techniques were tested against control sections where conventional snow and ice control practices of the particular state were used. Friction testing and chloride residual testing were used for performance measurement, and results were presented along with weather, pavement condition and air temperature records. State departments of transportation were the testing agencies, and training materials were developed within the study for anti-icing techniques, testing methods and quality control procedures. Difficulties encountered included the lack of equipment available for prewetting, equipment targeted for the low treatment levels associated with anti-icing, and a lack of vendor testing of operational characteristics of spreading equipment.

Findings of Blackburn et al. (1994) included a mixed outcome about the reduction of overall salt use, as some locations experienced increases in salt use and some locations first decreased then increased salt use. Salt use outcome variations were attributed to the contrasts of winter storm patterns between the two years. Overall, anti-icing at 100 pounds per lane mile with liquid or prewetted solid was found to greatly improve roadway operation during winter conditions when temperatures were above 20° F; dry solids were found to have persistence on the roadway inadequate for effective anti-icing due to blow off or traffic effects. Prewet rates of 5 – 6 gal/ton and 10 – 12 gal/ton were found minimal but effective for prewetting on the spinner and in the truck bed, respectively, although recommendation was given to increase the rate by 50% for greater effectiveness and reliability of method. Magnesium chloride was evaluated and found to be an effective anti-icing material as a liquid or prewet on sodium chloride. Anti-icing techniques were found to be ineffective or even detrimental if used during freezing rain or drizzle events, or on compacted snow.

Blackburn et al. (1993) presented preliminary observations of techniques and the overall program later presented Blackburn, et al. (1994).

Ketcham et al. (1998) produced a follow-on study to Blackburn, et al. (1994) using eight of the sites previously studied and adding eight new sites. Fifteen states were involved in the study (IA, KS, MA, NH, OR and WI were added), although results were only reported from twelve sites in eleven states addressing average daily traffic of 3000 – 40,000 vehicles. The goal of this study, similar to the previous study, was to evaluate new techniques of anti-icing in comparison with conventional practices of the particular state, with the objective to further encourage development and implementation of the new anti-icing practices. As before, performance was measured with friction tests and pavement observations, while perceptions of passenger vehicle handling after treatment was added. Results were graphed across the storm times then evaluated with statistical evaluations of friction values by pavement conditions and treatment approach (either conventional or anti-icing based). Two to fourteen storms per year were evaluated for each site. A wide range of treatment materials were evaluated including rock salt, fine salt, calcium chloride, magnesium chloride, potassium acetate, and abrasives.

In the study by Ketcham et al. (1998), friction was found to be reduced by lower air temperatures (greatest effect), higher precipitation rates and decreasing traffic volume (least effect). Snowfall intensity was also identified, as packed snow was observed to occur after an upturn in intensity, although the results were not quantified. Friction was consistently worse with "snow" conditions than with "light snow" conditions. Cost analyses of five highway sections were inconclusive, as anti-icing techniques resulted in both lower and higher costs. Reasons for the costs to increase included higher-priced chemicals being used, test operations not being completely typical, and anti-icing not being "tuned" to achieve the full potential of ice prevention and removal. Additionally, cleanup of abrasives (when used) was identified as a significant cost.

Anti-icing performance factors identified by Ketcham et al. (1998) as needing further evaluation included:

- Lower levels of service being incorporated as a flexible storm response;
- Rural versus urban roadway treatments;
- Abrasives as a complementary strategy to anti-icing;
- The effective application of solids and prewet solids for anti-icing;
- Persistence of anti-icing treatments between storms;
- The optimum timing of anti-icing treatments ahead of storms;
- Interaction of anti-icing with open graded pavement courses; and,
- Effective anti-icing techniques for freezing rain conditions.

Highway Innovative Technology Evaluation Center (1999) presents an evaluation of applications and techniques using Ice Ban Magic liquid deicer product. Seven state highway agencies (AK, CO, IN, NE, NY, WA and WI) and one county were involved. Performance advantages were observed in comparison to magnesium chloride at low temperatures and with residual material lasting from one storm to the next. Advantages over sodium chloride brine were also observed when used as either a prewet or stockpile treatment. However, Ice Ban was found to be particularly susceptible to occurrences of refreeze and freezing rain, in that lower effectiveness than traditional materials was observed under these conditions.

Two laboratory studies have particular applicability to this project. Trost et al. (1987) described deicing as fundamentally controlled by undercutting, allowing traffic to break up delaminated ice. Undercutting was further described as a two-phased behavior, first being controlled by ice melt capacity in a thermodynamic process and second being controlled by diffusion and density gradients in a kinetic process. Shi et al. (2013) connected this two-phase behavior to observations of time being a highly significant factor in roadway ice melting: Melting occurred within 30 minutes of application for magnesium chloride and calcium chloride but within 60 minutes for sodium chloride.

Recent work by Blomqvist et al. (2011) showed that anti-icing and deicing operations could be negatively affected by the roadway wetness as traffic removes salt through splash and spray as well as run off:

> "Road surface wetness, as shown from the wheel tracks, related positively to the rate of residual salt loss. The wetter the surface, the faster the salt left the wheel tracks. On a wet road surface, the salt in the wheel tracks was almost gone after only a couple of hundred vehicles had traveled across the surface, whereas on a moist road surface, it would take a couple of thousand vehicles to reach the same result."

Blomqvist et al. (2011) suggests that, while road wetness has a significant impact, it is first and foremost traffic that appears to reduce deicer persistence. This finding matches the conclusions of Raukola et al. (1993) and Stotterud and Reitan (1993), noted previously. However, this finding appears different than the finding noted by Ketcham et al. (1998) that decreasing traffic reduces friction; in essence, that traffic is helpful to anti-icing. It may be these two findings are describing two different behaviors within anti-icing:

- Vehicle as breaker of ice, perhaps by dislodging undercut ice; and,
- Vehicle as remover of salt chemical, perhaps by mobilizing saltwater spray or splash.

Additional descriptions of previous studies regarding deicing and anti-icing performance taken from Druschel (2017) (selected passages, and updated):

> Muthumani et al. (2014) explored the differences between lab and field tests for evaluation of deicing and anti-icing chemicals, and suggested approaches for reducing the discrepancies in test conditions to improve the applicability for actual traffic conditions.
>
> Wahlin and Klein-Paste (2015) evaluated the effects of deicing chemicals on the hardness of compacted snow and whether deicers cause an increase in snow compaction bonded to the pavement. The experiments of that study showed that increasing deicer concentration caused softer snow, and that there were modest but statistically significant differences between different deicers. The softer snow was a result of bond weakening within the snow structure, similar to what happens during the physical change of snow structure with increasing temperature around the melt point. No connection was demonstrated, only theorized, about roadway pavement snow compaction, such as with a continued snowfall after deicer treatment.
>
> Several studies have been conducted with the goal of plow route optimization, some taking advantage of temperature modeling and real-time weather measurement, either fixed-location or vehicle mounted.

- Salazar-Aguilar et al. (2012) evaluated synchronized routing of plow vehicles, such that multiple lane highways would be efficiently incorporated into a winter maintenance model. Chien et al. (2014) also looked at this question.
- Arvidsson (2017) considered the costs related to road condition, accident risk, fuel consumption, environmental consequences and other socio-economic effects as a way to improve the quantification of costs and benefits for snow clearing efforts.
- Dussault et al. (2013) evaluated the optimum plow route organization, incorporating the benefit of previously cleared roads for plow vehicle transit to areas of operation.
- Perrier et al. in four separate publications constructed models of winter maintenance optimization involving plow routes (Perrier et al. 2006a), snow disposal locations (Perrier et al. 2006b), depot locations (Perrier et al. 2007a) and fleet sizing (Perrier et al. 2007b).
- Crow et al. (2016) developed a cost-benefit analysis for incremental equipment acquisition, specifically looking at specialty equipment with unique snow clearing or treatment capabilities.
- Nordin and Arvidsson (2014) evaluated the change to energy costs of traffic caused by varying levels of winter maintenance and weather conditions. This work pointed at the importance of the threshold weather level for initiation of snow clearing efforts for determination of the energy costs.
- Testeshev and Timohovetz (2017) provided an assessment of benefits effected by travel speed management for traffic in winter snow conditions.
- Optimization of deicer efforts by weather conditions is considered by Kramberger and Zerovnik (2008).
- Sullivan, et al (2015) considered factors for strategically locating satellite salt facilities to gain efficiencies in roadway snow and ice control.
- Miller, et al (2018) and Blandford, et al (2018) evaluated the economic benefits gained through reduced demands on labor, equipment and deicer material that occur when optimizing snowplow routes at the Ohio Department of Transportation and the Kentucky Transportation Cabinet, respectively.

Trenouth et al. (2015) developed a road salt application planning tool for winter deicing operations using models for snow depletion, plowing, salt-induced melting, and salt wash off. The planning tool was assessed at three field sites using the concept of “bare pavement regain time” plus various chloride and flow measurement instruments placed in drainage structures.

Pavements with additives or aggregates that can enhance or even cause deicing are evaluated in several publications, including Gomis et al. (2015); Li et al. (2013); Luo et al. (2015); Wang et al. (2016); and Zhao (2011). Pavement degradation caused by deicers is evaluated in Goh et al. (2011) and Opara et al. (2016).

Anti-icing performance measures were evaluated in four publications. Snow-pavement bond strength, bond failure temperature and friction of pavement after snow removal were evaluated by Cuelho and Harwood (2012). Fjaerestad, et al (2020) evaluated the freezing process for anti-iced salted roadway surfaces during conditions of ice fog or hoar frost formation. Experiments indicated that a relationship could be developed between amount of precipitation and the protection time provided by an anti-icing application. Fu, et al (2012) was a field test of anti icer compounds derived from beet molasses that focused on friction of the pavement through nine snow events. Shi and Cui (2015) considered the economic, environmental and social benefits attributable to the proactive nature and environmentally responsible performance of anti-icing and pre-wetting.

Environmental damage done by roadway deicers was described in several publications. Dudley, et al (2014) evaluated the effects of roadway deicers on the germinations rate of native grasses and forbs. Rossi, et al (2016) characterized the effect of roadway deicers on soil-mineral interactions at roadside locations. Herb (2017) evaluated the transport and accumulation of chloride from road deicers through surface water runoff and soil infiltration in an urban area watershed. Results suggested a greater infiltration of chlorides into soil and subsurface waters than was previously assumed.

Chapter 2: Column Study

For in-ditch salt capture techniques based on mitigation of chloride migration through absorption and capture in a manufactured backfill media, laboratory column permeability and chloride capture effectiveness tests were done on different filter aggregate blends.

While chloride (salt) capture depends upon ionic bonding (chemical bonding based on ion charge), drainage depends upon permeability (flow through the filtering soil). Filter aggregates were used in this study to create flow at permeability levels associated with roadway drainage, generally considered to be a permeability above ("faster") than 0.001 cm/s, or 2.5 ft/day. Aggregates were used to distribute the calcium bentonite across the flow path such that the calcium bentonite could come into contact with chloride ions dissolved in drainage water, while maintaining flow sufficiently high. As described in Cedergren (1989):

> "The permeability of soils varies significantly with grain size and is extremely sensitive to the quantity, character, and distribution of the finest fractions."

Therefore, filter aggregates were selected to balance the amount of fine fractions – including the material targeted for chloride absorbance, calcium bentonite – and the coarse fractions used to promote drainage speed and increase permeability. These filter aggregates were used both as furnished and in blended compositions.

The goals of these evaluations were to understand: (a) the relationships between materials and permeability to achieve sufficient drainage flow; and (b) the capacity of the calcium bentonite to absorb the chloride component of salt from the drainage. These evaluations centered on "column tests" in which drainage water flowed under gravity pressure through filter media which incorporated the calcium bentonite to achieve absorption. Measurements were made of both the flow and the chloride concentrations to provide the results for evaluation.

2.1 Materials

Calcium bentonite (noted in the lab notes of this study by the abbreviation CaB), the clay centered in this study, was sourced from Lone Star Minerals of San Antonio, Texas. It was furnished dried and powdered (defined as passing #200 sieve of opening size 0.075 mm) (Figure 2-1) in 50-pound bags.

Figure 2.1 Calcium bentonite

Filter aggregates were used in this study to create flow at levels associated with roadway drainage, generally considered to be a permeability above ("faster") than 0.001 cm/s, or 2.5 ft/day. As described in Cedergren (1989):

> "The permeability of soils varies significantly with grain size and is extremely sensitive to the quantity, character, and distribution of the finest fractions."

Aggregates were used to distribute the calcium bentonite across the flow path such that the calcium bentonite could come into contact with chloride ions dissolved in drainage water, while maintaining flow at sufficiently high levels. Specific filter aggregates used in this study are shown in Figure 2-2 and include:

- Sugar Sand: A commercially available sand sold as "filter sand" in 50-pound bags, obtained from various sources. A medium sand with little fine sand, poorly graded, clean, white, sub rounded to rounded grains. The name "sugar sand" is used in the construction trades to denote that that the sand has the appearance of sugar by its color, shape, size and flow movement. The white color emanates from quartz being the primary mineral. Regionally to Southern Minnesota, sugar sand is obtained from the Jordan Sandstone geologic unit, a weakly cemented sandstone that is mined, crushed and washed then used for industrial and commercial products (Jirsa, et al, 2011).
- Beach Sand: A commercially available sand sold as "play sand" in 50-pound bags, obtained from various sources. A medium sand with some fine sand, poorly graded, clean., brown, sub rounded to rounded grains. Called beach sand because such sands are mined from fluvial and alluvial deposits such as beaches.
- Fine Filter Sand: a granular aggregate meeting MnDOT Highway Specification 3149.2.I.2. For this study, a 40-pound bag sample was graciously furnished by Minnesota Paving and Materials, Inc.. The bag was labeled as from their "Davis Pit" in Kasota, Minnesota, and is a borrow mixture mined from fluvial deposits with sub rounded to rounded particle shapes. It is characterized as a poorly graded sand, however it is the most graded of the materials used in this study with 6% fine gravel, 30% coarse sand, 40% medium sand, 24% fine sand, and less than 1% fine material (clean).

- Pea Stone Gravel: a fine gravel with a trace of sand, clean, screened and washed, sub rounded. Pea stone was obtained locally at Thomas Tree & Landscaping, Inc. of Mankato, Minnesota.
- Sunrise Granite Crushed Stone: a crushed stone, washed and screened, angular. While called "Sunrise Granite", it is actually mined regionally from the Sioux Quartzite geological unit (USGS, 2024). As a processed crushed stone passing ¾ inch sieve retained on a 3/8-inch sieve, it was obtained locally at Thomas Tree & Landscaping, Inc. of Mankato, Minnesota.
- Salt used in this study was obtained as Morton Pure and Natural Water Softener Salt (Morton Salt, Inc., Chicago, IL). This material is commonly referred to as a "solar salt" as it is produced from solution brine mine product that is evaporated and dried to achieve crystal forms of approximately ¼-inch in size. Salt prepared in this manner is characterized by high purity as clay and silt impurities are removed in the brine processing. Figure 2.2 also includes a photo of the salt used in this study.
- Water used in this study for calcium bentonite hydration and brine makeup was obtained from Seven Mile Creek, a perennial stream at Seven Mile Creek Park, Saint Peter, Minnesota, owned and maintained by the Nicollet County Public Works Department. The sample collection location was above the stream thalweg at a point approximately 2500 feet west of US 169 (Figure 2.3). Samples were taken as scoops of water in a 5-gallon plastic bucket to fill an upright bucket of similar size and composition; samples were gently decanted to prevent fines from collecting in the containing bucket.
- According to the trail map and park brochure (Nicollet County Public Works Department, 2024), Seven Mile Creek is a groundwater-dominated stream. This water source was selected to be a water of consistent composition that closely matches runoff water composition in Southern Minnesota.

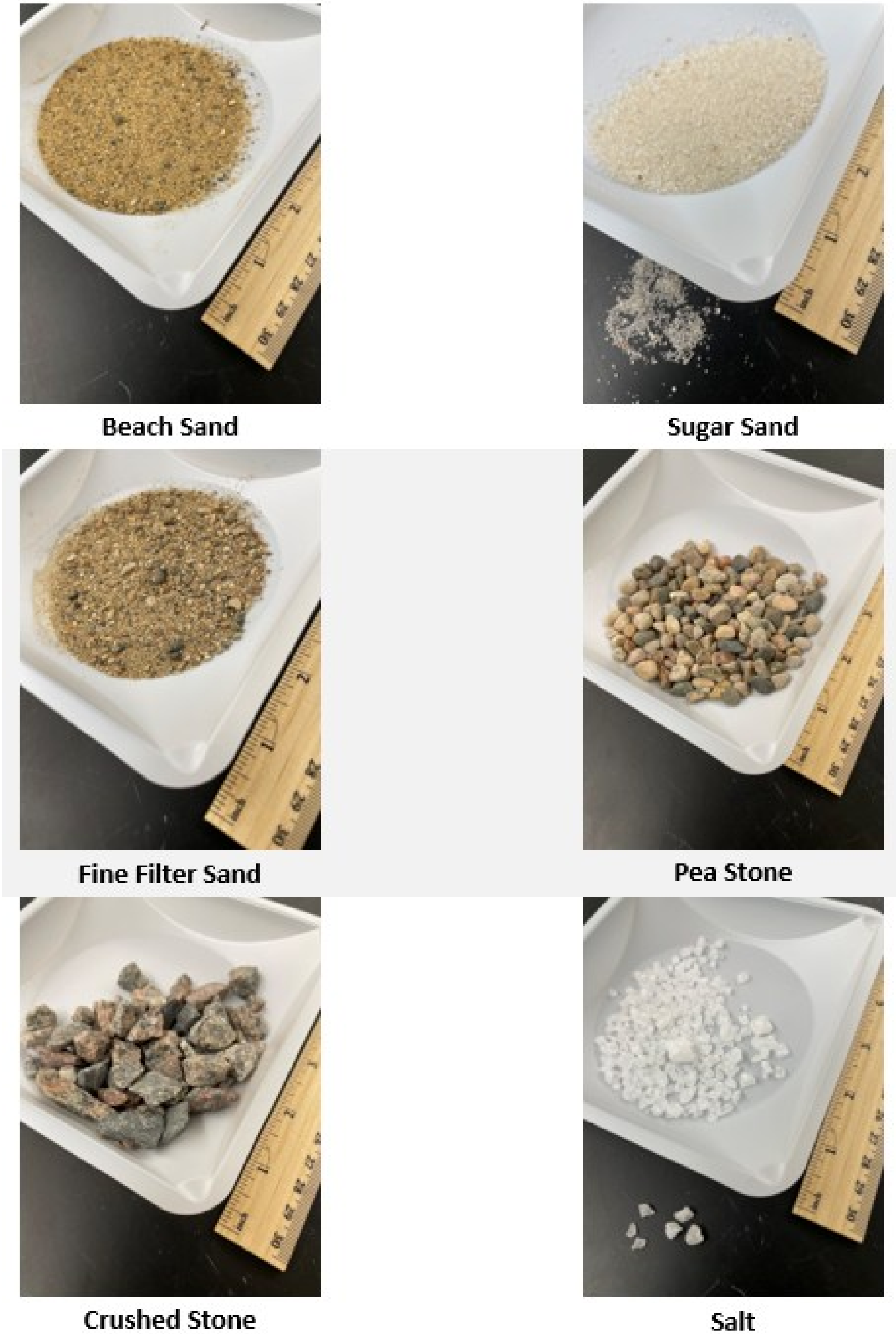


Figure 2.2 Filter aggregates used in this study, shown also with salt (bottom right).

Figure 2.3 Collection location of “stream water” used in this study.

2.2 Methods

The core method of experiment in this study was as a “column study” in which salt brine flows downward through a filter pack that occupies the lower portion of a vertical tube column. Six columns are installed in parallel in the testing rack of the column study equipment (Phipps and Bird, Inc., Richmond, Virginia). Filter pack material was weighed and mixed in 500 g batches using a process of cup-to-cup transfer while rotating; ten transfers were used to ensure mixing. The cups being rotated were “dispersion cups”, 4 inches diameter by 7 inches deep, specified by ASTM D422 that have four ¾-inch full-length internal baffles attached vertically to the inside of the cup wall.

A 200 g bed of crushed stone was first placed into the column to act as supporting layer that would reduce piping and loss of filter pack material. Filter pack material was then gently poured into the column. Another 200 g layer of crushed stone was then placed on top of the filter media to prevent erosion from high fluid velocities potentially associated with pouring. Stream water of approximately 2 L volume was then slowly poured into the column to hydrate the filter pack.

Salt was mixed into stream water in 1 L batches using a six-paddle mixer (Phipps and Bird, Inc., Richmond, Virginia) (Figure 2-4). Stream water without salt was used as a blank to test treatment effects.

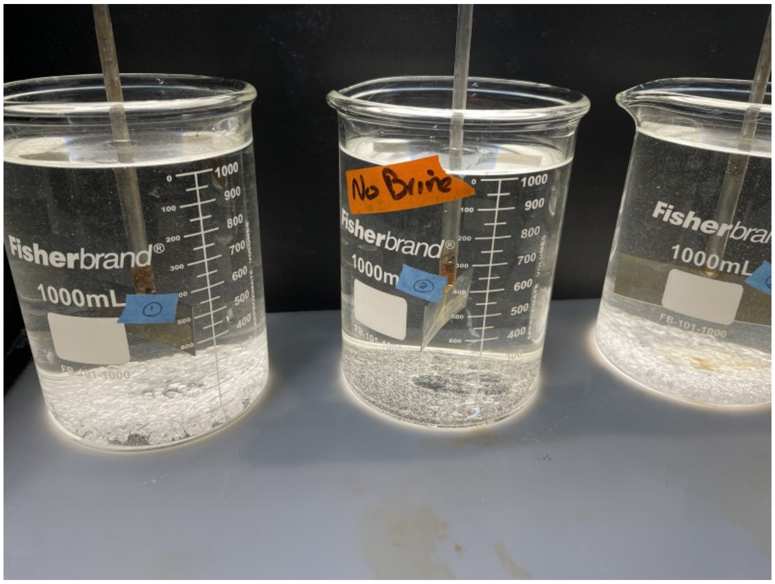


Figure 2.4 Salt being mixed with steam water. Shown immediately after salt crystals added and before initiation of paddle action.

Stream water and salt, typically at 25 g/L concentration, was then mixed, extending for a time approximately 10 minutes after all crystals disappeared (dissolved), creating brine. Brine or blank water was then poured into the top of the column to flow through the treatment media (Figure 2-5). Treated water, also known as effluent, was then collected in a 1 L graduated cylinder set beneath the column (Figure 2-6).

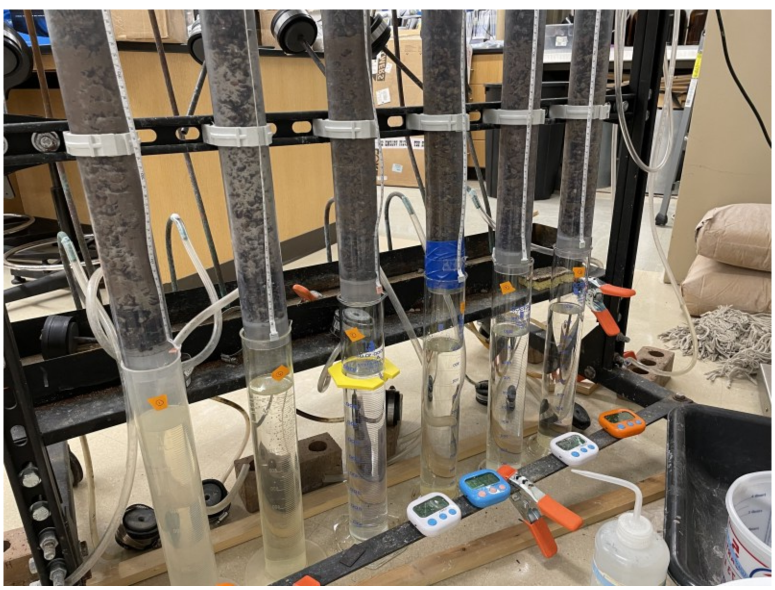


Figure 2.5 Columns with treatment media in place.

Figure 2.6 Graduated cylinders receiving treated effluent water beneath the columns.

Permeability (k) was determined in a "falling head" configuration by measurement of the liquid height (fluid head, h) above the lower end of the filter pack (of length L) at the start time (t_1) and end time (t_2) of a period in which no additional fluid was added to the amount already in the column. In this project, the initial fluid head (h_1) was typically 70 cm. The final fluid head (h_2) was measured prior to the fluid level reaching the filter pack (Figure 2-7). The permeability is then determined through the following equation (Cedergren, 1989):

$$k = \frac{L}{t_1 - t_2} \ln\left(\frac{h_1}{h_2}\right) \qquad \text{(Equation 1)}$$

Figure 2.7 Falling head permeability tests being conducted above and through filter packs with brine fluid in Column 5 at 60.6 cm (foreground) and in Column 6 at 49.8 cm (background).

Concentrations of total dissolved solids (TDS) were directly read in solutions with two instruments: a Hanna GroLine conductivity meter (Hanna Instruments, Inc., Smithfield, Rhode Island) and an Oakton EC 100 conductivity meter (Environmental Express, Inc., Charleston, South Carolina), both calibrated to salt concentrations of 0 to 60 g/L.

Concentrations of chloride and total hardness were determined using reverse titration methods that meters sample into a self-filling reagent ampoule (vacu-vial) until reaching a color change point that is calibrated to concentration (Chemetrics by AquaPhoenix Scientific, LLC, Midland, Virginia). Chloride was measured using a K-2070 test kit with a range of 10,000 to 100,000 ppm (1 to 10% chloride). This analytical approach is specified in APHA Standard Methods (Rice, et al., 2012) as Method 4500-Cl- C-1997.

Total hardness, a measure of calcium (and magnesium, though magnesium is not thought to be present in the filter pack material used herein) ions which are likely to react with chloride during absorption, was measured using a K-4585 test kit with a range of 100 to 1000 as $CaCO_3$ (the standard unit in water chemistry for expressing total hardness). This analytical approach is specified in APHA Standard Methods (Rice, et al., 2012) as Method 2340 C-1997.

Figure 2.8 A vacu-vial reverse titration analysis with purple-colored fluid currently reading 2% chloride; additional sample titration into the vial will cause the purple color to turn colorless signifying the actual concentration of chloride in the sample

2.3 Analyses and Results

A total of 48 filter packs were prepared and analyzed, organized into eight filter pack sets of similar composition and evaluation goal. Pack set goals, filter pack sizes, permeants and concentrations, filter pack compositions, permeability and chloride (when measured) test results are all presented in the following tables, organized by pack set:

- Table 2.1 First filter media pack set with permeability results. First filter media pack set. Evaluation of permeability (k) as a function of Calcium Bentonite (CaB) proportion when mixed with Sugar Sand.
- Table 2.2 Second filter media pack set with permeability results.: Second filter media pack set. Evaluation of permeability (k) as a function of media mass at 3% and 5% of Calcium Bentonite (CaB) proportion when mixed with Sugar Sand.Table 2.3 Third filter media pack set, first phase (top) and second phase (bottom), with permeability results.: Third filter media pack set, first phase. Evaluation of permeability (k) as a function of Calcium Bentonite (CaB) proportion when mixed with Fine Filter Sand.
- Table 2.4 Fourth filter media pack set with permeability results. Fourth filter media pack set. Evaluation of permeability (k) as a function of coarser aggregate blends when mixed with Calcium Bentonite (CaB) at 3% proportion.Table 2.5 Fifth filter media pack set with permeability results. Fifth filter media pack set. Evaluation of permeability (k) as a function of coarser aggregate blends when mixed with Calcium Bentonite (CaB) at 5% and 7% proportion.
- Table 2.6 Sixth filter media pack set with permeability and chloride test results. Sixth filter media pack set. Evaluation of permeability (k) as a function of coarser aggregate blends both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (Cin) and after (Cout) flow through filter pack.Table 2.7 Seventh filter media pack set with permeability and chloride test results. Seventh

filter media pack set. Evaluation of permeability (k) as a function of coarser aggregate blends both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (Cin) and after (Cout) every 1.0 L of flow through filter pack.

- Table 2.8 Eighth filter media pack set with and chloride test results. Eighth filter media pack set. Evaluation of permeability (k) as a function of Fine Filter Sand both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (Cin) and after (Cout) every 1.0 L of flow through filter pack.

Table 2.1 First filter media pack set with permeability results.

Pack Goal: Evaluation of permeability (k) as a function of Calcium Bentonite (CaB) proportion when mixed with Sugar Sand.
Filter pack size: 500 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
0% CaB 100% Sugar Sand	1% CaB 99% Sugar Sand	2% CaB 98% Sugar Sand	3% CaB 97% Sugar Sand	4% CaB 96% Sugar Sand	5% CaB 95% Sugar Sand
k = 0.097 cm/s	k = 0.019 cm/s	k = 0.015 cm/s	k = 0.047 cm/s	k = 0.048 cm/s	k = 0.021 cm/s

Table 2.2 Second filter media pack set with permeability results.

Pack Goal: Evaluation of permeability (k) as a function of media mass at 3% and 5% of Calcium Bentonite (CaB) proportion when mixed with Sugar Sand.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
3% CaB 97% Sugar Sand 500 g media	3% CaB 97% Sugar Sand 1000 g media	3% CaB 97% Sugar Sand 1500 g media	5% CaB 95% Sugar Sand 500 g media	5% CaB 95% Sugar Sand 1000 g media	5% CaB 95% Sugar Sand 1500 g media
k = 0.020 cm/s	k = 0.024 cm/s	k = 0.0037 cm/s	k = 0.0014 cm/s	k = 0.0060 cm/s	k = 0.0019 cm/s

Table 2.3 Third filter media pack set, first phase (top) and second phase (bottom), with permeability results.

Pack Goal: Evaluation of permeability (k) as a function of Calcium Bentonite (CaB) proportion when mixed with Fine Filter Sand.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
0% CaB 100% Fine Filter Sand	1% CaB 99% Fine Filter Sand	2% CaB 98% Fine Filter Sand	3% CaB 97% Fine Filter Sand	4% CaB 96% Fine Filter Sand	5% CaB 95% Fine Filter Sand
k = 0.012 cm/s	k = 0.0042 cm/s	k = 0.0036 cm/s	k = 0.00028 cm/s	k = 0.00077 cm/s	k = 0.00066 cm/s

Pack Goal: Evaluation of permeability (k) as a function of Calcium Bentonite (CaB) proportion when mixed with Fine Filter Sand.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
0% CaB 100% Fine Filter Sand	1% CaB 99% Fine Filter Sand	2% CaB 98% Fine Filter Sand	1.5% CaB 98.5% Fine Filter Sand	2.5% CaB 97.5% Fine Filter Sand	3.5% CaB 96.5% Fine Filter Sand
k = 0.012 cm/s	k = 0.0042 cm/s	k = 0.0036 cm/s	k = 0.018 cm/s	k = 0.0034 cm/s	k = 0.0014 cm/s

Table 2.4 Fourth filter media pack set with permeability results.

Pack Goal: Evaluation of permeability (k) as a function of coarser aggregate blends when mixed with Calcium Bentonite (CaB) at 3% proportion.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
3% CaB 97% Pea Stone	3% CaB 77% Pea Stone 20% Sugar Sand	3% CaB 77% Pea Stone 20% Beach Sand	3% CaB 57% Pea Stone 40% Sugar Sand	3% CaB 57% Pea Stone 40% Beach Sand	3% CaB 57% Pea Stone 20% Sugar Sand 20% Beach Sand
k = 0.58 cm/s	k = 0.508 cm/s	k = 0.421 cm/s	k = 0.861 cm/s	k = 0.182 cm/s	k = 0.046 cm/s

Table 2.5 Fifth filter media pack set with permeability results.

Pack Goal: Evaluation of permeability (k) as a function of coarser aggregate blends when mixed with Calcium Bentonite (CaB) at 5% and 7% proportion.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
5% CaB 55% Pea Stone 40% Sugar Sand	5% CaB 55% Pea Stone 40% Sugar Sand (duplicate of Column 1)	5% CaB 55% Pea Stone 20% Sugar Sand 20% Beach Sand	7% CaB 53% Pea Stone 40% Sugar Sand	7% CaB 53% Pea Stone 40% Sugar Sand (duplicate of Column 4)	7% CaB 53% Pea Stone 20% Sugar Sand 20% Beach Sand
k = 0.0057 cm/s	k = 0.024 cm/s	k = 0.012 cm/s	k = 0.000036 cm/s	k = 0.010 cm/s	k = 0.00084 cm/s

Table 2.6 Sixth filter media pack set with permeability and chloride test results.

Pack Goal: Evaluation of permeability (k) as a function of coarser aggregate blends both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (C_{in}) and after (C_{out}) flow through filter pack.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in all columns.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
4% CaB 56% Pea Stone 40% Sugar Sand	0% CaB 60% Pea Stone 40% Sugar Sand (CaB blank)	4% CaB 56% Pea Stone 40% Beach Sand	0% CaB 60% Pea Stone 40% Beach Sand (CaB blank)	4% CaB 56% Pea Stone 20% Sugar Sand 20% Beach Sand	0% CaB 60% Pea Stone 20% Sugar Sand 20% Beach Sand (CaB blank)
k = 0.11 cm/s	k = 0.26 cm/s	k = 0.00020 cm/s	k = 0.17 cm/s	k = 0.053 cm/s	k = 0.24 cm/s

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L
Chloride C_{out} 15,800 mg/L	Chloride C_{out} 16,500 mg/L	Chloride C_{out} 17,200 mg/L	Chloride C_{out} 16,500 mg/L	Chloride C_{out} 17,400 mg/L	Chloride C_{out} 17,500 mg/L

Table 2.7 Seventh filter media pack set with permeability and chloride test results.

Pack Goal: Evaluation of permeability (k) as a function of coarser aggregate blends both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (C_{in}) and after (C_{out}) every 1.0 L of flow through filter pack.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in columns 1, 3, 5 and 6. Stream water with no salt in columns 2 and 4.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
4% CaB 56% Pea Stone 40% Sugar Sand	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)	0% CaB 60% Pea Stone 40% Sugar Sand (CaB blank)	0% CaB 60% Pea Stone 40% Sugar Sand (duplicate of Column 3) (CaB blank)	4% CaB 56% Pea Stone 20% Sugar Sand 20% Beach Sand	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)
k = 0.22 cm/s	k = 0.095 cm/s	k = 0.23 cm/s	k = 0.19 cm/s	k = 0.035 cm/s	k = 0.080 cm/s
2.5% Salt Brine Permeant	Blank Permeant	2.5% Salt Brine Permeant	Blank Permeant	2.5% Salt Brine Permeant	2.5% Salt Brine Permeant
Chloride C_{in} 16,380 mg/L	Chloride C_{in} 0 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 0 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L
Chloride C_{out} 16,600 mg/L	Chloride C_{out} 0 mg/L	Chloride C_{out} 16,400 mg/L	Chloride C_{out} 0 mg/L	Chloride C_{out} 16,000 mg/L	Chloride C_{out} 15,700 mg/L

Table 2.8 Eighth filter media pack set with and chloride test results.

Pack Goal: Evaluation of permeability (k) as a function of Fine Filter Sand both with Calcium Bentonite (CaB) at 4% proportion and with no Calcium Bentonite (CaB). Chloride concentration measurement of permeant before (C_{in}) and after (C_{out}) every 1.0 L of flow through filter pack.
Filter pack size: 1000 g in all columns.
Permeant: Brine of 2.5% sodium chloride salt mixed in 1.000 L stream water in columns 1, 3, 4, 5 and 6. Stream water with no salt in column 2.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
5% CaB 95% Fine Filter Sand	4% CaB 96% Fine Filter Sand	4% CaB 96% Fine Filter Sand (duplicate of Column 2)	0% CaB 100% Fine Filter Sand (CaB blank)	3% CaB 97% Fine Filter Sand	4% CaB 96% Fine Filter Sand (duplicate of Column 2)
k = 0.00020 cm/s	k = 0.0026 cm/s	k = 0.0074 cm/s	k = 0.021 cm/s	k = 0.0093 cm/s	k = 0.012 cm/s
2.5% Salt Brine Permeant	Blank Permeant	2.5% Salt Brine Permeant	2.5% Salt Brine Permeant	2.5% Salt Brine Permeant	2.5% Salt Brine Permeant

Chloride C_{in} 16,380 mg/L	Chloride C_{in} 0 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 0 mg/L	Chloride C_{in} 16,380 mg/L	Chloride C_{in} 16,380 mg/L
Chloride C_{out} 16,000 mg/L	Chloride C_{out} 0 mg/L	Chloride C_{out} 15,500 mg/L	Chloride C_{out} 15,700 mg/L	Chloride C_{out} 15,900 mg/L	Chloride C_{out} 16,100 mg/L

Appendix B contains the filter pack logs and analyses for filter pack sets one through six. Appendices C and D contain the filter pack logs and analyses for filter pack sets seven and eight, respectively, including for each filter pack set:

- Permeability by Flow Analyses
- Chloride by Flow Analyses
- Chloride Mass Sum by Flow Analyses
- Alkalinity by Flow Analyses
- Brine Stock Measurements
- Stream Water Measurements

2.4 Evaluation

In reviewing the results shown in the tables and the appendices, the following evaluation points may be made:

1. Permeability needs to be high enough for flow to occur at levels conducive to roadway drainage, but slow enough to allow the calcium bentonite and chloride to make contact and bond.
    a. Recommend aiming for no lower than 0.01 cm/s. For a roadway ditch at 2% slope, this permeability would result in an apparent velocity of 0.6 ft/day, a result that is clearly too low for rainstorm runoff situations but that fits with anecdotal observations of snow melt out in spring conditions of Southern Minnesota.
2. Fine particles, those passing a #200 sieve (opening size 0.075 mm) have great effect on permeability, cutting permeability levels by ten-fold or more for an increase of just 2% of fines when at low (<5% levels). Blending in coarse material to adjust the proportion of fines down can increase permeability.
3. Filter pack materials can have variability of 10-fold (i.e., order of magnitude) differences in permeability for similar composition of blends when mixed with calcium bentonite. Trends of decreasing permeability with increasing levels of fines in blends also exhibit such large levels of variability even though the overall trend directions align. Clearly, less than perfect mixing resulting in formation of blocking layers can occur, though perhaps not in visible layers.
4. Hydration of calcium bentonite clay in filter pack blends is needed to swell the clay and achieve a representation of long-term, not initial, permeability. Water seems to flow around dry calcium bentonite when first hydrating, increasing permeability above (faster than) levels associated with fully hydrated conditions.
5. Salt brine flow through fully hydrated filter pack materials, whether with granular aggregate alone or with calcium bentonite, does not measurably "squeeze off" flow and cause lower permeability, at least in the exposure levels of up to 6 L of salt brine used in this experiment.

6. Evaluation of chloride measurement precision was done during the Seventh Filter Pack Set experiments using results from seven measurements of chloride in the salt brine stock for Column 3 as mixed and prior to contact with filter pack material. Precision, represented by the standard deviation of the measurements, was 330 ppm for an average concentration of 16,380 ppm, a relative standard deviation of 2.01% (within a single brine stock). Precision measured between nine salt brine stocks prepared for different columns was done in the Eighth Filter Pack Set and resulted in a standard deviation of 396 ppm for an average concentration of 16,122 ppm, a relative standard deviation of 2.46% (between brine stocks).
7. No chloride was measured in filter pack effluent when the permeant had no chloride mixed in to the influent (a "salt blank"). This result was interpreted as indicating that neither the calcium bentonite nor the granular aggregates released or contributed chloride into permeant flow.

Evaluating the results of the Seventh Filter Pack Set (Table 2and Appendix C), particularly focusing on the results shown in the Chloride Through Treatment Media by Brine Flow graph, several observations can be made about chloride capture:

a. Chloride in the effluent of a filter pack with no calcium bentonite ("CaB blank") mirrors the chloride value of the influent salt brine, suggesting that a filter pack with no calcium bentonite removes no chloride.
b. Calcium bentonite treatment pack seems to lower chloride level by about 0.5 to 1.0 g/L in two of the three columns, when observed across 6 L of brine flow through the pack, compared to the CaB blank. Chloride levels in the influent and the filter pack with no calcium bentonite are approximately 16.4 g/L. Therefore, the reduction in chloride is approximately 3 to 6% from influent levels when permeated through a filter pack with calcium bentonite, a value larger than the precision level suggesting a significant if not large removal.
c. The third column with calcium bentonite in the treatment pack (describe in (b) above) that did not appear to remove chloride had a comparably high permeability for the level of calcium bentonite in the filter pack. It is therefore interpreted as removal was affected by quicker flow and less residence time with chloride permeant next to the calcium bentonite.

Evaluating the results of the Eighth Filter Pack Set (Table 2 and Appendix D), particularly focusing on the results shown in the Chloride Through Treatment Media by Brine Flow graph, several observations can be made about chloride capture:

d. As with the Seventh Filter Pack Set, chloride in the effluent of the CaB blank filter pack mirrors the chloride value of the influent salt brine, suggesting that a CaB blank filter pack removes no chloride.
e. Similarly when compared to the evaluation of the Seventh Filter Pack Set, calcium bentonite filter pack seems to consistently lower chloride level by about 0.5 to 1.0 g/L (approximately 3 to 6% from influent levels), when observed across 6 L of brine flow through the pack, compared to the CaB blank filter pack.
f. Concentrations of calcium bentonite varying from 3% to 5% in the filter pack all had chloride levels lower in the effluent than in the influent, consistent with the observations of the Seventh Filter Pack Set.

g. Increasing calcium bentonite levels from 3% to 4% to 5% did not appreciably result in increased lowering of chloride concentrations; there did not seem to be a calcium bentonite mass effect once calcium bentonite was included at a level of at least 3%.
h. Duplicate filter packs of 4% calcium bentonite exhibited similar chloride capture behavior and effect, within the range of precision for the analytical method.
i. The filter pack with 5% calcium bentonite mixed with Fine Filter Sand granular aggregate nearly stopped all flow, with a very low permeability value of 0.00020 cm/s, a value 50 times below the threshold recommended in (1.a) above. Continuing the illustration used in (1.a) above, such a permeability level in treatment media in a roadway ditch at 2% slope, this permeability would result in an apparent velocity of 0.012 ft/day, or about 4 ft/year, a wholly unacceptable flow velocity even under snow melt out conditions.

2.5 Conclusions

Chloride capture by flow through treatment media when calcium bentonite is incorporated was observed, though at quite low levels of 3 to 6%. This result suggests that treatment flow lengths greater than the 32 cm (approximately 1 ft) is required. Such evaluation fits well with the experimental goals of the scale waterways tests described in Chapter 3.

Permeability levels are highly influenced by the fine particle amount from both the granular aggregate fines and the calcium bentonite used for chloride capture. Filter pack design must balance achieving a flow high enough to pass snow melt flows in a roadside ditch installation while accomplishing chloride-to-calcium bentonite contact of sufficient time such that chloride capture occurs.

Chloride measurement techniques support the analytical requirements of this project with a precision determined to be plus or minus approximately 2% of the full chloride measurement when working with salt brine at 2.5% concentration.

Chapter 3: Bench Scale Waterway Study

From the column studies described in Chapter 2 came evaluations of (a) the relationships between materials and permeability to achieve sufficient drainage flow; and (b) the capacity of the calcium bentonite to absorb the chloride component of salt from the drainage. Laboratory bench-scale experiments were then used for the evaluation of hydraulic flow and factors of salt capture related to flow-through, permeable bags of treatment media. These experiments were primarily in a 1/8th scale waterway model under conditions including deep frost and frozen media to be expected during a winter installation. The results of these experiments provided insight to design of in-ditch salt capture techniques based on mitigation of chloride migration through absorption and capture in a manufactured backfill media.

Figure 3-1 is an illustration of a possible configuration of in-ditch treatment for salt capture, sketched in an actual state highway drainage ditch during winter melt-out conditions; this illustration helped guide the bench-scale experiments.

Figure 3.1 Illustration of a possible configuration of in-ditch treatment for salt capture, sketched onto an actual state highway drainage ditch during winter melt-out conditions.

3.1 Materials

For this task, two new materials were added to those materials already described in Chapter 2:

- Geotextile, used for making "flow-through bags" that contained the treatment media, consisting of Mirafi 140N geotextile (TenCate Geosynthetics Americas, A Solmax Company, Pendergrass, GA) (Table 3.1); and,
- Ziplock "sandwich" seal top bags, 6.5 inches by 6 inches, made of linear low density polyethylene (LLDPE) (S.C. Johnson & Son, Inc., Racine WI).

Table 3.1 Geotextile characteristics, from the 2024 Geosynthetics Specifier's Guide (Bygness, 2024).

Characteristic	Value
Material	Polypropylene
Manufacture	non-woven, needle-punched
Apparent Opening Size (ASTM D4491)	70 sieve/.212 mm
Flow Rate (constant head test)	135 gal/min/ft2
Puncture Resistance (ASTM D4533	310 lb
Trapezoid Tearing Strength (ASTM D4533)	50 lb x 50 lb

Materials previously used as part of the column study described in Chapter 2 and used during the evaluations described here included:

- Calcium bentonite (CaB);
- Filter aggregates, including:
  - Beach sand;
  - Pea stone; and,
  - Sunrise granite crushed stone.
- Salt; and,
- Stream water.

3.2 Methods

Evaluations were done in three different experimental unit configurations. First, waterway experiments were conducted in a 1/8th scale ("bench-scale") model waterway that was configured to replicate a highway drainage ditch (Figure 3.2). The waterway was constructed in a 12-inch wide by 6-inch-deep channel, lined with plastic membrane, geotextile, and a second plastic membrane (Figure **3**.**3**). The plastic membranes prevented water loss through the bottom of the channel, and the geotextile provided cushioning. Pea stone was placed above the geotextile and below the upper plastic membrane to create a bottom shaped to be 4 inches wide flanked by 4-inch side slopes at a 1 vertical:4 horizontal slope, matching slopes typically used for highway ditches.

Figure 3.2 Waterway channel in operation with flowing water modeling snow and ice melt-out, treatment media flow-through bags in channel, water ponded behind bags, stream staff gage for depth measurement, light, and time lapse cameras.

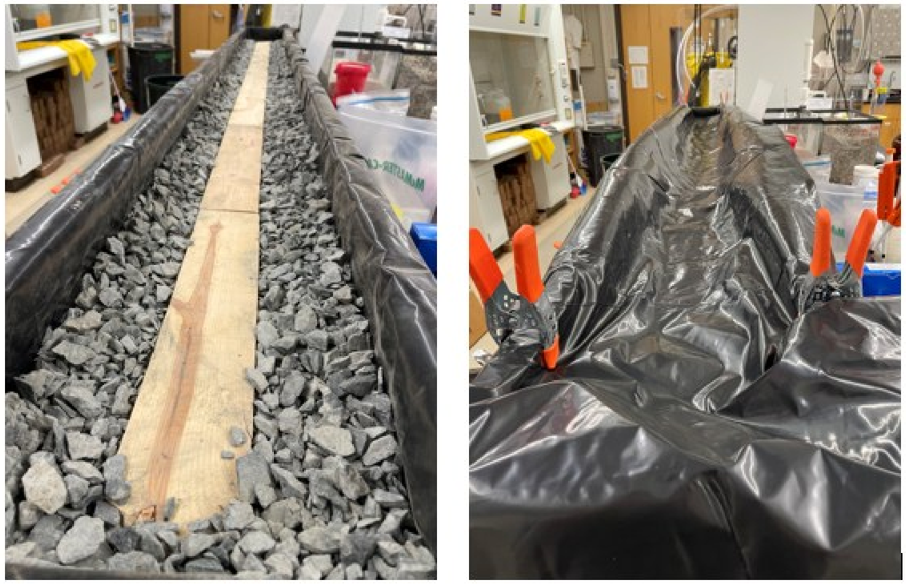


Figure 3.3 **Waterway construction: subbase grading (left), channel lining (right).**

The waterway was 12 feet long, with drain holes at one end that drained into a capture system consisting of a sloped plastic gutter leading to a 5-gallon bucket set within a 30-gallon plastic trash can (Figure **3**.**4**). The waterway was supported by bricks that could be increased or decreased to adjust the slope.

Water was pumped from an upper reservoir (5-gallon bucket) to the top of the waterway (Figure 3-4) where additional bricks were placed on a piece of geotextile within the waterway such that the pump flow velocity could be dissipated, and gravity be the force that moves the water through the ditch of the model, again replicating an actual highway ditch.

Flow (Q) through the treatment media may be analyzed through the relationship known as Darcy's Law:

$$Q = k\ i\ A \qquad \text{(Equation 2)}$$

in which permeability (k) is a function of the filter pack, gradient (i) may be conservatively assumed to be the channel slope, and area (A) is the cross section through which the flow occurs. As flow impinging upon the treatment media increases, the water level will increase, increasing the flow area through greater depth and possibly greater width, particularly if the flow expands to involve the whole ditch or channel width rather than just a small "thalweg" (the very lowest part of a flow channel) -based flow, often associated with winter snow melt out running through highway ditches and channels.

Within the full range of hydraulic possibility, the gradient may be a much higher value than the value of the channel slope if the treatment media hydraulic length is short, acting more like an earthen dam than a permeable media. If the gradient is higher, then the area will become less, meaning the depth would decrease, for a given flow amount. However, given that highway ditch and channel flows during winter snow melt out are relatively low flows and that the treatment media is likely to be at least as long as it is high, approximating gradient with the channel slope is appropriate here in the laboratory bench scale studies.

Second, batch experiments were conducted in a large beaker or pan which was used to contain the experiment in one place. Beakers were used for fluid evaluations alone, while pans were used for testing of treatment media flow-through bags either alone or in a fluid.

Third, column experiments were conducted using a configuration in which salt brine flows downward through a filter pack that occupies the lower portion of a vertical tube column (Phipps and Bird, Inc., Richmond, Virginia). Filter pack material was weighed and mixed in 500 g batches (using a process described in the Task 2 report) and placed between two 200 g bed of crushed stone that acted below as a supporting layer that would reduce piping and loss of filter pack material and above to prevent erosion from high fluid velocities potentially associated with pouring. Stream water of approximately 2 L volume was then slowly poured into the column to hydrate the filter pack.

Figure 3.4 **Waterway lower (discharge) end (left, with treatment bags, discharge gutter and receiving bucket) and upper (in-flow) end (right, with reservoir bucket, pump, and in-channel brick for holding the pump tubing)**

Salt was mixed into stream water in 2 L batches using a six-paddle mixer (Phipps and Bird, Inc., Richmond, Virginia). Stream water without salt was used as a blank to test treatment effects. Stream water and salt was mixed at 25 g/L concentration to create salt brine. Brine or blank water was then poured into the top of the column to flow through the treatment media Figure 2.5). Treated water, also known as effluent, was then collected in a 1 L graduated cylinder set beneath the column; the 2 L overall batch as mixed was poured in two aliquots, the first of about 1000 mL and the second with the salt brine remaining. Sampling, done in 30 mL volumes, was taken from the first aliquot then the volume made up with brine from the second aliquot.

Permeability (k) was determined in a "falling head" configuration by measurement of the liquid height (fluid head, h) above the lower end of the filter pack (of length L) at the start time (t_1) and end time (t_2) of a period in which no additional fluid was added to the amount already in the column. In this project, the initial fluid head (h_1) was typically 70 cm. The final fluid head (h_2) was measured prior to the fluid level reaching the filter pack, and was typically 40 cm. The permeability is then determined through Equation 1.

Concentrations of chloride were determined using reverse titration methods that meters sample into a self-filling reagent ampoule (vacu-vial) until reaching a color change point that is calibrated to concentration (Chemetrics by AquaPhoenix Scientific, LLC, Midland, Virginia) (Figure 2.8). Chloride was measured using a K-2070 test kit with a range of 10,000 to 100,000 ppm (1 to 10% chloride). This analytical approach is specified in APHA Standard Methods (Rice, et al., 2012) as Method 4500-Cl- C-1997.

3.3 Analyses and Results

Eleven different analyses were done, six as waterway experiments, four as batch experiments, and one as a column experiment. The analyses are listed here and detailed below in Table 3.2.

Waterway experiments

1. Treatment media bag orientation – Figure 3.5 Treatment media bag orientation experiment.
2. Treatment media bag relative permeability and flow direction – Figure 3.6
3. Use of flow seals (Ziplocks) – Figure 3.7
4. Effect of slope in channel – Equation 2
5. Flow rate and depth – Figure 3.8
6. Effect of water flow on frozen treatment media – Table 3.3

Batch experiments

7. Effect of cold water on frozen treatment media – Table 3.4
8. Frost entry into treatment media – Table 3.5
9. Salt density separation – **Error! Reference source not found.** 3.9 to 3.12
10. Immersion in a calcium bentonite solution – Table 3.6

Column experiments

11. Repeated calcium bentonite treatment (path length evaluation) – Table 3.7 and Table 3.8; Appendix A

Table 3.2 Analyses of waterway bench-scale study (summary table)

Evaluation	**Analysis**	**Objective**	**Description**	**Result**
Waterway	Treatment media bag orientation	Evaluate the orientation of flow through the treatment bags and the effect of edge seams, bag top bunching and bag closure wire	Place bags of the same treatment media in the waterway with seam-seam adjacency and with locations where the seams or bag top closure is adjacent to the liner surface. Figure 2.7	Seams and openings between treatment media bags or against the liner surface captured flow pathway, moving the flow out of the treatment media
	Treatment media bag relative permeability and flow directions	Evaluate flow capture by treatment bags of different media mixtures with different permeability levels	Place treatment media bags of 10x different permeability levels in waterway in parallel with flow seals between bags Figure 3.8	Flow pathway followed highest permeability media, and only flowed into the lower permeability media at much lower rates
	Use of flow seals	Evaluate using sand-containing soft polyethylene bags (Ziplocks) to seal between treatment bags and prevent seam zone leakage	Place sand-containing Ziplock bags in tight contact between treatment media bags within waterway. Test with tracer dye Figure 3.9	Flow pathway shifted into treatment media bags, even when bags were in line, not just in parallel across the flow
	Effect of slope in channel	Evaluate treatment media contact area as a function of flow depth caused by flow down different channel slopes	Compare effect of two waterway channel slopes on depth and area of flow through treatment media (Equation 2)	Increase in slope decreases slightly the depth of water for the same flow level as the gradient increases
	Flow rate and depth	Evaluate how flow rate is increased by greater depth through increased water pressure on treatment media	Measure depth against treatment media bags across a range of flow rates Figure 3.10	Higher flow rate causes greater depth which in turn increases flow cross section of treatment media
	Effect of water flow on frozen treatment media	Evaluate how frost lenses and frozen treatment media redirecting or blocking flow can change in response to water contact	Measure temperature response of frozen treatment media to flowing water using thermometers and infrared thermography Table 3.3	Frozen treatment media melts out quickly in the presence of liquid water

Evaluation	**Analysis**	**Objective**	**Description**	**Result**
Batch or Single Unit	Effect of cold water on frozen treatment media	Evaluate how frost lenses and frozen treatment media can change in response to cold water contact	Measure temperature response of frozen treatment media to 39° F water using thermometers and infrared thermography Table 3.4	Frozen treatment media melts out in the presence of liquid water, quicker with warmer water but not slow with cold water
	Frost entry into treatment media	Evaluate the rate of frost entry and temperature decline into the treatment media	Impose very cold (-45° F) temperatures on treatment media and measure the response with depth into the media using thermometers and infrared thermography Table 3.5	Temperature decline of treatment media is modest even when in contact with a very cold thermal source
	Salt density separation	Evaluate how salt brine may resist blending with freshwater in the absence of mixing action	Gently and separately insert differentially-dyed salt brines of two different concentrations beneath a layer of freshwater Figures 3.9 to 3.12	Brines of different salt concentration blend easily; blended brine remains separate from freshwater for 5+ days, only blending slowly by diffusion
	Immersion in Calcium Bentonite (CaB) solution	Evaluate the effect of time on chloride absorbance by CaB when salt brine is in extended contact through solution	Inject salt brine into a solution of CaB mixed with stream water and evaluate chloride level over time while mixing Table 3.6	Chloride level not significantly reduced over time
Column	Retreatment of treated effluent	Evaluate capacity for chloride absorbance by CaB during repeated salt brine-treatment media contact (retreatment of treated effluent)	Repeated CaB treatment of a salt brine volume passed ten times through the same treatment media and tested for permeability and chloride concentration after most passes Table 3.7 and 3.8;	Chloride level not significantly reduced with repeated treatment media permeation; permeability generally not affected with repeated media permeation, though greater variation observed with brine flows than with non-brine flow

Figure 3.5 Treatment media bag orientation experiment.

Figure 3.6 **Treatment media bag relative permeability and flow direction experiment.**

Figure 3.7 Use of flow seals (Ziplocks) experiment.

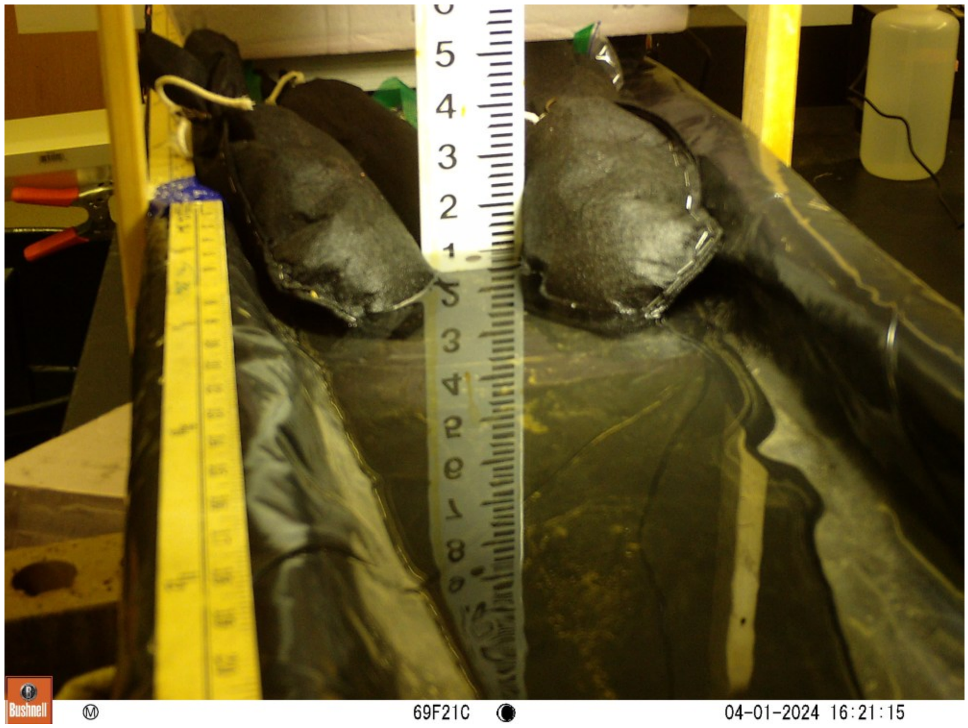
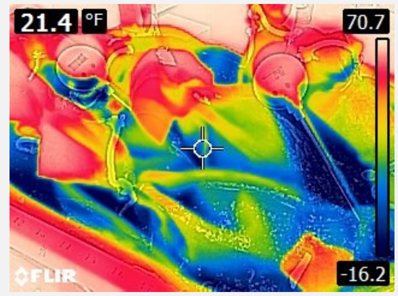
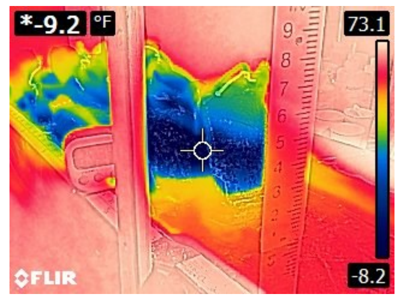
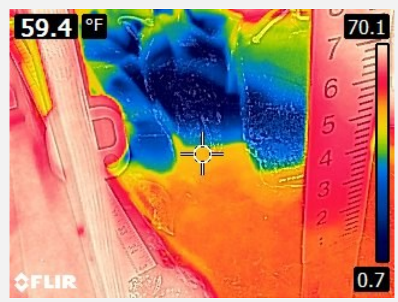
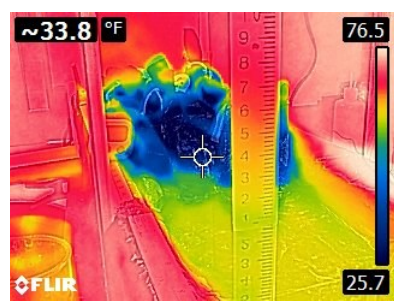


Figure 3.8 Flow rate and depth experiment (time lapse camera photograph).

Table 3.3 Effect of water flow on frozen treatment media experiment.

Time elapsed	Optical Photograph	Infrared Thermograph
Prior to test initiation No water flow		
0 minutes Water flow initiated		
5 minutes of water flow		
15 minutes of water flow		

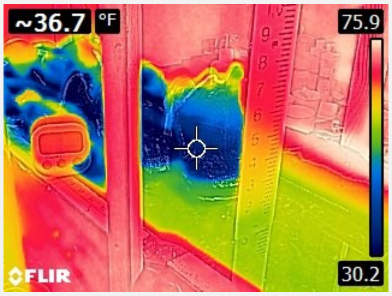
Time elapsed	Optical Photograph	Infrared Thermograph
20 minutes of water flow		

Table 3.4 Effect of cold water on frozen treatment media.

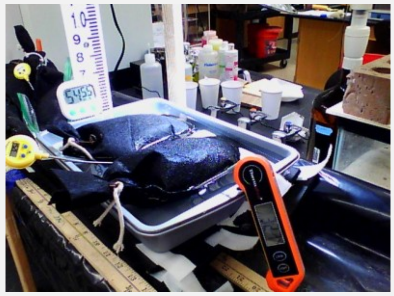
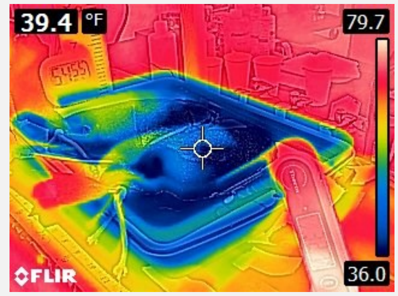
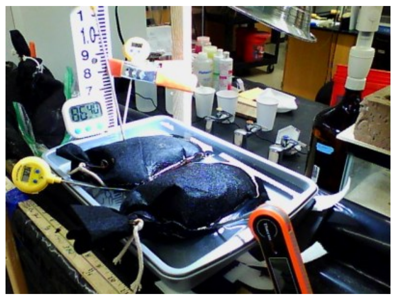
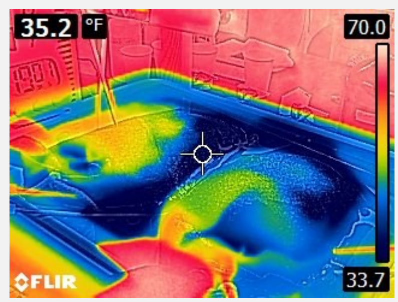
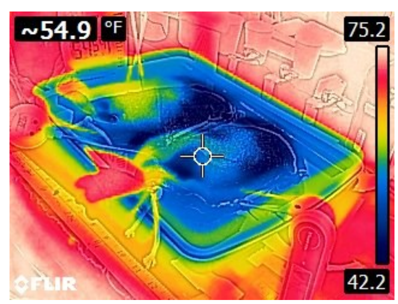
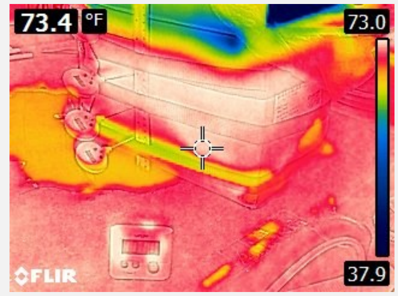
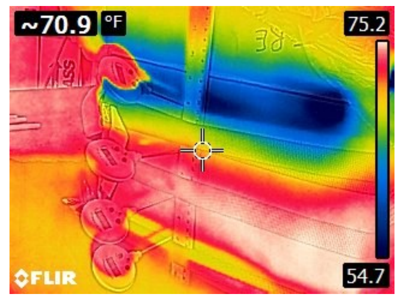
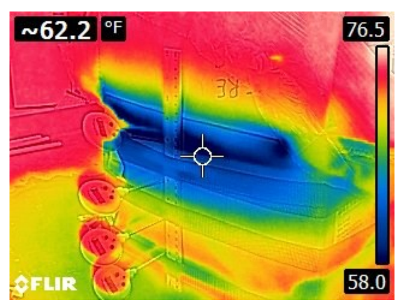
Time elapsed	Optical Photograph	Infrared Thermograph
0 minutes Cold (39° F) water placed around treatment media bags		
30 minutes of water contact		
60 minutes of water contact		
100 minutes of water contact		

Table 3.5 Frost entry into treatment media experiment.

Time elapsed	Optical Photograph	Infrared Thermograph
5 minutes after placement of cold source (2.25 inches of aluminum plate, chilled to -45° F) placed on treatment media surface		
15 minutes after placement of cold source		
30 minutes after placement of cold source		
50 minutes after placement of cold source		

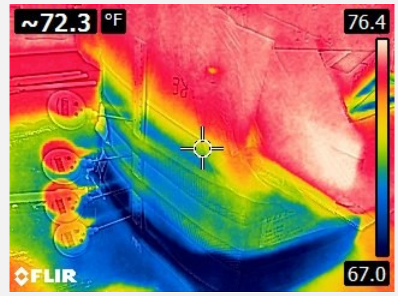
Time elapsed	Optical Photograph	Infrared Thermograph
260 minutes after placement of cold source		

Figure 3.9 Density at time of injection.

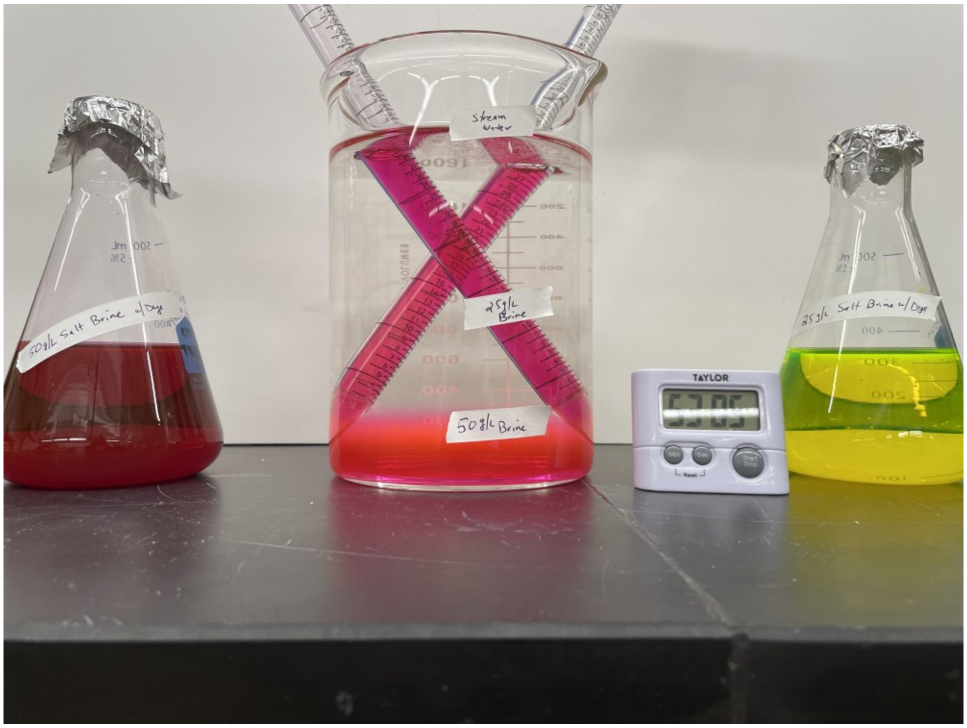


Figure 3.10 Density 1 day after brine injection.

Figure 3.11 Density 2 days after brine injection.

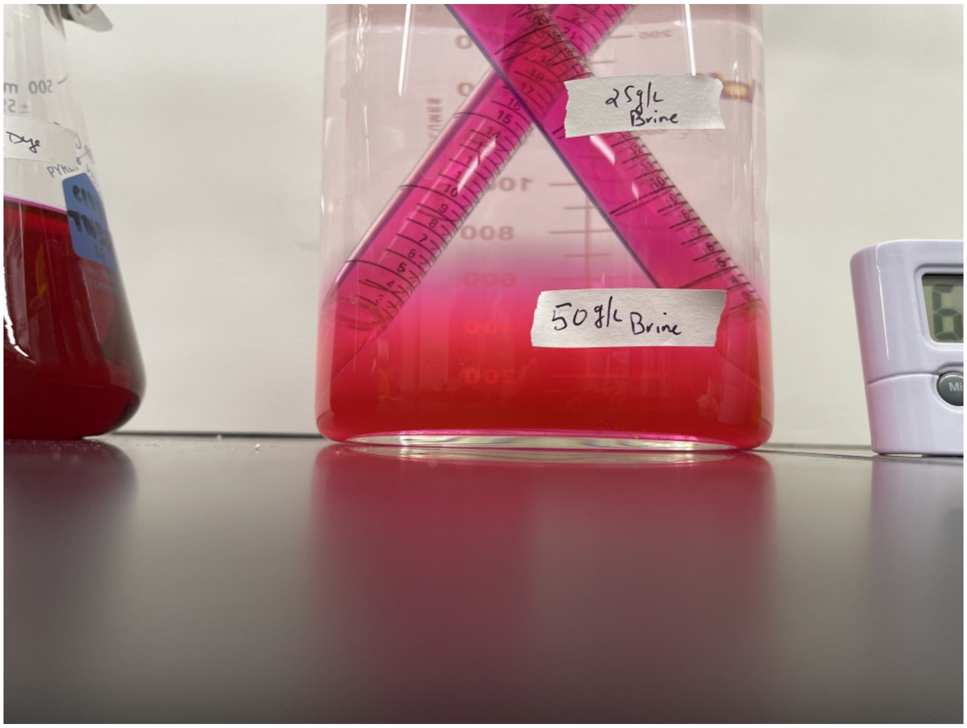


Figure 3.12 Density 5 days after brine injection

Table 3.6 Immersion in Calcium Bentonite (CaB) solution experimental results.

Time elapsed since start of mixing	Chloride concentration (ppm)
Before mixing	Below detection limit (BDL)
At time of mixing	15,300
12 minutes	16,000
24 minutes	15,000 15,400
24 hours	17,000 16,400
14 days	15,000 15,500 14,000 14,500 15,000 14,600 15,200

Note: Experiment consisted of a 2 L mixture of 25 g CaB and 50 g salt in 2000 mL of stream water, continuously mixed.

Table 3.7 Permeability by permeant flow cycle through the treatment media.

Pack Goal: Evaluation of permeability (k) and chloride concentration as a function of 2.0L cycles of flow through filter pack.

	Column 1	Column 2	Column 3	Column 4	Column 5
Treatment Media (1000 g all columns)	4% CaB 56% Pea Stone 40% Sugar Sand	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)	0% CaB 50% Pea Stone 40% Sugar Sand (CaB blank)	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)
Permeant	2.5% Salt Brine	2.5% Salt Brine	2.5% Salt Brine	2.5% Salt Brine	Stream water only (blank)

Measured Permeability (cm/s)

Permeant Flow Amount	Column 1	Column 2	Column 3	Column 4	Column 5
4^{th} – 6^{th} L (third cycle)	0.30	0.35	0.24	0.32	0.11
6^{th} – 8^{th} L (fourth cycle)	0.30	0.34	0.21	0.32	0.11
8^{th} – 10^{th} L (fifth cycle)	0.31	0.28	0.22	0.32	0.11
10^{th} – 12^{th} L (sixth cycle)	0.28	0.24	0.24	0.30	0.10
12^{th} – 14^{th} L (seventh cycle)	0.26	0.19	0.25	0.30	0.10
14^{th} – 16^{th} L (eighth cycle)	0.30	0.22	0.28	0.30	0.10
16^{th} – 18^{th} L (ninth cycle)	0.30	0.19	0.27	0.31	0.10
18^{th} – 20^{th} L (tenth cycle)	Did not measure	0.19	0.25	0.31	0.09
After 20^{th} L	0.34	0.22	0.28	0.34	0.11

Note: Each cycle is 2L of permeant flowing through the treatment media, with effluent brought back to the top of the treatment media to flow through again for the next cycle.

Table 3.8 Chloride concentration by permeant flow cycle through the treatment media.

Pack Goal: Evaluation of permeability (k) and chloride concentration as a function of 2.0L cycles of flow through filter pack.

	Column 1	Column 2	Column 3	Column 4	Column 5
Treatment Media (1000 g all columns)	4% CaB 56% Pea Stone 40% Sugar Sand	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1))	0% CaB 50% Pea Stone 40% Sugar Sand (CaB blank)	4% CaB 56% Pea Stone 40% Sugar Sand (duplicate of Column 1)
Permeant	2.5% Salt Brine	2.5% Salt Brine	2.5% Salt Brine	2.5% Salt Brine	Stream water only (blank)

Chloride Concentration mg/L

Permeant Flow Cycle	Column 1	Column 2	Column 3	Column 4	Column 5
Prior to any treatment	16,200	16,200	16,200	16,100	BDL
After 1st cycle	16,200	16,200	16,300	16,500	BDL
After 4th cycle	16,100	16,200	16,000	16,100	BDL
After 5th cycle	16,300	16,400	16,300	16,500	BDL
After 6th cycle	16,200	16,600	15,600	16,600	BDL
After 8th cycle	16,300	16,600	16,800	16,300	BDL
After 9th cycle	16,800	16,400	16,600	16,600	BDL
After 10th cycle	16,800	16,300	16,200	16,100	BDL

Note 1: Each cycle is 2L of permeant flowing through the treatment media, with effluent brought back to the top of the treatment media to flow through again for the next cycle.
BDL: Below Detection Limit.

Appendix E contains the filter pack logs and analyses for the ninth filter pack set (measured from the start of Task 2), which provides the full data and graphs of the permeability and the chloride concentration measurements for the retreatment of treated effluent experiment.

3.4 Evaluation

In reviewing the results shown in the tables and the appendices, the following evaluation points may be made:

1. Getting flow into the treatment media requires all other flow path possibilities to be less permeable.
    a. Treatment media permeability should be as high as possible while still supporting treatment.

   b. Seams and edges of treatment media flow-through bags must be intentionally blocked. Partially filled commercial sandbags, designed to be relatively impermeable, may be needed in parallel to treatment media bags.

2. Steeper ditch slopes increase the gradient and therefore the flow through the treatment media.
3. Gradients through the treatment media, while in small sections may be different, overall, through a treatment length will mirror the ditch or waterway longitudinal slope.
4. Observations of winter snow melt out suggest flow applied to treatment media in a field installation will be modest to low when compared to the full ditch or channel sizing which typically addresses volume rainfall events. Therefore, the treatment media placement in the ditch or channel will need to be more broad than deep.
5. Frost will occur in treatment media and can block flow, but liquid water runoff will quickly melt the frost out, meaning that any blockage will quickly resolve with treatment media installed as bags above the ground surface.
6. Once frost is melted out of the treatment media, it is unlikely to reestablish in the presence of liquid water because of the relative heat capacity of liquid water.
7. Highway runoff in winter months may carry significant salt concentration, increasing the liquid density and moving it to the ditch or channel bottom, reducing the likelihood of it mixing or diluting away with further runoff.
8. Concentrated salty water, typical of winter runoff levels, may require turbulence during flow in order to mix with fresh water, meaning slow winter snow melt out events may not move salt very far or very fast through the drainage system. Instead, spring and summer rains may be needed to create turbulence associated with higher flow levels.
9. Extended mix time with calcium bentonite does not appear to cause chloride absorbance.
10. Regarding repeated percolation of salt brine through treatment media:
    a. Salt in percolating fluid appears to shift permeability lower by up to one third in some calcium bentonite media. This result may be caused by swelling due to osmotic (salt) absorbance.
    b. Non-salty flow of fresh water does not change permeability with repeated percolation through the treatment media.
    c. Salt in percolation fluid does not shift permeability when the treatment media does not include calcium bentonite over repeated percolation through the treatment media.
    d. Repeated percolation through the treatment media does not appear to cause chloride reduction, as chloride concentrations neither reduce nor appreciably differ from percolation through treatment media without calcium bentonite.
    e. Repeated percolation through the treatment media does not appear to impart any measurable chloride of its own when percolating freshwater fluid with no salt.
    f. Variability in chloride concentration measurements appears to increase with repeated percolation through the treatment media.
11. Results of this work do not lead to an estimation of treatment media contact time or length.

3.5 Conclusions

Chloride capture by flow through treatment media when calcium bentonite is incorporated was not observed in the experiments of this task. Capture of chloride remains elusive. Factors of repeated exposure to the treatment media and extended contact time did not lead to observable chloride capture. Additional evaluations should be made of extended treatment length, not cycling, with variations on salt brine strength. These evaluations should be incorporated into the next task prior to embarking on the field installation.

Hydraulics of in-waterway flow into treatment media flow-through bags will need to be intentionally designed around the flow path, in order to prevent "short circuiting" of the treatment media. Sandbags preventing "treatment leakage" may need to be deployed in parallel to the treatment media bags.

Permeabilities of greater than 0.10 cm/s appear sufficient to capture winter melt out-level flows for treatment in flow through configurations, assuming no alternative pathway of even greater permeability exist at the treatment location.

Frost does not appear to be a significant issue for treatment of winter melt out flows.

Increased slopes of ditch and channel bottom increase the treatment flow, thereby increasing the robustness of the proposed deployment of flow through treatment media bags. Ditch and channel locations with greater slopes should be sought out for deployment location during the next task.

Chapter 4: Performance Optimization Field Installation Study

An in-ditch treatment approach was developed and prototyped such that hydraulic performance and the performance monitoring approach of the treatment technique could be assessed. Installation and performance of in-ditch treatments, consisting of flow-through berms (or “chevrons”) (Figure 3.1) composed of geotextile bags filled with treatment media mixture were the model for the experiments described here.

Summarizing from the evaluations presented in Chapters 2 and 3, design guidance was developed including:

- Chloride capture by flow through treatment media when calcium bentonite is incorporated was initially observed, though at quite low levels of 3 to 6%. This result suggested that treatment flow lengths greater than the 32 cm (approximately 1 ft) are required. However, chloride capture by flow through treatment media when calcium bentonite was incorporated was not observed in the follow-on experiments associated with the treatment media design. Capture of chloride remained elusive. Factors of repeated exposure to the treatment media and extended contact time did not lead to observable chloride capture. Additional evaluations should be made of extended treatment length, not cycling, with variations on salt brine strength. These evaluations should be incorporated into the next task prior to embarking on the field installation.
- Permeability levels were highly influenced by the fine particle amount from both the granular aggregate fines and the calcium bentonite used for chloride capture. Filter pack design must balance achieving a flow high enough to pass snow melt flows in a roadside ditch installation while accomplishing chloride-to-calcium bentonite contact of sufficient time such that chloride capture occurs.
- Hydraulics of in-waterway flow into treatment media flow-through bags will need to be intentionally designed around the flow path, in order to prevent “short circuiting” of the treatment media. Sandbags preventing “treatment leakage” may need to be deployed in parallel to the treatment media bags.
- Permeabilities of greater than 0.10 cm/s appeared sufficient to capture winter melt out-level flows for treatment in flow through configurations, assuming no alternative pathway of even greater permeability exist at the treatment location.
- Frost did not appear to be a significant issue for treatment of winter melt out flows.
- Increased slopes of ditch and channel bottom increased the treatment flow, thereby increasing the robustness of the proposed deployment of flow through treatment media bags. Ditch and channel locations with greater slopes should be sought out for deployment location during the next task.

4.1 Materials

Calcium bentonite (noted in the lab notes of this study by the abbreviation CaB), the clay centered in this study, was sourced from Lone Star Minerals of San Antonio, Texas. It was furnished dried and powdered (defined as passing #200 sieve of opening size 0.075 mm) in 50-pound bags.

Filter aggregates were used in this study to create flow at levels associated with roadway drainage, generally considered to be a permeability above ("faster") than 0.001 cm/s, or 2.5 ft/day. As described in Cedergren (1989):

> "The permeability of soils varies significantly with grain size and is extremely sensitive to the quantity, character, and distribution of the finest fractions."

Filter aggregates are used to distribute the calcium bentonite across the flow path such that the calcium bentonite can come into contact with chloride ions dissolved in drainage water, while maintaining flow at sufficiently high levels. Two filter aggregates used in this study include:

- A fine filter aggregate, determined to be a course, poorly graded sand comprised of angular crushed rock particles; and,
- A course filter aggregate, determined to be a medium, poorly graded gravel also comprised of angular crushed rock particles.

Appendix F presents the grain size analyses used in the characterization of these filter aggregates. Appendix G presents permeability evaluations of different proportions of the two components and calcium bentonite.

These filter aggregates were obtained from Yohnco, Inc. (Yohnco) at their Lake Crystal, MN concrete mix plant.

Geotextile was used for making "flow-through bags" that contained the treatment media. Geotextile consisted of Mirafi 140N geotextile (TenCate Geosynthetics Americas, a Solmax Company, Pendergrass, GA) (Table 3.1).

4.2 Methods

Installation and performance of in-ditch treatments, consisting of flow-through berms (or "chevrons") (Figure 3.1) composed of geotextile bags filled with treatment media mixture, were the core feature of the study in this task.

Because field work along state highways was planned for this effort, a safety plan was prepared (Appendix H) and submitted to both MnDOT District 7 (based on the location of the field test sites) and Minnesota State University, Mankato. Approval by both agencies was received prior to any field activities.

4.2.1 Treatment media

4.2.1.1 Media mixture design

Based on the results of the Task 2 study, a value of 4% by weight was set for the amount of calcium bentonite in the treatment media proposed for the field study. Yohnco was willing to do the mixing using one of their concrete ready-mix trucks, if we supplied the calcium bentonite and they could make up the rest of the mixture using some proportion of fine and coarse aggregate that they had available at their Lake Crystal concrete batching facility.

As discussed previously, the key to successful treatment media is having a permeability high enough to encourage flow while low enough such that contact between the water to be treated and the calcium bentonite is sufficient in amount and duration. Further, it is important that the media mixture be fine enough such that the calcium bentonite is retained and does not pipe or wash through the mixture over time.

Permeability (k) was determined in a "falling head" configuration by measurement of the liquid height (fluid head, h) above the lower end of the filter pack (of length L) at the start time (t_1) and end time (t_2) of a period in which no additional fluid was added to the amount already in the column. In this project, the initial fluid head (h_1) was typically 70 cm. The final fluid head (h_2) was measured prior to the fluid level reaching the filter pack, and was typically 40 cm. The permeability is then determined through Equation 1.

Three rounds of permeability study were done to compare aggregate mixtures, all using 4% calcium bentonite:

- First round: from 30 to 80% fine aggregate (sand), stepping with increments of 10%;
- Second round: from 10 to 35% fine aggregate (sand), stepping with increments of 5%; and,
- Third round: replicating some of the second-round conditions from 20 to 35% fine aggregate (sand), stepping with increments of 5%, plus two additional replicates of 25% fine aggregate.

Figure 2-5 shows the permeability testing equipment, which were also used in the earlier experiments. Results are provided as Appendix G. After four replicate analyses, a mixture was selected of: 4% calcium bentonite, 25% fine aggregate, and 71% coarse aggregate. An average permeability of 0.180 cm/s was determined across four replicates, a level of permeability that is relatively high for natural soils. Minimal calcium bentonite movement through the treatment media was observed over the course of the permeability tests.

4.2.1.2 Treatment media sourcing, mixing and delivery

Treatment media fine and coarse aggregates were sourced and mixed from Yohnco's Lake Crystal MN concrete batch plant. Powdered, dry calcium bentonite was supplied by MSU Mankato research staff as sixteen 50 lb bags. The treatment media mixture was prepared using the following formula:

For Yohn Co.'s Lake Crystal concrete plant:

- 14,400 lbs Gravel (moist, from stockpile)
- 5,100 lbs Sand (moist, from stockpile)
- Calcium bentonite clay, powdered, dry, supplied by MSU/Druschel , 16 at 50 lb bags = 800 lbs

20,300 lbs = 10 tons total

Approximately 6 cy

The calcium bentonite was added to the aggregate mixture by the concrete ready-mix truck operator one bag at a time, with the bags lifted to the level and proximity of the mixer opening using a payloader (Figure 4-1). Mixing was done while the mixer was spun slowly in mixing mode. Mixing continued during the approximately 20-minute transit to the MnDOT truck station at Madelia, MN, offered by MnDOT for a staging area as close to our proposed locations, with plenty of space available. The mixture was then discharged by the ready-mix truck to a pile on the ground (Figure 4.2).

Figure 4-3 is a closeup of the mixed treatment media, showing clay, fine (sand sized) aggregate and coarse aggregate mixed together. Armored clay balls (Figure 4.4), 1 to 2 inches in diameter, were observed having tumbled to the toe of the discharge pile. Armored clay balls, caused by pockets of unmixed clay picking up a coating of fine aggregate, may also be seen in the lower right corner of Figure 4.3.

Figure 4.1 Mixing of treatment media in a concrete ready-mix truck.

Figure 4.2 Delivery of mixed treatment media.

Figure 4.3 Mixed treatment media, showing clay, fine (sand sized) aggregate and coarse aggregate mixed together (pen for scale).

Figure 4.4 Armored clay balls created during the mixing process (pen for scale).

Geotextile bags were made by cutting geotextile off the roll in a strip configuration (Figure 4-5), folding the strip in half, making the center fold into the bag bottom. The sides were then sewn closed leaving the top of the bag open. Sewing was done using a Juki (Juki America, Inc., Morrisville, NC, a subsidiary of Juki Company, Toyko, Japan) DNU-1541 flatbed sewing machine, capable of working with thick thread and heavy weight textiles. Thread was black nylon size 89. Machine and thread were obtained from Service First Sewing Resources of St. Paul, MN.

Figure 4.5 **Geotextile cutting, the first step in making flow-through bags.**

Geotextile bags were filled with treatment media mixture on October 1, 2024, working in two modes. First, bags were filled by hand (Figure 4-6a) using shovels with the bags held open using a polyethylene rectangle as a bag opening spreader. Second, bags were filled using a sandbag filler (supplied by MnDOT) with a hopper for the treatment media, auger system to lift the treatment media out of the hopper, and a chute for the discharge into to the geotextile bag (Figure 4-6b). MnDOT personnel operated both the sandbag filler auger and the payloader required to lift the treatment media and feed it into the auger of the sandbag filler.

Figure 4.6 Treatment bag filling by hand (top) and sandbag filler with hopper and auger system (bottom)

Geotextile bags were closed using wire ties, made for reinforcing bar tying of soft iron and with a loop on each end. The wire ties were wound around the scrunched-up top of a filled geotextile bag, then the tie wire ends twisted tightly together using a tie wire twister (Kraft Tool Company, Shawnee, KS).

4.2.2 Locations selected for in-ditch treatment tests

4.2.2.1 Location selection criteria

Locations for treatment berm testing were identified for proposal using a multi-point criterion with the following factors:

1. Proximity to MSU Mankato to reduce travel time and improve researcher access during installation, monitoring, sampling and removal operations;
2. Slope of ditch line to ensure sufficient water pressure against the treatment berm;
3. Watershed size such that the runoff water captured by the ditch at the proposed location was significant enough to likely build up behind the treatment berm but not be so much as to constantly be overtopping the berm and threatening ditch soil erosion;
4. Position along a low- or medium-volume Minnesota state highway such that salt deicer amounts would be certain to be tracked for the winter events;
5. Locations having wide shoulders off the traveling lanes such that research operations could be carried out with greater safety;
6. Long site visibility distance such that research operations could be spotted by drivers well ahead of the research location, again to increase safety;
7. No critical habitat likely to be encountered or disturbed on the ditch bottom or sides; and,
8. Availability of Advanced Vehicle Location (AVL) data for the state highway.

4.2.2.2 Location selection

Locations for the in-ditch treatments were proposed to the Technical Assistance Panel (TAP) of this research project in the Instrumentation and Sampling Plan, provided as Appendix I.

Four locations along MN 30 in the vicinity of Amboy and Mapleton were proposed for in-ditch treatment:

1. Willow Creek: MN 30, Mile 127, approximately five miles west of Amboy, MN; Pleasant Mound Township, Blue Earth County. AADT 698 (2022).
    a. East location: South side of MN 30, approximately 2075 feet east of CSAH 40/499th Avenue crossroad. 43° 53’ 41.31” N, 94° 15’ 39.63” W. Estimated elevation 1021 feet.
    b. West location: South side of MN 30, approximately 1015 feet east of CSAH 40/499th Avenue crossroad. 43° 53’ 41.28” N, 94° 15’ 54.40” W. Estimated elevation 1023 feet.
2. Sterling: MN 30, Mile 137, approximately five miles east of Amboy, MN and six miles west of Mapleton, MN. Sterling Township, Blue Earth County. AADT 1118 (2023)
    a. North location: North side of MN 30, approximately 1685 feet southwest of County Road 151/119th Street crossroad and approximately 4700 feet northeast of CSAH 1/550th Avenue. 43° 53’ 40.40” N, 94° 03’ 45.75” W. Estimated elevation 995 feet.
    b. South location: South side of MN 30, approximately 1685 feet southwest of County Road 151/119th Street crossroad and approximately 4700 feet northeast of CSAH 1/550th Avenue. 43° 53’ 44.88” N, 94° 03’ 34.80” W. Estimated elevation 989 feet.

Watershed characteristics (Table 4.1) were developed using the topography of MnTOPO (http://arcgis.dnr.state.mn.us/maps/mntopo/) and the distance estimating capability of Google Earth of each location. The TAP concurred with the selection of these locations.

Table 4.1 Sampling location watershed characteristics.

Location	Estimated Watershed Area	Estimated Highway Lane Length
Willow Creek East	780,000 sf (17.9 ac)	2,600 ft single lane
Willow Creek West	80,000 sf (1.8 ac)	500 ft double lane (curve in superelevation)
Sterling North	5,650,000 sf (130 ac)	3600 ft single lane
Sterling South	745,000 sf (17.1 ac)	2140 ft single lane

4.2.2.3 Design of installations

The in-ditch treatments, consisting of flow-through berms (or "chevrons") were developed through Task 2 and 3 efforts to be composed of three to four layers of geotextile bags filled with treatment media mixture, involve placing about 75 flow-through bags, each containing about 60 pounds of a treatment media, in a chevron formation across a stormwater ditch. The installed treatment-bag chevron will likely measure 16 to 20 inches high (above ditch bottom), 2 to 4 feet across (direction of ditch flow), and 25 to 30 feet long (ditch bottom plus side slopes). Wider ditch bottoms will require more bags and be longer.

To limit leakage of water between the bag layers, a "water stop" was proposed that would consist of sand sandwiched between a folded over layer of 6 mil thick polyethylene sheeting (sometimes termed "visqueen") that was laid beneath a layer of treatment bags before placement.

4.2.2.4 Utility clearance

Prior to any in-ditch treatment berm or associated instrumentation being installed at the selected locations, utility clearance was requested through Gopher State One Call (GSOC) (https://www.gopherstateonecall.org) after marking the proposed location with white pin flags as requested by GSOC. Utility clearance was done for each location, typically indicating one or more fiber optic communication cables along the state highway right of way. Research operations stayed a minimum of 3 ft away from any indicated utility location or line.

4.2.3 Berm construction

Treatment berms were constructed using previously filled and tied treatment media bags transported to the locations and placed in an interlayered lifts (Figure 4-7) above water stops (Figure 4-8). Installation occurred on October 15 and 22, 2024.

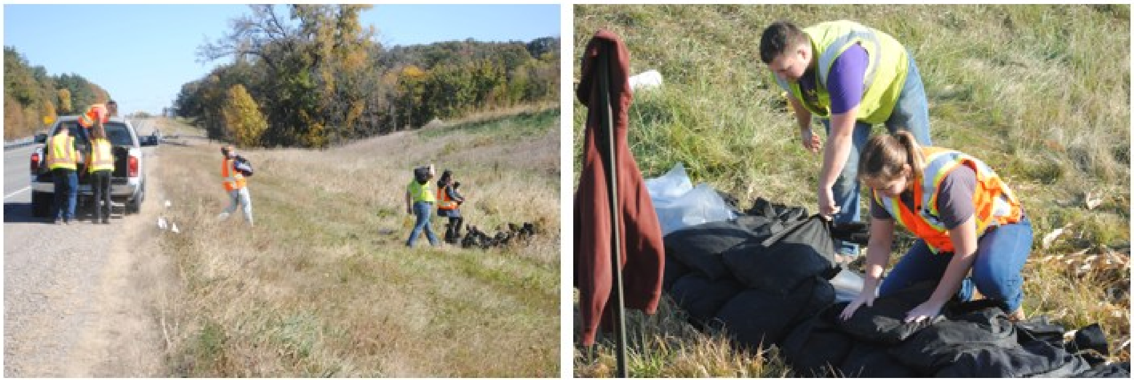


Figure 4.7 Treatment bag hauling to berm location (left); bag placement (right).

Figure 4.8 Water stop construction: sand filling and polyethylene sheet folding (left); interlocking with treatment bags with water stop between layers (right).

4.2.4 Instrumentation installation

At each location, the berm and instruments were protected from potential snowmobile traffic by installation of warning posts with reflective tape, placed approximately 20 ft both upstream and downstream of each treatment berm (Figure 4-9).

Figure 4.9 **Instrumentation installation December 3, 2024. From left to right along ditch line: snowmobile warning post with reflective tape, time lapse camera being installed in an imitation "bird house" on post, post and PVC standpipe for ditch water access up**

Instrumentation was installed on November 12 and December 3, 2024. After subsurface utility clearance, observation instrument mounting posts were installed, instruments and cameras attached and calibrated or aimed, and security measures installed. Data including photographs was checked for data collection occurring. Instruments and cameras were turned on and made operational. Ambient air temperature and humidity (dew point) were measured and recorded using Kestral Drop D3 loggers (Kestral Weather & Environmental Meters, a Nielsen-Kellerman Company, Boothwyn, PA), located 1 and 5 ft above the ditch bottom plus on the ditch side slope near the right of way line.

Water depth measuring devices (Levelogger® 5 LTC, Barologger; Solinst, Canada, Ltd., Georgetown, Ontario) were to be installed on the upstream and downstream ends of the treatment media in accessible sumps once sufficient snow cover existed to protect the devices from extreme cold (devices are warranted only to 32° F, but have been used successfully in previous work to 0° F ambient, if kept submerged or snow covered). However, such snow did not occur until late February and then came in too much of a drift to get the devices down to the ditch bottom. 4-inch diameter PVC standpipes located approximately 4 ft above and below the treatment berms were used for possible installation of the water depth measuring devices effectively as surface water wells.

At each selected location, data including conductivity and temperature measurements and photographs was collected and instruments maintained (cleaned, power sources checked, battery replacement, recalibration as necessary) on an approximately bi-weekly basis. Instruments and cameras were turned on and operational from early November to early-April. Data and photographs are stored in two separate electronic locations at MSU Mankato, for purposes of data security and reliability, filed by location, collection date and instrument or camera.

4.2.5 Monitoring and sampling.

A weather summary of the period from November 2024 to April 2025, by month, for Clear Lake, Iowa from Weatherunderground.com is provided in Appendix J. It includes hourly temperature, wind, and wind gust information plus minimum, maximum and daily average dew point information. Clear Lake, Iowa is about 65 miles away to the southeast of the testing locations.

Figures 20 through 29 show the in-ditch treatment berms as installed at the four locations on February 21, 2025. Little to no accumulating snow had occurred by that time, hence no ditch water to monitor or sample.

Snow events, though minor, occurred in March, and melting that followed created ditch water at the field locations (Figures 30 to 33). Field samples were collected on three days in March: March 7th, March 11th, and March 20th. Samples were collected in two ways, depending upon the conditions present: directly collected water samples, scooped with the sample container when the water was sufficiently deep; and using a pre-weighed paper towel to absorb water when shallow depth was present (Figure 4-18); the "paper towel method".

Figure 4.10 Berm as installed at Sterling South (views downstream and to east). February 21, 2025.

Figure 4.11 Berm as installed at Sterling North (views upstream and to west). February 21, 2025.

Figure 4.12 Berm as installed at Willow Creek West (views upstream and to west). February 21, 2025.

Figure 4.13 Berm as installed at Willow Creek East (views upstream and to east). February 21, 2025.

Figure 4.14 Ditch water flowing as a thin layer through the base of the snowpack then through the treatment berm; Sterling North location, March 7, 2025.

Figure 4.15 Ditch water flowing through and slightly over the treatment berm during melt out; Willow Creek East location, March 11, 2025. Flow from right to left.

Figure 4.16 Ditch water flowing through the treatment berm during melt out; Sterling South location, March 11, 2025. Flow from right to left.

Figure 4.17 Ditch water flowing as a very thin layer through the treatment berm during melt out; Willow Creek East location, March 20, 2025. Flow from left to right.

Figure 4.18 Paper towel method of sampling (March 7, 2025; Sterling North location)

Concentrations of chloride were determined using a reverse titration method that meters samples into a self-filling reagent ampoule (vacu-vial) until reaching a color change point that is calibrated to concentration (Figure 2.8). Chloride was measured using specific test kits (Chemetrics by AquaPhoenix Scientific, LLC, Midland, Virginia) for different ranges of chloride level:

- K-2070 test kit with a range of 10,000 to 100,000 ppm (1 to 10% chloride).
- K-2055 test kit with a range of 1,000 to 10,000 ppm (0.1 to 1% chloride).
- K-2051 test kit with a range of 250 to 2,500 ppm (0.025 to 0.25% chloride).
- K-2050 test kit with a range of 50 to 500 ppm (0.005 to 0.05% chloride).

This analytical approach is specified in APHA Standard Methods (Rice, et al., 2012) as Method 4500-Cl-C-1997.

When used, the paper towel with ditch water is then placed in 100.0 mL of deionized water (DI water); massing the combined sample then chloride testing the combined water allows a calculation of the chloride concentration in the original sampled water. (Appendix K).

4.2.6 Removal of installations

All bags and water stops of the in-ditch treatment berms and all associated instrumentation and mounting posts were removed April 8, 2025. MnDOT District 7 provided and operated an excavator and dump truck to assist, along with a pickup truck for use in traffic safety. Bags were manually lifted to the stationary excavator bucket, sliced open and emptied (Figure 4-19). Geotextile bags were disposed by MSU Mankato as trash, treatment media was recycled by MnDOT as granular fill.

Figure 4.19 **Treatment bag removal.**

4.3 Analyses and Results

A mostly snowless winter limits what can be analyzed. Samples were collected on three days in March when ditch water was present: March 7th, March 11th, and March 20th.

Field observations saw that flows during the early stages of late winter melting may be very thin on the ditch bottom; effectively flowing through the lower part of the snowpack (Figure 15). When snow melt out was fully underway, flows through and sometimes over the treatment berms were observed to be occurring, as shown in Figures 16 and 17 from March 11th. Late-stage melt-out returned conditions to ditch water being very thin on the ditch bottom.

Appendix F contains the sampling notes and the analytical chemistry results for both directly collected samples and samples collected using the paper towel method.

Highest concentration levels were measured in the March 7th samples, with concentrations declining through the March 11th and March 20th samples. This trend is attributed to less salt being placed as the winter season approaches the end, plus greater snowmelt turns into greater dilution. However, with only three data points, it is difficult to make strong conclusions.

No consistent change or trend in the results can be seen from upstream, untreated ditch water to downstream, treated water. In some instances, concentrations increase across the treatment. This behavior is attributed to the presence of lower volumes of ditch water being present below the treatment berm, as the ponding behind the treatment berm necessarily causes backup and therefore a measure of dilution. Density differences of water with higher salt concentration compared to water of lower concentration may also be a factor.

4.4 Evaluation

In reviewing the results described above, and as shown in the photographs, the tables and the appendices, the following evaluation points may be made:

1. The hydraulics of in-ditch treatment appeared to work when the media mixture is designed around achieving a minimum permeability, though greatly dependent upon numerous factors including:
    j. The size of the watershed;
    k. The length of the ditch upstream of the in-ditch treatment;
    l. Drainage tiling connections both to and away from the ditch;
    m. Seasonal snow cover; and,
    n. Melt out weather.
2. Mixing of treatment media by concrete ready-mix truck occurred without difficulty. The largest obstacle was convincing the concrete company that the process would not muck up their equipment with clay that could then affect their subsequent concrete operations. Clearing the equipment of the mixture seemed to be aided by the high rate of aggregate to clay in the mixture and the overall dryness of the mixture (clay added dry with no added water; aggregate surface moisture only).
3. Armored clay balls occurred during the mixing process. Their presence in the treatment mixture could be an impediment to flow (all clay in the center, not a mixture, meaning much less permeability at that location) or could create a reduction in the amount of treatment from a reduction of clay contact area due to perimeter flow in the armoring aggregate, not flow through the clay-rich core.
4. Geotextile flow-through bags required manufacture specifically for the project as such bags do not seem to be commercially available. The bags are relatively easy to make with an industrial sewing machine and a skilled seamstress, which are resources not typically available for stormwater management activities. The bags worked well when employed, with sufficient strength and permeability for the filling, hauling and deployment in-ditch.
5. Filling bags is possible by hand shoveling but much easier by machine feed of the treatment mixture. Discharging the mixed treatment media to the ground turned out to be a significant squander of available energy, as the mixer truck discharge could have been used to fill bags directly, if bag handling personnel were available at the time.
6. Transport of previously filled treatment bags worked, but as stated in item 5, the operation is most efficient if the transport is done with the treatment media in the mixing truck then geotextile flow-through bags are filled and tied at the installation site. However, logistically scheduling all the resources (concrete ready-mix truck, bag handling personnel, highway safety protection vehicles) to be present concurrently could be difficult.
7. Hauling and placing of treatment bags requires either an excavator to lift bags to the ditch bottom or lots of foot traffic to carry bags. If the soil of the ditch is moist or wet, it is likely that the amount of foot traffic required for treatment bag hauling and placement would create a densified pathway; this pathway could harm the stormwater protection characteristics of the roadside vegetation as drainage rill erosion may be caused through localized runoff down the densified pathway, rather than dispersed through the vegetation.
8. Water stop inclusion within the in-ditch treatment berm was helpful, though not perfect in preventing pathways for untreated flow. Dye tracer testing of the flow through the berm would help, though tracing during melt out conditions of mixed ice and water would likely be difficult.

9. Frost in the in-ditch treatment berm happens, as theorized during Task 3 of this project, as found when the treatment berms were removed at the end of the winter experiment. Frost could cause blockage of the flow through the berm. As to be expected, depth of frost impingement will depend upon severity of temperatures and the timing of the spring melt out. Ditch water is likely to accelerate frost out, but not significantly because the melt water would likely be cold. Frost is likely to be most impactful when severely cold temperatures follow warm conditions during a melt out cycle in which the treatment media would have been saturated as the temperature dropped, though the extent of frost may be neither continuous nor full depth meaning ditch water might still be able to flow, moving around the frost lenses.
10. Removal of chloride was difficult to identify with the scale of the ditch water testing used in the project, as either effects were too low to notice or contradictory in result. Secondary factors such as density currents, flow short-circuiting/incomplete layers of water stop, flow overtopping may have influence on the results.
11. Sampling thin layers of flowing ditch water using a pre-weighed paper towel section which after sample collection is placed in jar with a measured volume of deionized water aliquot provided a successful collection for analysis. The method as used on this project resulted in a dilution factor of between 4:1 and 25:1, depending upon the amount of ditch water absorbed by a paper towel section, which did not significantly reduce the precision of the analyses.
12. Removal of the in-ditch treatment berm was a significant effort requiring an excavator to lift out spent treatment media and a dump truck for hauling away. Cutting bags open was the only practical method of separating the geotextile bag from the media; many utility knife blades were required as they dulled quickly on the aggregate pieces. Working with materials from the ditch bottom meant wet and sloppy conditions; many pairs of gloves were needed.

4.5 Conclusions

An in-ditch treatment approach was developed and prototyped, allowing assessment of the hydraulic performance and evaluation of the performance monitoring approach of the treatment technique. Installation and performance of in-ditch treatments, consisting of flow-through berms composed of geotextile bags filled with treatment media mixture, are the core aspects of study in this task. Many of the operational aspects that govern installation and operation of the in-ditch treatment were evaluated including aspects of mix design, mixing, flow-through bag filling, hauling and placement, monitoring, treatment and removal. Lessons learned were documented for future guidance.

Chapter 5: Conclusions

Roadway deicers are essential to the functioning of daily life in northern states in winter. After plowing, roadway salting is currently the most practical way of making safe transportation possible in winter months; amounts in excess of 3 pounds per foot of roadway per winter season are common. However, road deicer chloride (salt) has severe negative effects on surrounding watersheds. Yet, currently no methods or procedures have been developed to capture the chloride. The situation is particularly dire where highways cross small receiving streams that are the habitat of endangered and threatened species, as the high concentration of chloride in the highway runoff does not dilute sufficiently to prevent toxicity in the hatching and juvenal rearing areas of the streams.

Chloride capture by flow through treatment media when calcium bentonite is incorporated was not observed in the experiments of this task. Capture of chloride remains elusive. Factors of repeated exposure to the treatment media and extended contact time did not lead to observable chloride capture. Additional evaluations should be made of extended treatment length, not cycling, with variations on salt brine strength. Permeability levels are highly influenced by the fine particle amount from both the granular aggregate fines and the calcium bentonite used for chloride capture. Filter pack design must balance achieving a flow high enough to pass snow melt flows in a roadside ditch installation while accomplishing chloride-to-calcium bentonite contact of sufficient time such that chloride capture occurs. Chloride measurement techniques support the analytical requirements of this project with a precision determined to be plus or minus approximately 2% of the full chloride measurement when working with salt brine at 2.5% concentration.

Both lab and field experiments provided direction about how to get flow through the treatment media. Directing flow requires all other flow path possibilities to be less permeable, so treatment media permeability should be as high as possible while still supporting treatment. Seams and edges of treatment media flow-through bags must be intentionally blocked. Partially filled commercial sandbags, designed to be relatively impermeable, may be needed in parallel to treatment media bags. Permeabilities of greater than 0.10 cm/s appear sufficient to capture winter melt out-level flows for treatment in flow through configurations, assuming no alternative pathway of even greater permeability exist at the treatment location.

Steeper ditch slopes increase the gradient and therefore the flow through the treatment media. Gradients through the treatment media, while in small sections may be different, overall, through a treatment length will mirror the ditch or waterway longitudinal slope. Observations of winter snow melt out suggest flow applied to treatment media in a field installation will be modest to low when compared to the full ditch or channel sizing, which typically addresses volume rainfall events. Therefore, the treatment media placement in the ditch or channel will need to be broader than deep.

Frost in the in-ditch treatment berm happens and can cause blockage of the flow through the berm. As to be expected, depth of frost impingement will depend on severity of temperatures and timing of the spring melt out. Ditch water is likely to accelerate frost out but not significantly because the melt water would likely be cold. Frost is likely to be most impactful when severely cold temperatures follow warm conditions during a melt out cycle in which the treatment media would have been saturated as the temperature dropped, though the extent of frost may be neither continuous nor full depth, meaning ditch water might still be able to flow, moving around the frost lenses.

Highway runoff in winter months may carry significant salt concentration, increasing the liquid density and moving it to the ditch or channel bottom, reducing the likelihood of it mixing or diluting away with further runoff. Concentrated salty water, typical of winter runoff levels, may require turbulence during flow to mix with fresh water, meaning slow winter snow melt out events may not move salt very far or very fast through the drainage system. Instead, spring and summer rains may be needed to create turbulence associated with higher flow levels.

Extended mix time with calcium bentonite does not appear to cause chloride absorbance. Salt in salt brine percolating through treatment media appears to shift permeability lower by up to one third in some calcium bentonite media. This result may be caused by swelling due to osmotic (salt) absorbance. Non-salty flow of fresh water does not change permeability with repeated percolation through the treatment media. Salt in percolation fluid does not shift permeability when the treatment media does not include calcium bentonite over repeated percolation through the treatment media. Repeated percolation through the treatment media does not appear to cause chloride reduction, as chloride concentrations neither reduce nor appreciably differ from percolation through treatment media without calcium bentonite. Repeated percolation through the treatment media does not appear to impart any measurable chloride of its own when percolating freshwater fluid with no salt. Variability in chloride concentration measurements appears to increase with repeated percolation through the treatment media.

Results of this work do not lead to an estimation of treatment media contact time or length, due to the lack of any measured chloride absorption.

The hydraulics of in-ditch treatment appeared to work when the media mixture was designed around achieving a minimum permeability, although it was greatly dependent on numerous factors including watershed size, ditch length, drainage tiling connections, seasonal snow cover, and melt out weather.

Mixing of treatment media by concrete ready-mix trucks occurred without difficulty. The largest obstacle was convincing the concrete company that the process would not muck up their equipment with clay that could then affect their subsequent concrete operations. Clearing the equipment of the mixture seemed to be aided by the high rate of aggregate to clay in the mixture and the overall dryness of the mixture (clay added dry with no added water; aggregate surface moisture only). Armored clay balls occurred during the mixing process. Their presence in the treatment mixture could be an impediment to flow (all clay in the center, not a mixture, meaning much less permeability at that location) or could create a reduction in the amount of treatment from a reduction of clay contact area due to perimeter flow in the armoring aggregate, not flow through the clay-rich core.

Geotextile flow-through bags required manufacture specifically for the project because such bags do not seem to be commercially available. The bags are relatively easy to make with an industrial sewing machine and a skilled seamstress, which are resources not typically available for stormwater management activities. The bags worked well when employed, with sufficient strength and permeability for the filling, hauling, and deployment in-ditch. Filling bags was possible by hand shoveling but much easier by machine feed of the treatment mixture; filling off the concrete mixer discharge chute would be the most efficient method to fill bags directly. Hauling and placing of treatment bags would require either an excavator to lift bags to the ditch bottom or lots of foot traffic to carry bags.

Sampling thin layers of flowing ditch water using a pre-weighed paper towel section, which after sample collection is placed in jar with a measured volume of deionized water aliquot, provided a successful collection for analysis. The method as used on this project results in a dilution factor of between 4:1 and 25:1, depending on the amount of ditch water absorbed by a paper towel section, which did not significantly reduce the precision of the analyses.

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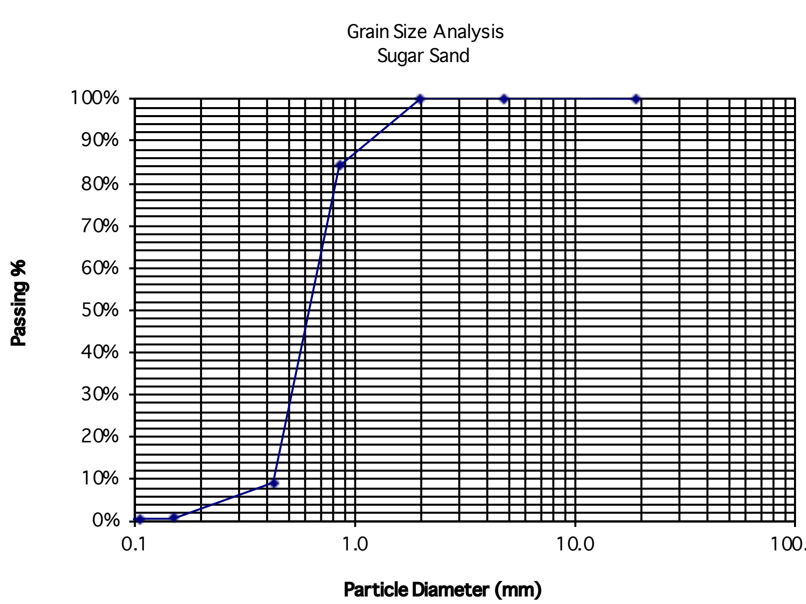
Appendix A:

Filter Aggregate Grain Size Analyses

Sugar Sand Grain Size Analysis

Column Study: Permeability and Chloride Capture
Salt Waterways
January 19, 2024

Initial Dry Mass of Sample		587.8	g	Material:	Sugar Sand	USCS Char =	SP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	525.7	0	0%	587.5	100%
#10	2	488.1	488	-0.1	0%	587.6	100%
#20	0.85	420.3	513.7	93.4	16%	494.2	84%
#40	0.425	372.9	814.1	441.2	75%	53	9%
#100	0.15	350.8	398.8	48	8%	5	1%
#140	0.106	336.6	338.8	2.2	0%	2.8	0%
#200	0.075	336.3	337.4	1.1	0%	1.7	0%
pan		371.9	373.6	1.7	0%	1.7	0%
total =				587.5	100%		
						pan	0.3

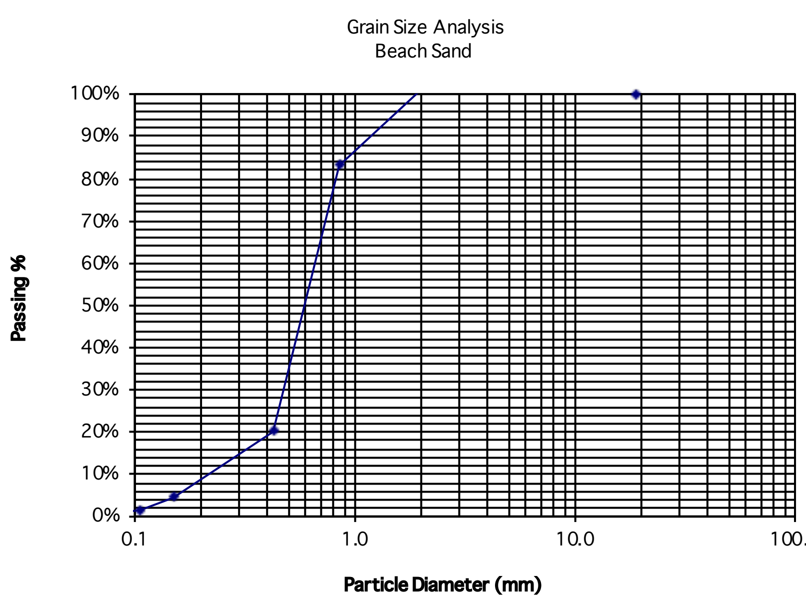


D_{10} =	0.44	mm	
D_{30} =	0.52	mm	
D_{60} =	0.67	mm	

Coefficient of Uniformity	C_u =	1.52	Coefficient of Curvature	C_c =	0.92

Beach Sand Grain Size Analysis

Column Study: Permeability and Chloride Capture							
Salt Waterways							
January 19, 2024							
Initial Dry Mass of Sample		573.5	g	Material:	Beach Sand	USCS Char =	SP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	523.3	-2.4	0%	599.5	105%
#10	2	488.1	508.3	20.2	4%	579.3	101%
#20	0.85	420.3	522.6	102.3	18%	477	83%
#40	0.425	372.9	733.7	360.8	63%	116.2	20%
#100	0.15	350.8	440.8	90	16%	26.2	5%
#140	0.106	336.6	353.5	16.9	3%	9.3	2%
#200	0.075	336.3	342.9	6.6	1%	2.7	0%
pan		371.9	374.6	2.7	0%	2.7	0%
total =				597.1	104%		
						pan	-23.6

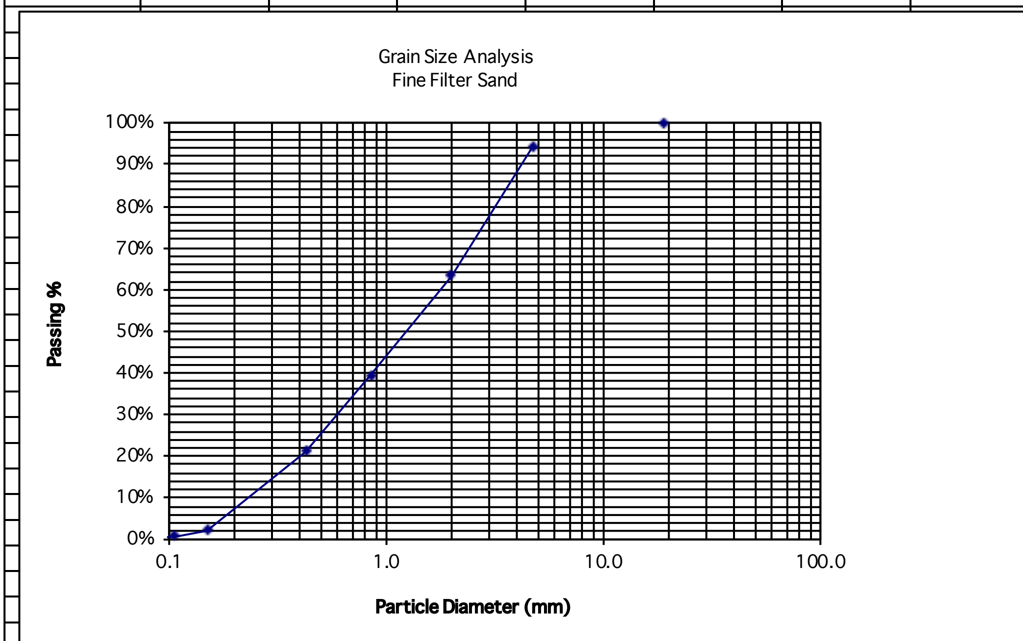


	D_{10} =	0.22	mm				
	D_{30} =	0.47	mm				
	D_{60} =	0.66	mm				
Coefficient of Uniformity	C_u =	3.00		Coefficient of Curvature	C_c =	1.52	

Fine Filter Sand - Grain Size Analysis

Column Study: Permeability and Chloride Capture
Salt Waterways
January 19, 2024

Initial Dry Mass of Sample		727.5	g	Material:	Fine Filter Sand	USCS Char =	SP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
3/8 inch	9.5						
#4	4.75	525.7	565.1	39.4	5%	687	94%
#10	2	488.1	714.2	226.1	31%	460.9	63%
#20	0.85	420.3	594	173.7	24%	287.2	39%
#40	0.425	372.9	506.4	133.5	18%	153.7	21%
#100	0.15	350.8	488.2	137.4	19%	16.3	2%
#140	0.106	336.6	347.1	10.5	1%	5.8	1%
#200	0.075	336.3	339.9	3.6	0%	2.2	0%
pan		371.9	374.1	2.2	0%	2.2	0%
total =				726.4	100%		
						pan	1.1



	D_{10} =	0.23	mm				
	D_{30} =	0.60	mm				
	D_{60} =	1.09	mm				
Coefficient of Uniformity	C_u =	4.74		Coefficient of Curvature	C_c =	1.44	

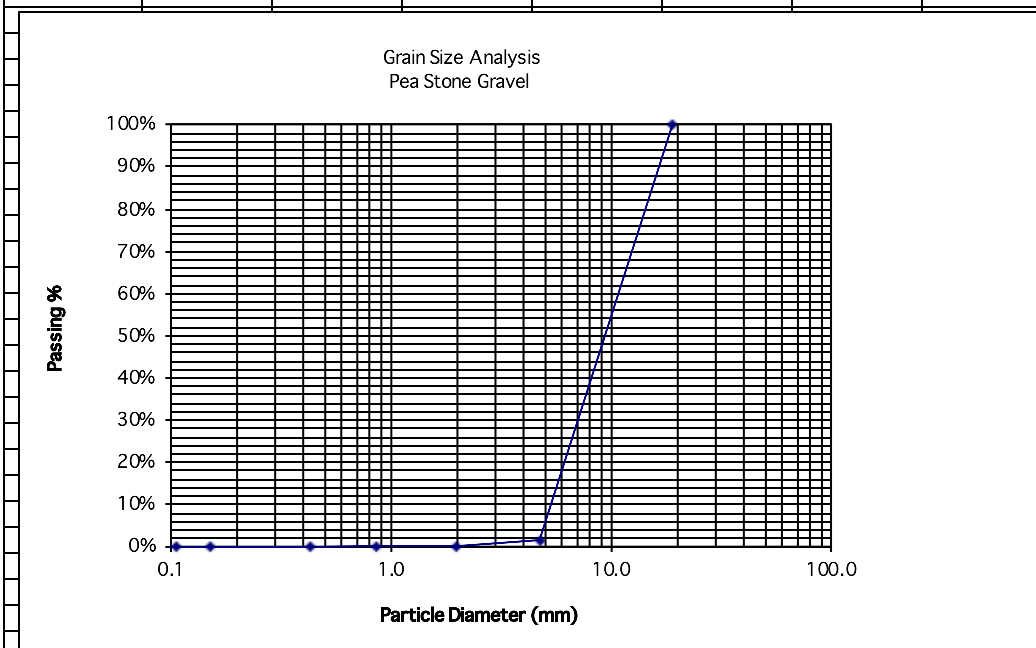
Pea Stone Gravel - Grain Size Analysis

Column Study: Permeability and Chloride Capture

Salt Waterways

January 19, 2024

Initial Dry Mass of Sample		666.1	g	Material:	Pea Stone	USCS Char =	GP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	1181.1	655.4	98%	10.4	2%
#10	2	488.1	498	9.9	1%	0.5	0%
#20	0.85	420.3	420.6	0.3	0%	0.2	0%
#40	0.425	372.9	373.1	0.2	0%	0	0%
#100	0.15	350.8	350.8	0	0%	0	0%
#140	0.106	336.6	336.6	0	0%	0	0%
#200	0.075	336.3	336.3	0	0%	0	0%
pan		371.9	371.9	0	0%	0	0%
total =				665.8	100%		
						pan	0.3



D_{10} =		mm	
D_{30} =		mm	
D_{60} =		mm	

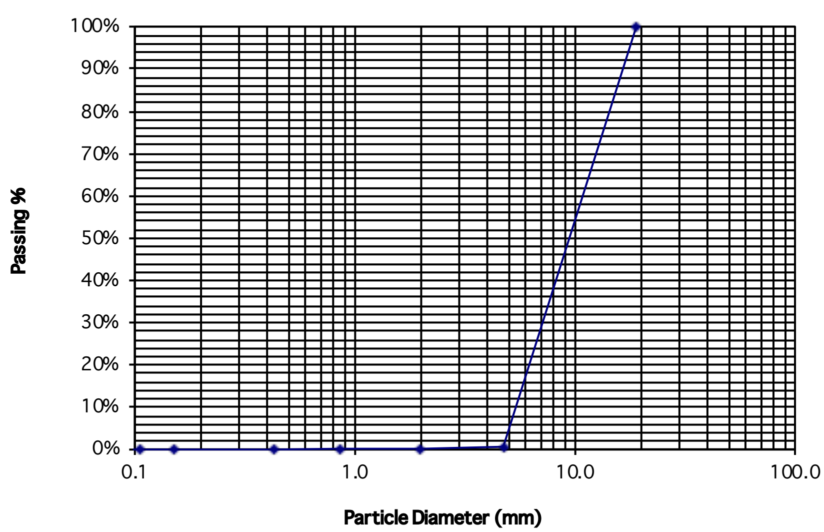
Coefficient of Uniformity	C_u =		Coefficient of Curvature	C_c =

Sunrise Granite Crushed Stone Grain Size Analysis

Column Study: Permeability and Chloride Capture
Salt Waterways
January 19, 2024

Initial Dry Mass of Sample		829.1	g	Material:	Crushed Stone	USCS Char =	GP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	1350	824.3	99%	4.6	1%
#10	2	488.1	492.6	4.5	1%	0.1	0%
#20	0.85	420.3	420.3	0	0%	0.1	0%
#40	0.425	372.9	373	0.1	0%	0	0%
#100	0.15	350.8	350.8	0	0%	0	0%
#140	0.106	336.6	336.6	0	0%	0	0%
#200	0.075	336.3	336.3	0	0%	0	0%
pan		371.9	371.9	0	0%	0	0%
total =				828.9	100%		
						pan	0.2

Grain Size Analysis
Sunrise Granite Crushed Stone



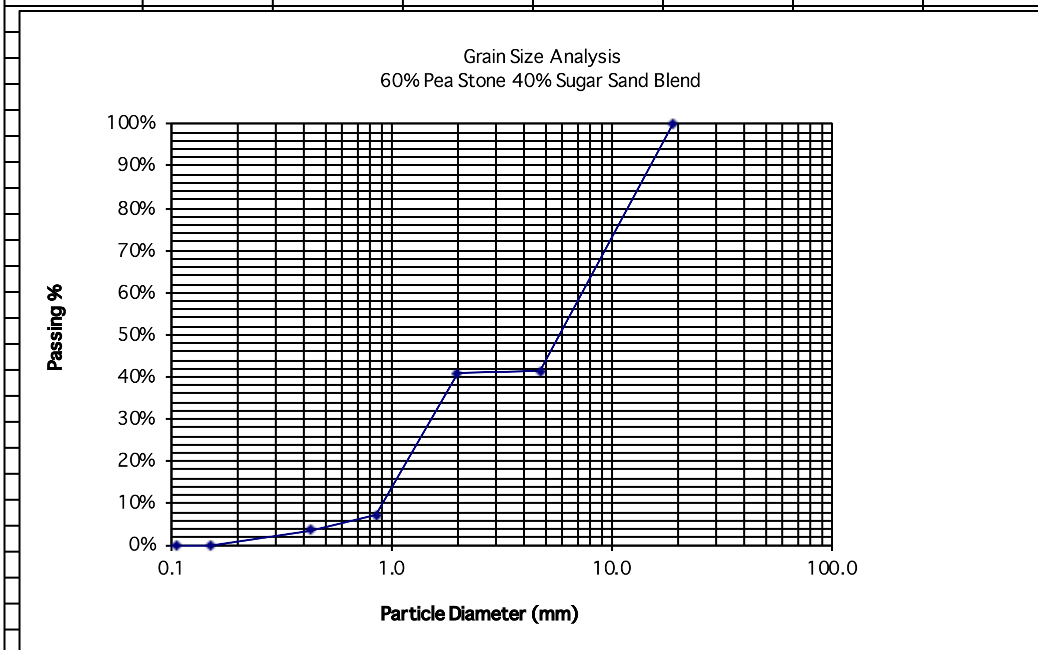
D_{10} =		mm	
D_{30} =		mm	
D_{60} =		mm	

Coefficient of Uniformity	C_u =		Coefficient of Curvature	C_c =

Pea Stone Sugar Sand Blend Grain Size Analysis

Column Study: Permeability and Chloride Capture
Salt Waterways
January 19, 2024

Initial Dry Mass of Sample		100	g	Material:	60% Pea Stone with 40% Sugar Sand	USCS Char =	GP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75			58.8	59%	41.2	41%
#10	2			0.4	0%	40.8	41%
#20	0.85			33.6	34%	7.2	7%
#40	0.425			3.6	4%	3.6	4%
#100	0.15			3.6	4%	0	0%
#140	0.106			0	0%	0	0%
#200	0.075			0	0%	0	0%
pan				0	0%	0	0%
total =				100	100%		
						pan	0



D_{10} =	0.9	mm	
D_{30} =	1.6	mm	
D_{60} =	7.3	mm	

Coefficient of Uniformity	C_u = 8.11		Coefficient of Curvature	C_c = 0.39

Appendix B:
First Through Sixth Filter Pack Logs and Analyses

Salt Waterways								
Column Study: Permeability and Chloride Capture								
September 9, 2023								
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm		
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/							
		inside area =	21.23	cm^2				
Hanna Groline Soil Test Conductivity Meter Model HI98331 S/N L04370336								
Conc (g/L) =	15.727	Conductivity (ms/cm)						
From Chloride Columns calibration study								
Temp	72	deg F						
Column	1	2	3	4	5	6		
Trmt Media Mass (g)	500	500	500	500	500	500		
Sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand		
Ca-B %	0%	1%	2%	3%	4%	5%		
Length (cm)	16	16	16	16	16	16		
Height of support laye	16	16	16	16	16	16		
Starting Level (cm)	70	70	70	70	70	70		
Ending Level (cm)	50	50	50	50	50	50		
Flow Volume (mL)	424.6	424.6	424.6	424.6	424.6	424.6		
Elapsed Time (s)	76	382	487	158	155	358		
Flow Velocity (seconds per mL)	3.80	19.10	24.35	7.90	7.75	17.90		
Flow Velocity (minutes per mL)	0.06	0.32	0.41	0.13	0.13	0.30		
Head at start (cm) = dist above end of treatment media	54.0	54.0	54.0	54.0	54.0	54.0		
Head at end (cm) = dist above end of treatment media	34.0	34.0	34.0	34.0	34.0	34.0		
Permeability (cm/s)	0.097	0.019	0.015	0.047	0.048	0.021		
Permeability (cm/s)	9.7E-02	1.9E-02	1.5E-02	4.7E-02	4.8E-02	2.1E-02		
increment of permeab	0.01	0.001	0.001	0.01	0.01	0.01		
Amt of time for incren	69	363	457	130	128	241		
delta time (sec)	7	19	30	28	27	117		
delta time (min)	0.1	0.3	0.5	0.5	0.4	1.9		
Second run time (sec)	107	716	676	294	152	370		
Perm Second (cm/sec)	0.069	0.010	0.011	0.025	0.049	0.020		
Third run time (sec)								
Perm Third (cm/sec)								
Stock Conc (g/L) Mix	50	50	50	50	50	50		
Stock Vol (mL)	2000	2000	2000	2000	2000	2000		
Stock Conc Meas (g/L)	50	50	50	50	50	50		
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0		
Effluent Cond (mS/cm	3.467	3.623	3.69	3.297	3.13	3.137	AVERAGES of 3 meas	
Effluent Vol (mL)	1945	1965	1945	1965	1965	1975	drip loss in col 4. Actual 1	
Dilution	25	25	25	25	25	25		
Effluent Conc Meas (g	54.5	57.0	58.0	51.9	49.2	49.3		
Mass in Effluent (g)	106.1	112.0	112.9	101.9	96.7	97.4		
Mass Captured (g)	-6.1	-12.0	-12.9	-1.9	3.3	2.6		
Mass Captured/Mass Challenged (%)	-6%	-12%	-13%	-2%	3%	3%		
Captured/CaB (g/g)	#DIV/0!	-239%	-129%	-13%	16%	10%		
QUESTION ABOUT RESULTS DUE TO VARIATIONS NOTED IN PIPET FOR CONCENTRATION SAMPLING								
USE ONLY PERMEABILITY DATA AND RERUN								

Salt Waterways							
Column Study: Permeability and Chloride Capture							
September 19, 2023							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensi						
		inside area =	21.23	cm^2			
Hanna Groline Soil Test Conductivity Meter Model HI98331 S/N L04370336							
Conc (g/L) =	15.727	Conductivity (ms/cm)		REVISED FOR CALIBRATION 100323			
From Chloride Columns calibration study							
Temp	72	deg F					
Column	1	2	3	4	5	6	Filled Sept 11th
Trmt Media Mass (g)	500	1000	1500	500	1000	1500	
Sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand	Sugar sand	
Ca-B %	3%	3%	3%	5%	5%	5%	
Length (cm)	16	32	46.5	16	32	46.5	
Height of support laye	5	5	5	5	5	5	
Starting Level (cm)	70	70	70	70	70	70	9/11/23 12:40
Ending Level (cm)	41	37	56	46.5	53.3	61.1	
Flow Volume (mL)	615.7	700.7	297.2	499.0	354.6	189.0	
Elapsed Time (s)	480	480	480	480	480	480	
Flow Velocity (seconds per mL)	16.55	14.55	34.29	20.43	28.74	53.93	
Flow Velocity (minutes per mL)	0.28	0.24	0.57	0.34	0.48	0.90	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	36.0	32.0	51.0	41.5	48.3	56.1	
Permeability (cm/s)	0.020	0.047	0.023	0.015	0.020	0.014	
Permeability (cm/s)	2.0E-02	4.7E-02	2.3E-02	1.5E-02	2.0E-02	1.4E-02	
increment of permeab	0.01	0.01	0.01	0.01	0.01	0.01	
Amt of time for incren	318	396	337	288	319	282	
delta time (sec)	162	84	143	192	161	198	
delta time (min)	2.7	1.4	2.4	3.2	2.7	3.3	
Stock Conc (g/L) Mix	50	50	50	50	50	50	9/12/23 10:00
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (mS/cm	4.00	3.74	3.49	3.71	3.67	3.07	
Effluent Cond (mS/cm	3.75	3.59	3.43	3.87	3.50	3.05	
Effluent Cond (mS/cm	3.77	3.89	3.40	3.64	3.31	3.06	
AVG Effl Cond	3.84	3.74	3.44	3.74	3.49	3.06	
Effluent Vol (mL)	1885	1865	1865	1885	1876	1844	

Dilution	25	25	25	25	25	25	
Effluent Conc Meas (g,	60.4	58.8	54.1	58.8	54.9	48.1	
Mass in Effluent (g)	113.8	109.7	100.9	110.9	103.1	88.7	
Mass Captured (g)	-13.8	-9.7	-0.9	-10.9	-3.1	11.3	
Mass Captured/Mass Challenged (%)	-14%	-10%	-1%	-11%	-3%	11%	
Captured/CaB (g/g)	-92%	-32%	-2%	-43%	-6%	15%	
Starting Level (cm)	70	70	70	70	70	70	9/13/23 10:40
Ending Level (cm)	30	45	60	30	45	61	
Flow Volume (mL)	849.3	530.8	212.3	849.3	530.8	191.1	
Elapsed Time (s)	906	1295	2405	3134	1290	3150	
Flow Velocity (seconds per mL)	22.65	51.80	240.50	78.35	51.60	350.00	
Flow Velocity (minutes per mL)	0.38	0.86	4.01	1.31	0.86	5.83	
Head at start (cm) = dist above end of treatment media	70.9	70.3	70.0	70.4	70.1	69.8	
Head at end (cm) = dist above end of treatment media	30.9	45.3	60.0	30.4	45.1	60.8	
Permeability (cm/s)	0.020	0.018	0.005	0.002	0.007	0.002	
Permeability (cm/s)	2.0E-02	1.8E-02	4.7E-03	2.3E-03	7.4E-03	2.2E-03	
increment of permeab	0.01	0.01	0.01	0.01	0.01	0.01	
Amt of time for incren	-4	-2	0	-7	-1	1	
delta time (sec)	910	1297	2405	3141	1291	3149	
delta time (min)	15.2	21.6	40.1	52.4	21.5	52.5	
Stock Conc (g/L) Mix	50	50	50	50	50	50	9/14/23 10:00
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (mS/cm	3.51	3.49	3.46	3.52	3.45	3.46	
Effluent Cond (mS/cm	3.52	3.48	3.45	3.52	3.44	3.44	
Effluent Cond (mS/cm	3.60	3.49	3.46	3.53	3.43	3.44	
AVG Effl Cond	3.54	3.49	3.46	3.52	3.44	3.45	
Sample volume (mL)	6.00	6.00	6.00	6.00	6.00	6.00	
Effluent Vol (mL)	1930	1930	1945	1900	1920	1930	
Effluent Vol (mL)	1936	1936	1951	1906	1926	1936	
Dilution	25	25	25	25	25	25	
Effluent Conc Meas (g,	55.7	54.8	54.4	55.4	54.1	54.2	
Mass in Effluent (g)	107.9	106.2	106.1	105.6	104.2	104.9	
Mass Captured (g)	-7.9	-6.2	-6.1	-5.6	-4.2	-4.9	

Mass Captured/Mass Challenged (%)	-8%	-6%	-6%	-6%	-4%	-5%	
Captured/CaB (g/g)	-53%	-21%	-13%	-22%	-8%	-7%	
Starting Level (cm)	70	70	70	70	70	70	9/15/23 11:40
Ending Level (cm)	30	45	60	30	45	60	
Flow Volume (mL)	849.3	530.8	212.3	849.3	530.8	212.3	
Elapsed Time (s)	1102	955	3047	5233	1583	3550	
Flow Velocity (seconds per mL)	27.55	38.20	304.70	130.83	63.32	355.00	
Flow Velocity (minutes per mL)	0.46	0.64	5.08	2.18	1.06	5.92	
Head at start (cm) = dist above end of treatment media	70.5	70.2	70.1	70.2	70.1	70.1	
Head at end (cm) = dist above end of treatment media	30.5	45.2	60.1	30.2	45.1	60.1	
Permeability (cm/s)	0.020	0.024	0.004	0.001	0.006	0.002	
Permeability (cm/s)	2.0E-02	2.4E-02	3.7E-03	1.4E-03	6.0E-03	1.9E-03	
increment of permeab	0.01	0.01	0.001	0.001	0.001	0.001	
Amt of time for incren	-2	-1	-2	-20	-3	-3	
delta time (sec)	1104	956	3049	5253	1586	3553	
delta time (min)	18.4	15.9	50.8	87.5	26.4	59.2	
Stock Conc (g/L) Mix	50	50	50	50	50	50	
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (mS/cm	4.00	3.90	4.00	3.69	3.37	3.50	9/19/23 13:00
Effluent Cond (mS/cm	3.86	3.56	3.75	3.63	3.39	3.64	
Effluent Cond (mS/cm	3.94	3.54	3.77	3.87	3.45	3.49	
AVG Effl Cond	3.93	3.67	3.84	3.73	3.40	3.54	
Sample volume (mL)	6.00	6.00	6.00	6.00	6.00	6.00	
Effluent Vol (mL)	1932	1925	1948	2050	1898	1230	
Effluent Vol (mL)	1938	1931	1954	2056	1904	1236	
Dilution	25	25	25	25	25	25	
Effluent Conc Meas (g,	61.9	57.7	60.4	58.7	53.5	55.7	
Mass in Effluent (g)	119.9	111.4	118.0	120.6	101.9	68.9	
Mass Captured (g)	-19.9	-11.4	-18.0	-20.6	-1.9	31.1	
Mass Captured/Mass Challenged (%)	-20%	-11%	-18%	-21%	-2%	31%	
Captured/CaB (g/g)	-133%	-38%	-40%	-82%	-4%	41%	
Columns taken apart and emptied, then washed with alconox detergent and triple rinsed in DI.							

Salt Waterways			THIRD PACK							
Column Study: Permeability and Chloride Capture										
10/05/2023										
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm				
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/									
		inside area =	21.23	cm^2						
Oakton Conductivity Meter										
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)				
From Chloride Columns calibration study										
							Columns 1-6 Filled Sept 18th			
Temp	72	deg F					Columns 7-9 Filled Sept 27th			
Column	1	2	3	4	5	6	7	8	9	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	1000	1000	1000	
Fine Filter Sand Propo	100%	99%	98%	97%	96%	95%	98.5%	97.5%	96.5%	
Sugar Sand Proportion	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Beach Sand Proportior	0%	0%	0%	0%	0%	0%	0%	0%	0%	
Ca-B %	0%	1%	2%	3%	4%	5%	1.5%	2.5%	3.5%	
Length (cm)	32	32	32	32	32	32	32	32	32	
Height of support laye	5	5	5	5	5	5	5	5	5	
Starting Level (cm)	70	70	70	70	70	70				Sept 18th
Ending Level (cm)	45	52	56	55	57.8	60.6				
Flow Volume (mL)	530.8	382.2	297.2	318.5	259.0	199.6				
Elapsed Time (s)	900	1740	1680	6840	6780	6660				
Flow Velocity (seconds per mL)	36.00	96.67	120.00	456.00	555.74	708.51				
Flow Velocity (minutes per mL)	0.60	1.61	2.00	7.60	9.26	11.81				
Head at start (cm) = dist above end of treatment media	70.0	70.0	70.0	70.0	70.0	70.0				
Head at end (cm) = dist above end of treatment media	45.0	52.0	56.0	55.0	57.8	60.6				
Permeability (cm/s)	0.016	0.0055	0.0043	0.0011	0.0009	0.0007				
Permeability (cm/s)	1.6E-02	5.5E-03	4.3E-03	1.1E-03	9.0E-04	6.9E-04				
increment of permeab	0.01	0.001	0.001	0.001	0.001	0.001				
Amt of time for incren	0	0	0	0	0	0				
delta time (sec)	900	1740	1680	6840	6780	6660				
delta time (min)	15.0	29.0	28.0	114.0	113.0	111.0				
Starting Level (cm)	70	70	70	70	70	70	70	70	70	Sept 20 & 27
Ending Level (cm)	43	43.6	46.6	67.8	64.2	65	41	41	50	
Flow Volume (mL)	573.3	560.5	496.8	46.7	123.1	106.2	615.7	615.7	424.6	
Elapsed Time (s)	1440	3960	3960	3960	3900	3900	1053	5517	8189	
Flow Velocity (seconds per mL)	53.33	150.00	169.23	1800.00	672.41	780.00	36.31	190.24	409.45	
Flow Velocity (minutes per mL)	0.89	2.50	2.82	30.00	11.21	13.00	0.61	3.17	6.82	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	38.0	38.6	41.6	62.8	59.2	60.0	36.0	36.0	45.0	
Permeability (cm/s)	0.012	0.004	0.004	0.0003	0.0008	0.0007	0.018	0.0034	0.0014	
Permeability (cm/s)	1.2E-02	4.2E-03	3.6E-03	2.8E-04	7.7E-04	6.6E-04	1.8E-02	3.4E-03	1.4E-03	
increment of permeab	0.01	0.001	0.001	0.001	0.001	0.001	0.01	0.001	0.001	
Amt of time for incren	783	3200	3100	862	1693	1546	676	4271	4829	
delta time (sec)	657	760	860	3098	2207	2354	377	1246	3360	
delta time (min)	10.9	12.7	14.3	51.6	36.8	39.2	6.3	20.8	56.0	

Stock Conc (g/L) Mix	50	50	50	50	50	50	50	50	50	Sept 22 & 26
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (uS/cm)	5880.00	5950.00	5980.00	5810.00	5690.00	5960.00	5920.00	5550.00	5480.00	
AVG Effl Cond	5880.00	5950.00	5980.00	5810.00	5690.00	5960.00	5920.00	5550.00	5480.00	
Effluent Vol (mL)	1965	1980	1985	1870	1929	1868	1967	2015	1972	
Effluent Conc Meas (g/	44.4	45.1	45.4	43.7	42.5	45.2	44.8	41.2	40.5	
Mass in Effluent (g)	87.3	89.3	90.1	81.7	82.1	84.4	88.1	83.0	79.9	
Mass Captured (g)	12.7	10.7	9.9	18.3	17.9	15.6	11.9	17.0	20.1	
Mass Captured/Mass Challenged (%)	13%	11%	10%	18%	18%	16%	12%	17%	20%	
Captured/CaB (g/g)	#DIV/0!	107%	49%	61%	45%	31%	79%	68%	57%	
Stock Conc (g/L) Mix	50	50	50				50	50	50	Oct 5th
Stock Vol (mL)	2000	2000	2000				2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50				50	50	50	
Mass Challenged (g)	100.0	100.0	100.0				100.0	100.0	100.0	
Effluent Cond (uS/cm)	6060.00	6190.00	6140.00				6130.00	6140.00	6110.00	
AVG Effl Cond	6060.00	6190.00	6140.00				6130.00	6140.00	6110.00	
Effluent Vol (mL)	1955	1972	1975				1975	2010	1982	
Effluent Conc Meas (g/	46.2	47.5	47.0				46.9	47.0	46.7	
Mass in Effluent (g)	90.3	93.7	92.8				92.6	94.5	92.6	
Mass Captured (g)	9.7	6.3	7.2				7.4	5.5	7.4	
Mass Captured/Mass Challenged (%)	10%	6%	7%				7%	6%	7%	
Captured/CaB (g/g)	#DIV/0!	63%	36%				25%	14%	15%	
Starting Level (cm)			70					70	70	Oct 5th
Ending Level (cm)			45.8					42.7	59.6	
Flow Volume (mL)			513.8					579.6	220.8	
Elapsed Time (s)			6000					6000	6000	
Flow Velocity (seconds per mL)			247.93					219.78	576.92	
Flow Velocity (minutes per mL)			4.13					3.66	9.62	
Head at start (cm) = dist above end of treatment media			70.0					70.0	70.0	
Head at end (cm) = dist above end of treatment media			45.8					42.7	59.6	
Permeability (cm/s)			0.002					0.0032	0.0020	
Permeability (cm/s)			2.4E-03					3.2E-03	2.0E-03	
increment of permeability			0.001					0.001	0.001	
Amt of time for increment			62					81	31	
delta time (sec)			5938					5919	5969	
delta time (min)			99.0					98.6	99.5	
Columns taken apart and emptied, then washed with alconox detergent and triple rinsed in DI.										

Salt Waterways							
Column Study: Permeability and Chloride Capture							
10/05/2023							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensi						
		inside area =	21.23	cm^2			
Oakton Conductivity Meter							
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)	
From Chloride Columns calibration study							
Temp	72	deg F					
Column	1	2	3	4	5	6	Filled Oct 5th
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	97%	77%	77%	57%	57%	57%	
Sugar Sand Proportion	0%	20%	0%	40%	0%	20%	
Beach Sand Proportior	0%	0%	20%	0%	40%	20%	
Ca-B %	3%	3%	3%	3%	3%	3%	
Length (cm)	32	32	32	32	32	32	
Height of support laye	5	5	5	5	5	5	
Starting Level (cm)	70	70	70	70	70	70	
Ending Level (cm)	40	40	40	40	40	40	
Flow Volume (mL)	637.0	637.0	637.0	637.0	637.0	637.0	
Elapsed Time (s)	34	39	47	23	109	433	checked
Flow Velocity (seconds per mL)	1.13	1.30	1.57	0.77	3.63	14.43	
Flow Velocity (minutes per mL)	0.02	0.02	0.03	0.01	0.06	0.24	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	35.0	35.0	35.0	35.0	35.0	35.0	
Permeability (cm/s)	0.583	0.508	0.421	0.861	0.182	0.046	
Permeability (cm/s)	5.8E-01	5.1E-01	4.2E-01	8.6E-01	1.8E-01	4.6E-02	
increment of permeab	0.1	0.1	0.1	0.1	0.1	0.01	
Amt of time for incren	29	33	38	21	70	355	
delta time (sec)	5	6	9	2	39	78	
delta time (min)	0.1	0.1	0.2	0.0	0.6	1.3	
Stock Conc (g/L) Mix	50	50	50	50	50	50	9/12/23 10:00
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (uS/cm)	5710.00	5820.00	5870.00	6110.00	6050.00	5890.00	checked
AVG Effl Cond	5710.00	5820.00	5870.00	6110.00	6050.00	5890.00	

Effluent Vol (mL)	2010	2050	2020	1940	2025	1844	checked
Effluent Conc Meas (g	42.7	43.8	44.3	46.7	46.1	44.5	
Mass in Effluent (g)	85.9	89.8	89.5	90.6	93.4	82.1	
Mass Captured (g)	14.1	10.2	10.5	9.4	6.6	17.9	
Mass Captured/Mass Challenged (%)	14%	10%	11%	9%	7%	18%	
Captured/CaB (g/g)	47%	34%	35%	31%	22%	60%	
Stock Conc (g/L) Mix	50	50	50	50	50	50	9/14/23 10:00
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (uS/cm)	6520.00	6680.00	7630.00	5590.00	6690.00	6760.00	checked
AVG Effl Cond	6520.00	6680.00	7630.00	5590.00	6690.00	6760.00	
Effluent Vol (mL)	1978	1836	1890	1862	1862	1843	checked
Effluent Conc Meas (g	50.9	52.6	63.0	41.6	52.7	53.4	
Mass in Effluent (g)	100.7	96.5	119.0	77.4	98.1	98.5	
Mass Captured (g)	-0.7	3.5	-19.0	22.6	1.9	1.5	
Mass Captured/Mass Challenged (%)	-1%	3%	-19%	23%	2%	2%	
Captured/CaB (g/g)	-2%	12%	-63%	75%	6%	5%	
Stock Conc (g/L) Mix	50	50	50	50	50	50	
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (mS/cm	6525.00	6600.00	6650.00	6700.00	6640.00	6760.00	checked
AVG Effl Cond	6525.00	6600.00	6650.00	6700.00	6640.00	6760.00	
Effluent Vol (mL)	1988	1952	2000	1918	2025	1993	checked
Dilution	25	25	25	25	25	25	
Effluent Conc Meas (g	51.0	51.7	52.3	52.8	52.2	53.4	
Mass in Effluent (g)	101.3	101.0	104.5	101.3	105.6	106.5	
Mass Captured (g)	-1.3	-1.0	-4.5	-1.3	-5.6	-6.5	
Mass Captured/Mass Challenged (%)	-1%	-1%	-5%	-1%	-6%	-6%	
Captured/CaB (g/g)	-4%	-3%	-15%	-4%	-19%	-22%	
Columns taken apart and emptied, then washed with alconox detergent and triple rinsed in DI.							

Salt Waterways				FIFTH PACK			
Column Study: Permeability and Chloride Capture							
10/31/2023							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensi						
		inside area =	21.23	cm^2			
Oakton Conductivity Meter							
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)	
From Chloride Columns calibration study							
Temp	72	deg F					
Column	1	2	3	4	5	6	Filled Oct 24th
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	55%	55%	55%	53%	53%	53%	
Sugar Sand Proportion	40%	40%	20%	40%	40%	20%	
Beach Sand Proportion	0%	0%	20%	0%	0%	20%	
Ca-B %	5%	5%	5%	7%	7%	7%	
Length (cm)	32	32	32	32	32	32	
Height of support laye	5	5	5	5	5	5	
Starting Level (cm)	70	70	70	70	70	70	
Ending Level (cm)	40	40	40	64	37	67	
Flow Volume (mL)	637.0	637.0	637.0	127.4	700.7	63.7	
Elapsed Time (s)	3490	820	1680	86400	2236	1800	checked
Flow Velocity (seconds per mL)	116.33	27.33	56.00	14400.00	67.76	600.00	
Flow Velocity (minutes per mL)	1.94	0.46	0.93	240.00	1.13	10.00	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	35.0	35.0	35.0	59.0	32.0	62.0	
Permeability (cm/s)	0.006	0.024	0.012	0.000036	0.010	0.00084	
Permeability (cm/s)	5.7E-03	2.4E-02	1.2E-02	3.6E-05	1.0E-02	8.4E-04	
increment of permeab	0.1	0.1	0.1	0.1	0.1	0.01	
Amt of time for incren	187	160	177	31	206	139	
delta time (sec)	3303	660	1503	86369	2030	1661	
delta time (min)	55.0	11.0	25.0	1439.5	33.8	27.7	
Stock Conc (g/L) Mix	50	50	50	50	50	50	Oct 25th
Stock Vol (mL)	2000	2000	2000	2000	2000	2000	
Stock Conc Meas (g/L)	50	50	50	50	50	50	
Mass Challenged (g)	100.0	100.0	100.0	100.0	100.0	100.0	
Effluent Cond (uS/cm)	6320.00	6340.00	6350.00				
AVG Effl Cond	6320.00	6340.00	6350.00		these columns		
Effluent Vol (mL)	1940	1925	1925		took too long		
Effluent Conc Meas (g	48.8	49.0	49.1				
Mass in Effluent (g)	94.8	94.4	94.6				
Mass Captured (g)	5.2	5.6	5.4				
Mass Captured/Mass Challenged (%)	5%	6%	5%				
Captured/CaB (g/g)	10%	11%	11%				
Columns taken apart and emptied, then washed with alconox detergent and triple rinsed in DI.							

Salt Waterways				SIXTH PACK			
Column Study: Permeability and Chloride Capture							
November 7, 2023							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensi						
		inside area =	21.23	cm^2			
Oakton Conductivity Meter							
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)	
From Chloride Columns calibration study							
Temp	72	deg F					
Column	1	2	3	4	5	6	Filled Oct 31st
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	56%	60%	56%	60%	56%	60%	
Sugar Sand Proportion	40%	40%	0%	0%	20%	20%	
Beach Sand Proportior	0%	0%	40%	40%	20%	20%	
Ca-B %	4%	0%	4%	0%	4%	0%	
Length (cm)	32	32	32	32	32	32	
Height of support laye	5	5	5	5	5	5	
Starting Level (cm)	70	70	70	70	70	70	
Ending Level (cm)	44	44	64.7	44	51	44	
Flow Volume (mL)	552.0	552.0	112.5	552.0	403.4	552.0	
Elapsed Time (s)	147	63	560	82	342	64	checked
Flow Velocity (seconds per mL)	5.65	2.42	105.66	3.15	18.00	2.46	
Flow Velocity (minutes per mL)	0.09	0.04	1.76	0.05	0.30	0.04	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	39.0	39.0	59.7	39.0	46.0	39.0	
Permeability (cm/s)	0.111	0.259	0.005	0.199347	0.032	0.25541	
Permeability (cm/s)	1.1E-01	2.6E-01	4.9E-03	2.0E-01	3.2E-02	2.6E-01	
increment of permeab	0.1	0.1	0.001	0.1	0.01	0.1	
Amt of time for incren	77	45	464	55	261	46	
delta time (sec)	70	18	96	27	81	18	
delta time (min)	1.2	0.3	1.6	0.5	1.3	0.3	
Stream Water uS/cm	53	53	53	53	53	53	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3	
Stock Conc (g/L) Mix	0	0	0	0	0	0	Nov 6th
Stock Vol (mL)	1000	1000	1000	1000	1000	1000	
Stock Conc Meas (g/L)	0	0	0	0	0	0	
Mass Challenged (g)	0.0	0.0	0.0	0.0	0.0	0.0	

Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60	
AVG Effl Cond	59.50	53.10	62.30	58.20	60.30	56.60	
Effluent Vol (mL)	815	840	760	820	755	760	col 6 estim
Effluent Conc Meas (g/	0.3	0.3	0.3	0.3	0.3	0.3	
Mass in Effluent (g)	0.3	0.2	0.2	0.2	0.2	0.2	
Mass Captured (g)	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	
Mass Captured/Mass Challenged (%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	
Captured/CaB (g/g)	-1%	#DIV/0!	-1%	#DIV/0!	-1%	#DIV/0!	
Starting Level (cm)	70	70	70	70	70	70	
Ending Level (cm)	44	42	64.6	40	60.2	40	
Flow Volume (mL)	552.0	594.5	114.7	637.0	208.1	637.0	
Elapsed Time (s)	159	71	750	95	150	79	
Flow Velocity (seconds per mL)	6.12	2.54	138.89	3.17	15.31	2.63	
Flow Velocity (minutes per mL)	0.10	0.04	2.31	0.05	0.26	0.04	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	39.0	37.0	59.6	35.0	55.2	35.0	
Permeability (cm/s)	0.111	0.230	0.004	0.172068	0.074	0.20692	
Permeability (cm/s)	1.1E-01	2.3E-01	3.6E-03	1.7E-01	7.4E-02	2.1E-01	
increment of permeab	0.1	0.1	0.001	0.1	0.01	0.1	
Amt of time for incren	77	55	600	73	62	65	
delta time (sec)	82	16	150	22	88	14	
delta time (min)	1.4	0.3	2.5	0.4	1.5	0.2	
Stream Water uS/cm	53	53	53	53	53	53	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3	
Stock Conc (g/L) Mix	25	25	25	25	25	25	Nov 6th
Stock Vol (mL)	1000	1000	1000	1000	1000	1000	
Stock Conc Meas (g/L)	25	25	25	25	25	25	
Mass Challenged (g)	25.0	25.0	25.0	25.0	25.0	25.0	
Effluent Cond (uS/cm)	3300.00	3470.00	3370.00	3510.00	3670.00	3540.00	
AVG Effl Cond	3300.00	3470.00	3370.00	3510.00	3670.00	3540.00	
Effluent Vol (mL)	970	968	970	980	970	980	col 3 not yet co
Effluent Conc Meas (g/	21.5	22.9	22.1	23.2	24.5	23.4	
Mass in Effluent (g)	20.9	22.1	21.4	22.7	23.7	23.0	

Mass Captured (g)	4.1	2.9	3.6	2.3	1.3	2.0	
Mass Captured/Mass Challenged (%)	17%	11%	14%	9%	5%	8%	
Captured/CaB (g/g)	10%	#DIV/0!	9%	#DIV/0!	3%	#DIV/0!	
Starting Level (cm)	70	70	72	70	70	70	11/8/23 0:00
Ending Level (cm)	41	44	40	41	51	41	
Flow Volume (mL)	615.7	552.0	679.4	615.7	403.4	615.7	
Elapsed Time (s)	165	63	13500	97	208	69	
Flow Velocity (seconds per mL)	5.69	2.42	421.88	3.34	10.95	2.38	
Flow Velocity (minutes per mL)	0.09	0.04	7.03	0.06	0.18	0.04	
Head at start (cm) = dist above end of treatment media	65.0	65.0	67.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	36.0	39.0	35.0	36.0	46.0	36.0	
Permeability (cm/s)	0.111	0.259	0.00020	0.169	0.053	0.24	
Permeability (cm/s)	1.1E-01	2.6E-01	2.0E-04	1.7E-01	5.3E-02	2.4E-01	
increment of permeab	0.1	0.1	0.0001	0.1	0.01	0.1	
Amt of time for incren	90	45	68893	70	175	56	
delta time (sec)	75	18	-55393	27	33	13	
delta time (min)	1.3	0.3	-923.2	0.4	0.5	0.2	
Stream Water uS/cm	53	53	53	53	53	53	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3	
Stock Conc (g/L) Mix	25	25	25	25	25	25	Nov 6th
Stock Vol (mL)	1000	1000	1000	1000	1000	1000	
Stock Conc Meas (g/L)	25	25	25	25	25	25	
Mass Challenged (g)	25.0	25.0	25.0	25.0	25.0	25.0	
Effluent Cond (uS/cm)	3770.00	3920.00	3760.00	3930.00	4030.00	4030.00	
AVG Effl Cond	3770.00	3920.00	3760.00	3930.00	4030.00	4030.00	
Effluent Vol (mL)	985	980	990	990	980	990	col 3 complete
Effluent Conc Meas (g,	25.3	26.5	25.2	26.6	27.5	27.5	
Mass in Effluent (g)	24.9	26.0	25.0	26.3	26.9	27.2	
Mass Captured (g)	0.1	-1.0	0.0	-1.3	-1.9	-2.2	
Mass Captured/Mass Challenged (%)	0%	-4%	0%	-5%	-8%	-9%	
Captured/CaB (g/g)	0%	#DIV/0!	0%	#DIV/0!	-5%	#DIV/0!	

Starting Level (cm)	64	62	67	60	64	61	11/10/23 0:00
Ending Level (cm)	44	44	63.5	41	44	41	
Flow Volume (mL)	424.6	382.2	74.3	403.4	424.6	424.6	
Elapsed Time (s)	113	47	480	72	303	46	
Flow Velocity (seconds per mL)	5.65	2.61	137.14	3.79	15.15	2.30	
Flow Velocity (minutes per mL)	0.09	0.04	2.29	0.06	0.25	0.04	
Head at start (cm) = dist above end of treatment media	59.0	57.0	62.0	55.0	59.0	56.0	
Head at end (cm) = dist above end of treatment media	39.0	39.0	58.5	36.0	39.0	36.0	
Permeability (cm/s)	0.111	0.348	0.00567	0.227	0.037	0.36	
Permeability (cm/s)	1.1E-01	3.5E-01	5.7E-03	2.3E-01	3.7E-02	3.6E-01	
increment of permeab	0.1	0.1	0.0001	0.1	0.01	0.1	
Amt of time for incren	63	27	322	41	285	31	
delta time (sec)	50	20	158	31	18	15	
delta time (min)	0.8	0.3	2.6	0.5	0.3	0.2	
Stream Water uS/cm	53	53	53	53	53	53	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3	
Stock Conc (g/L) Mix	25	25	25	25	25	25	Nov 10th
Stock Vol (mL)	1000	1000	1000	1000	1000	1000	
Stock Conc Meas (g/L)	25	25	25	25	25	25	
Mass Challenged (g)	25.0	25.0	25.0	25.0	25.0	25.0	
Effluent Cond (uS/cm)	3890.00	3990.00	3980.00	3990.00	3970.00	4010.00	11/13 meas
AVG Effl Cond	3890.00	3990.00	3980.00	3990.00	3970.00	4010.00	
Effluent Vol (mL)	988	980	985	970	955	965	
Effluent Conc Meas (g,	26.3	27.1	27.0	27.1	26.9	27.3	
Mass in Effluent (g)	26.0	26.6	26.6	26.3	25.7	26.3	
Mass Captured (g)	-1.0	-1.6	-1.6	-1.3	-0.7	-1.3	
Mass Captured/Mass Challenged (%)	-4%	-6%	-7%	-5%	-3%	-5%	
Captured/CaB (g/g)	-2%	#DIV/0!	-4%	#DIV/0!	-2%	#DIV/0!	
Starting Level (cm)	65	65	70	61	67	62	11/13/23 0:00
Ending Level (cm)	45	45	65.7	40	45	42	
Flow Volume (mL)	424.6	424.6	91.3	445.9	467.1	424.6	
Elapsed Time (s)	114	51	600	56	410	46	

Flow Velocity (seconds per mL)	5.70	2.55	139.53	2.67	18.64	2.30	
Flow Velocity (minutes per mL)	0.10	0.04	2.33	0.04	0.31	0.04	
Head at start (cm) = dist above end of treatment media	60.0	60.0	65.0	56.0	62.0	57.0	
Head at end (cm) = dist above end of treatment media	40.0	40.0	60.7	35.0	40.0	37.0	
Permeability (cm/s)	0.111	0.321	0.00454	0.292	0.027	0.36	
Permeability (cm/s)	1.1E-01	3.2E-01	4.5E-03	2.9E-01	2.7E-02	3.6E-01	
increment of permeab	0.1	0.1	0.0001	0.1	0.01	0.1	
Amt of time for incren	61	31	472	38	379	30	
delta time (sec)	53	20	128	18	31	16	
delta time (min)	0.9	0.3	2.1	0.3	0.5	0.3	
Stream Water uS/cm	53	53	53	53	53	53	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3	
Stock Conc (g/L) Mix	25	25	25	25	25	25	Nov 13th
Stock Vol (mL)	1000	1000	1000	1000	1000	1000	
Stock Conc Meas (g/L)	25	25	25	25	25	25	
Mass Challenged (g)	25.0	25.0	25.0	25.0	25.0	25.0	
Influent Cond (uS/cm)	3960	3960	4010	3990	3970	3960	11/13 meas
Meas Effl Conc	15.80	16.50	17.20	16.50	17.40	17.50	Chemet 2070
Effluent Vol (mL)	990	990	990	990	990	990	est vol/not mea
Effluent Conc Meas (g	15.8	16.5	17.2	16.5	17.4	17.5	
Mass in Effluent (g)	15.6	16.3	17.0	16.3	17.2	17.3	
Mass Captured (g)	9.4	8.7	8.0	8.7	7.8	7.7	
Mass Captured/Mass Challenged (%)	37%	35%	32%	35%	31%	31%	
Captured/CaB (g/g)	23%	#DIV/0!	20%	#DIV/0!	19%	#DIV/0!	
Total Alk mg/L $CaCO_3$	600	360	450	425	460	510	Chemet
Total Alk mg/L $CaCO_3$					475		Chemet
Streamwater Alk	260	Total Alk mg/L CaCO3					
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	56%	60%	56%	60%	56%	60%	
Sugar Sand Proportion	40%	40%	0%	0%	20%	20%	
Beach Sand Proportion	0%	0%	40%	40%	20%	20%	
Ca-B %	4%	0%	4%	0%	4%	0%	

Appendix C:
Seventh Filter Pack Log and Analyses

Salt Waterways			SEVENTH PACK					
Column Study: Permeability and Chloride Capture								
December 13, 2023								
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm		
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/							
		inside area =	21.23	cm^2				
Oakton Conductivity Meter								
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)		
From Chloride Columns calibration study								
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 13th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000		
Pea Stone Proportion	56%	56%	60%	60%	56%	56%		
Sugar Sand Proportion	40%	40%	40%	40%	20%	40%		
Beach Sand Proportion	0%	0%	0%	0%	20%	0%		
Ca-B %	4%	4%	0%	0%	4%	4%		
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
Stream Water uS/cm	53	53	53	53	53	53	No salt just water	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	500 mL	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		
Stock Vol (mL)	500	500	500	500	500	500		
Stock Chloride Meas (g/L)	0	0	0	0	0	0	assumed	
Chloride Mass Challenged (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Effluent Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Effluent Chloride Dup	0	0	0	0	0	0	assumed	
Effluent Total Alk (ppm as Ca	195	185	250	255	185	200		
Effluent Cond (uS/cm)								
AVG Effl Cond	0	0	0	0	0	0		
Effluent Vol (mL)	500	500	500	500	500	500	assumed	
Effluent Conc Meas (g/L)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass in Effluent (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured/Mass Challenged (%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Captured/CaB (g/g)	0%	0%	#DIV/0!	#DIV/0!	0%	0%		
Stream Water uS/cm	53	53	53	53	53	53	First brine batch	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	1 L and 25 g total	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Chloride Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Chloride Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		

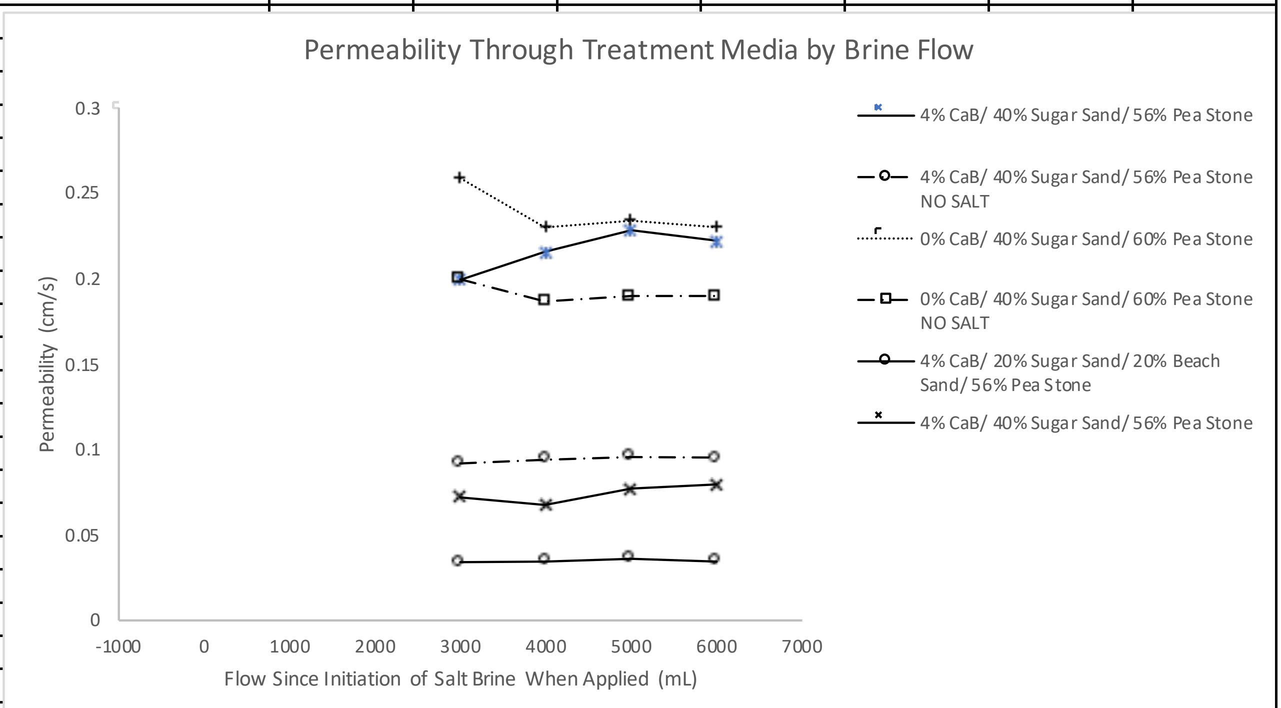
Effluent Chloride	14,700	0	13,700	0	15,100	14,600	BDL = 0	
Effluent Chloride Dup	15,700	0	16,300	0	16,000	15,500		
Effluent Total Alk (ppm as Ca	375	320	480	340	580	520		
Effluent Cond (uS/cm)								
AVG Effl Cond	15,200	0	15,000	0	15,550	15,050		
Effluent Vol (mL)	1005	990	1000	990	1000	995		
Effluent Conc Meas (g/L)	15.2	0.0	15.0	0.0	15.6	15.1		
Mass in Effluent (g)	15.3	0.0	15.0	0.0	15.6	15.0		
Mass Captured (g)	1.1	0.0	1.4	0.0	0.8	1.4		
Mass Captured/Mass Challenged (%)	7%	#DIV/0!	8%	#DIV/0!	5%	9%		
Captured/CaB (g/g)	3%	0%	#DIV/0!	#DIV/0!	2%	4%		
Stream Water uS/cm	53	53	53	53	53	53	Second brine batch	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	2 L and 50 g total	
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Chloride Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Chloride Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	15,500	0	15,600	0	15,100	15,200	BDL = 0	
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	470	340	470	360	500	510		
Effluent Cond (uS/cm)								
AVG Effl Cond	15,500	0	15,600	0	15,100	15,200		
Effluent Vol (mL)	1005	995	1000	995	1000	1000		
Effluent Conc Meas (g/L)	15.5	0.0	15.6	0.0	15.1	15.2		
Mass in Effluent (g)	15.6	0.0	15.6	0.0	15.1	15.2		
Mass Captured (g)	0.8	0.0	0.8	0.0	1.3	1.2		
Mass Captured/Mass Challenged (%)	5%	#DIV/0!	5%	#DIV/0!	8%	7%		
Captured/CaB (g/g)	2%	0%	#DIV/0!	#DIV/0!	3%	3%		
Starting Level (cm)	70	70	70	70	70	70	Third brine batch	
Ending Level (cm)	50	50	45	43	55	49	3 L and 75 g total	
Flow Volume (mL)	424.6	424.6	530.8	573.3	318.5	445.9		
Elapsed Time (s)	59	128	60	86	246	173		
Flow Velocity (seconds per mL)	2.95	6.40	2.40	3.19	16.40	8.24		
Flow Velocity (minutes per mL)	0.05	0.11	0.04	0.05	0.27	0.14		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	45.0	45.0	40.0	38.0	50.0	44.0		
Permeability (cm/s)	0.199	0.092	0.259	0.199740	0.034	0.07218		
Permeability (cm/s)	2.0E-01	9.2E-02	2.6E-01	2.0E-01	3.4E-02	7.2E-02		

increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	39	61	60	57	190	73		
delta time (sec)	20	67	0	29	56	100		
delta time (min)	0.3	1.1	0.0	0.5	0.9	1.7		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	16000	0	16800	0	16200	16700		
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	410	315	420	355	440	410		
Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60		
AVG Effl Cond	16,000	0	16,800	0	16,200	16,700		
Effluent Vol (mL)	1000	975	1005	1000	1000	1005		
Effluent Conc Meas (g/L)	16.0	0.0	16.8	0.0	16.2	16.7		
Mass in Effluent (g)	16.0	0.0	16.9	0.0	16.2	16.8		
Mass Captured (g)	0.4	0.0	-0.5	0.0	0.2	-0.4		
Mass Captured/Mass Challenged (%)	2%	#DIV/0!	-3%	#DIV/0!	1%	-2%		
Captured/CaB (g/g)	1%	0%	#DIV/0!	#DIV/0!	0%	-1%		
Starting Level (cm)	70	70	70	70	70	70	Fourth brine batch	
Ending Level (cm)	45	45	50	50	50	50	4 L and 100 g total	
Flow Volume (mL)	530.8	530.8	424.6	424.6	424.6	424.6		
Elapsed Time (s)	72	165	51	63	341	174		
Flow Velocity (seconds per mL)	2.88	6.60	2.55	3.15	17.05	8.70		
Flow Velocity (minutes per mL)	0.05	0.11	0.04	0.05	0.28	0.15		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	40.0	40.0	45.0	45.0	45.0	45.0		
Permeability (cm/s)	0.216	0.094	0.231	0.186781	0.035	0.06763		
Permeability (cm/s)	2.2E-01	9.4E-02	2.3E-01	1.9E-01	3.5E-02	6.8E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	49	80	51	41	264	70		
delta time (sec)	23	85	0	22	77	104		
delta time (min)	0.4	1.4	0.0	0.4	1.3	1.7		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		

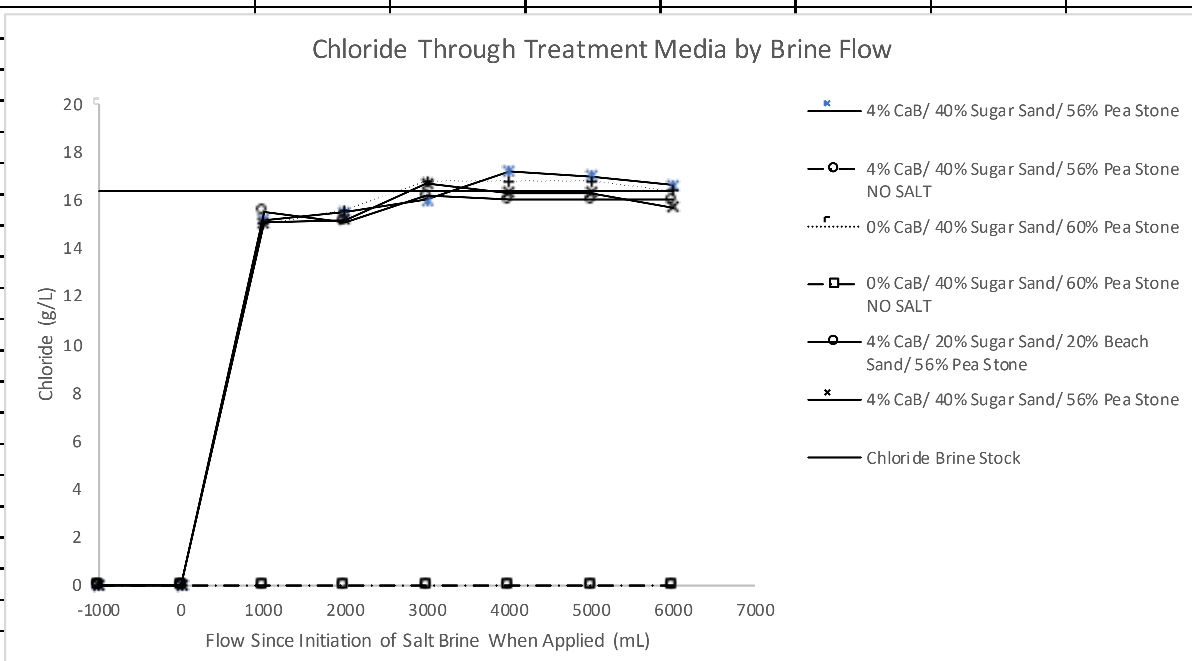
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	17200	0	16800	0	16000	16300		
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	320	260	360	280	380	400		
Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60		
AVG Effl Cond	17,200	0	16,800	0	16,000	16,300		
Effluent Vol (mL)	1015	1000	1015	1000	1010	1010		
Effluent Conc Meas (g/L)	17.2	0.0	16.8	0.0	16.0	16.3		
Mass in Effluent (g)	17.5	0.0	17.1	0.0	16.2	16.5		
Mass Captured (g)	-1.1	0.0	-0.7	0.0	0.2	-0.1		
Mass Captured/Mass Challenged (%)	-7%	#DIV/0!	-4%	#DIV/0!	1%	-1%		
Captured/CaB (g/g)	-3%	0%	#DIV/0!	#DIV/0!	1%	0%		
Starting Level (cm)	70	70	70	70	70	70	Fifth brine batch	
Ending Level (cm)	45	50	42	45	50	50	5 L and 125 g total	
Flow Volume (mL)	530.8	424.6	594.5	530.8	424.6	424.6		
Elapsed Time (s)	68	123	77	82	326	153		
Flow Velocity (seconds per mL)	2.72	6.15	2.75	3.28	16.30	7.65		
Flow Velocity (minutes per mL)	0.05	0.10	0.05	0.05	0.27	0.13		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	40.0	45.0	37.0	40.0	45.0	45.0		
Permeability (cm/s)	0.228	0.096	0.234	0.189466	0.036	0.07691		
Permeability (cm/s)	2.3E-01	9.6E-02	2.3E-01	1.9E-01	3.6E-02	7.7E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	47	60	77	54	255	67		
delta time (sec)	21	63	0	28	71	86		
delta time (min)	0.3	1.0	0.0	0.5	1.2	1.4		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	17000	0	16800	0	16000	16300		
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	405	295	350	310	400	420		
Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60		
AVG Effl Cond	17,000	0	16,800	0	16,000	16,300		

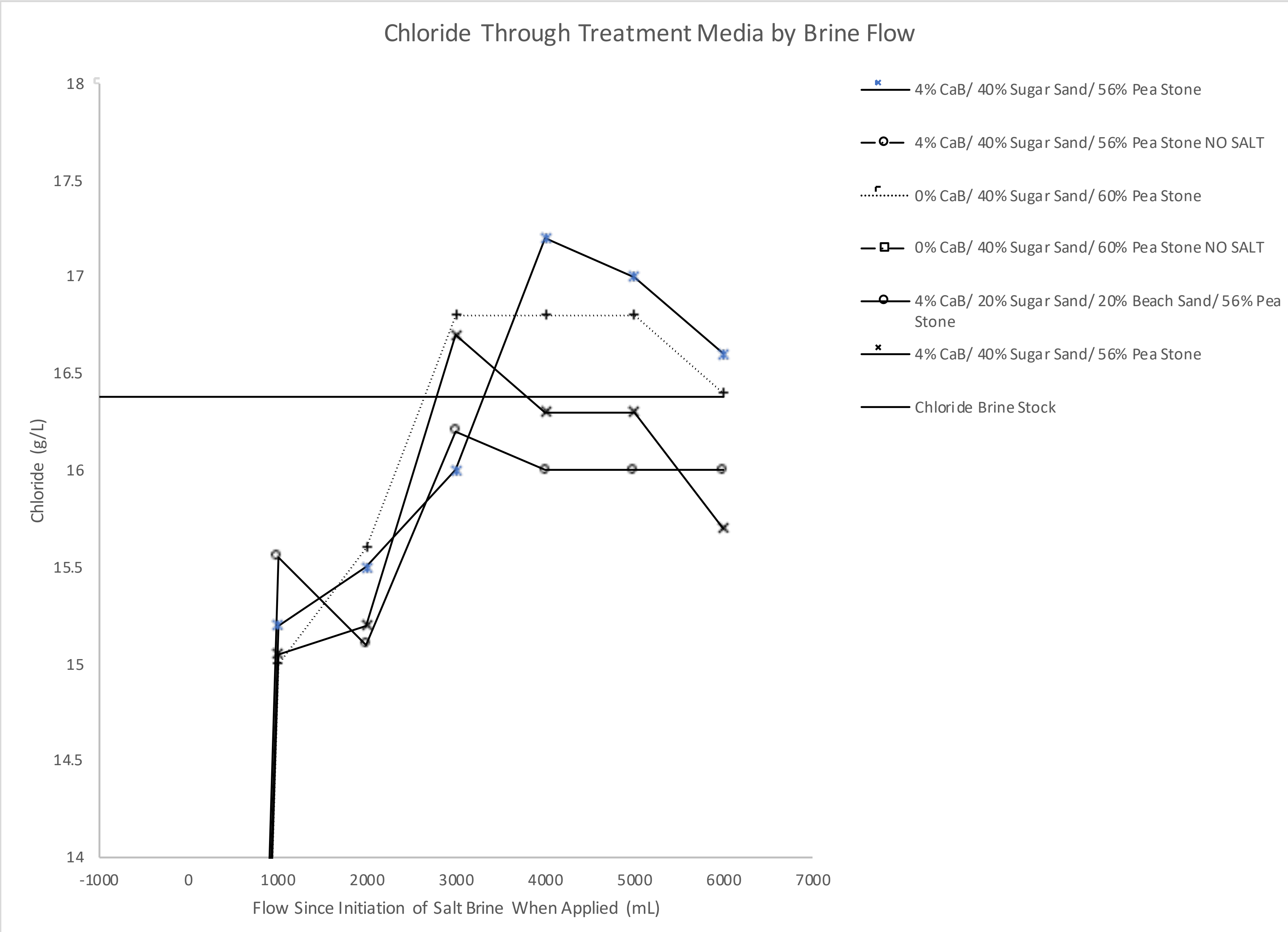
Effluent Vol (mL)	1015	995	1000	1003	1005	1010		
Effluent Conc Meas (g/L)	17.0	0.0	16.8	0.0	16.0	16.3		
Mass in Effluent (g)	17.3	0.0	16.8	0.0	16.1	16.5		
Mass Captured (g)	-0.9	0.0	-0.4	0.0	0.3	-0.1		
Mass Captured/Mass Challenged (%)	-5%	#DIV/0!	-3%	#DIV/0!	2%	-1%		
Captured/CaB (g/g)	-2%	0%	#DIV/0!	#DIV/0!	1%	0%		
Starting Level (cm)	70	70	70	70	70	70	Sixth brine batch	
Ending Level (cm)	45	45	44	45	54	48	6 L and 150 g total	
Flow Volume (mL)	530.8	530.8	552.0	530.8	339.7	467.1		
Elapsed Time (s)	70	163	71	82	259	166		
Flow Velocity (seconds per mL)	2.80	6.52	2.73	3.28	16.19	7.55		
Flow Velocity (minutes per mL)	0.05	0.11	0.05	0.05	0.27	0.13		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	40.0	40.0	39.0	40.0	49.0	43.0		
Permeability (cm/s)	0.222	0.095	0.230	0.189466	0.035	0.07965		
Permeability (cm/s)	2.2E-01	9.5E-02	2.3E-01	1.9E-01	3.5E-02	8.0E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	48	80	71	54	201	74		
delta time (sec)	22	83	0	28	58	92		
delta time (min)	0.4	1.4	0.0	0.5	1.0	1.5		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	16600	0	16400	0	16000	15700		
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	400	280	400	305	420	390		
Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60		
AVG Effl Cond	16,600	0	16,400	0	16,000	15,700		
Effluent Vol (mL)	1005	995	1000	1000	1000	1000		
Effluent Conc Meas (g/L)	16.6	0.0	16.4	0.0	16.0	15.7		
Mass in Effluent (g)	16.7	0.0	16.4	0.0	16.0	15.7		
Mass Captured (g)	-0.3	0.0	0.0	0.0	0.4	0.7		
Mass Captured/Mass Challenged (%)	-2%	#DIV/0!	0%	#DIV/0!	2%	4%		
Captured/CaB (g/g)	-1%	0%	#DIV/0!	#DIV/0!	1%	2%		

Salt Waterways			SEVENTH PACK				
Column Study: Permeability and Chloride Capture							
December 13, 2023							
					brine avg	16,380	ppm
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride		
Column	1	2	3	4	5	6	Filled Dec 13
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	56%	56%	60%	60%	56%	56%	
Sugar Sand Proportion	40%	40%	40%	40%	20%	40%	
Beach Sand Proportion	0%	0%	0%	0%	20%	0%	
Ca-B %	4%	4%	0%	0%	4%	4%	
Length (cm)	32	32	32	32	32	32	
Height of support layer	5	5	5	5	5	5	
	Permeability Measurements (cm/s)						
Flow (mL) after Salt Brine Initiation	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Chloride Brine Stock
-1000							
0							
1000							
2000							
3000	0.199	0.092	0.259	0.200	0.034	0.072	
4000	0.216	0.094	0.231	0.187	0.035	0.068	
5000	0.228	0.096	0.234	0.189	0.036	0.077	
6000	0.222	0.095	0.230	0.189	0.035	0.080	



Salt Waterways			SEVENTH PACK					
Column Study: Permeability and Chloride Capture								
December 13, 2023								
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 13th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000		
Pea Stone Proportion	56%	56%	60%	60%	56%	56%		
Sugar Sand Proportion	40%	40%	40%	40%	20%	40%		
Beach Sand Proportion	0%	0%	0%	0%	20%	0%		
Ca-B %	4%	4%	0%	0%	4%	4%		
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
	Chloride Measurements (g/L)							
Flow (mL) after Salt Brine Initiation	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Chloride Brine Stock	
-1000	0	0	0	0	0	0	16.38	
0	0	0	0	0	0	0	16.38	
1000	15.2	0.0	15.0	0.0	15.6	15.1	16.38	
2000	15.5	0.0	15.6	0.0	15.1	15.2	16.38	
3000	16.0	0.0	16.8	0.0	16.2	16.7	16.38	
4000	17.2	0	16.8	0	16	16.3	16.38	
5000	17.0	0.0	16.8	0.0	16.0	16.3	16.38	
6000	16.6	0.0	16.4	0.0	16.0	15.7	16.38	





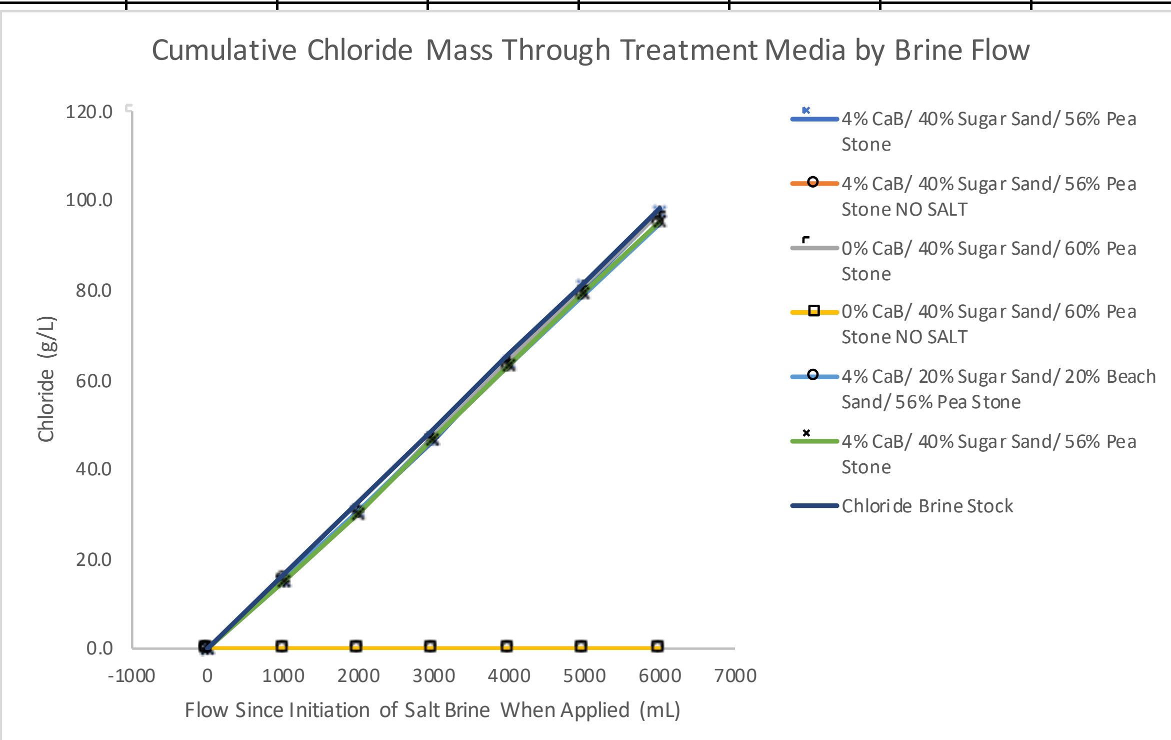
Chloride Through Treatment Media by Brine Flow
18
17.5
17
16.5
16
15.5
15
14.5
14
Chloride (g/L)
-1000
0
1000
2000
3000
4000
5000
6000
7000
Flow Since Initiation of Salt Brine When Applied (mL)
4% CaB/ 40% Sugar Sand/ 56% Pea Stone
4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT
0% CaB/ 40% Sugar Sand/ 60% Pea Stone
0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT
4% CaB/ 20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone
4% CaB/ 40% Sugar Sand/ 56% Pea Stone
Chloride Brine Stock

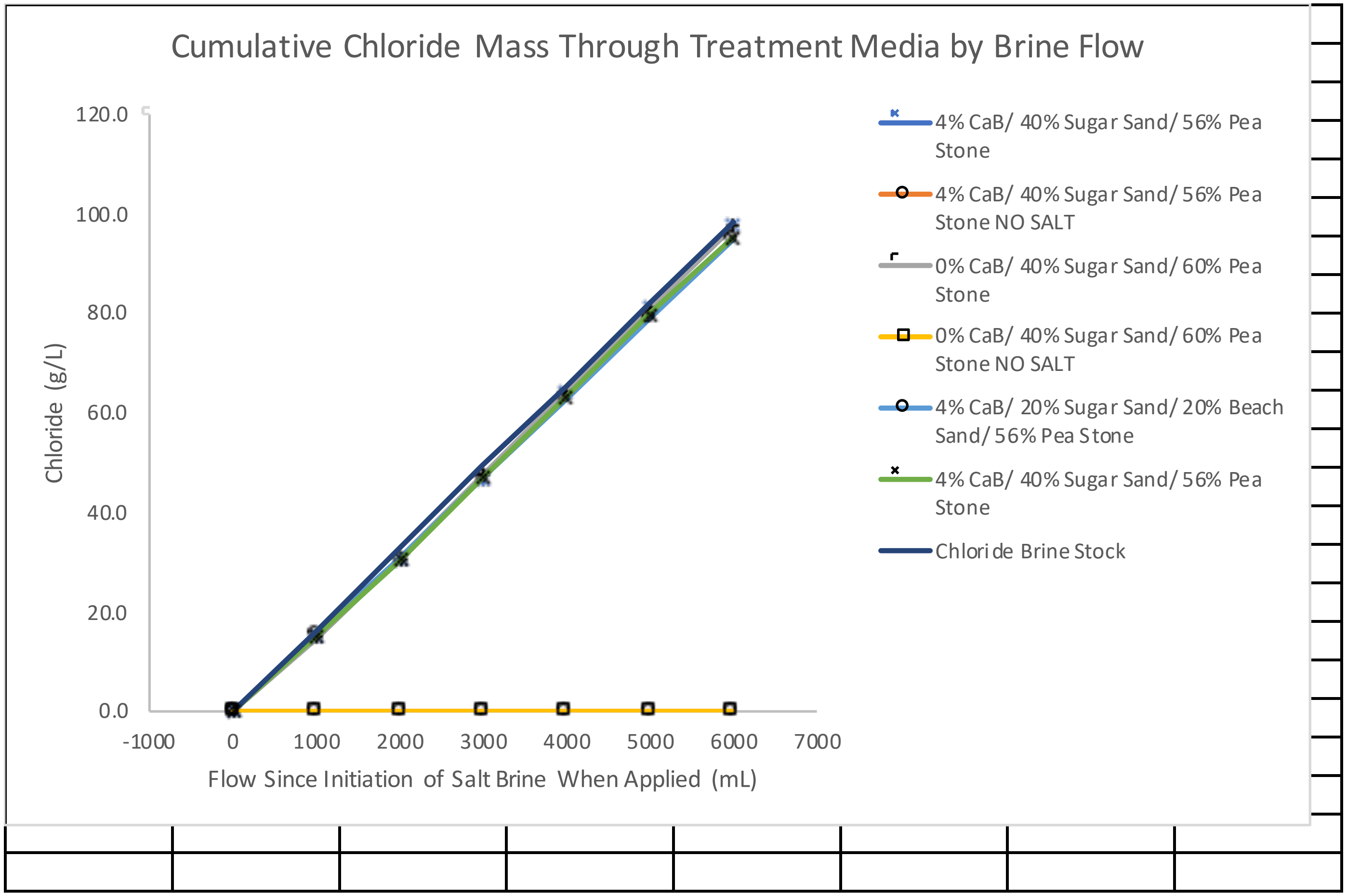
Salt Waterways		SEVENTH PACK						
Column Study: Permeability and Chloride Capture								
December 13, 2023								
	DATA FROM SEVENTH PACK							
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 13th	
Trmt Media	1000	1000	1000	1000	1000	1000		
Pea Stone Pr	56%	56%	60%	60%	56%	56%		
Sugar Sand F	40%	40%	40%	40%	20%	40%		
Beach Sand I	0%	0%	0%	0%	20%	0%		
Ca-B %	4%	4%	0%	0%	4%	4%		
Length (cm)	32	32	32	32	32	32		
Height of sup	5	5	5	5	5	5		

	Chloride Measurements (g/L)							
Flow (mL) after Salt Brine Initiation	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	4% CaB/ 20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Chloride Brine Stock	
0	0	0	0	0	0	0	16.38	
1000	15.2	0.0	15.0	0.0	15.6	15.1	16.38	
2000	15.5	0.0	15.6	0.0	15.1	15.2	16.38	
3000	16.0	0.0	16.8	0.0	16.2	16.7	16.38	
4000	17.2	0	16.8	0	16	16.3	16.38	
5000	17.0	0.0	16.8	0.0	16.0	16.3	16.38	
6000	16.6	0.0	16.4	0.0	16.0	15.7	16.38	

	Chloride Mass (Conc x Flow Volume) (g)							
Flow (mL) between Measurement Steps	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	4% CaB/ 20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Chloride Brine Stock	
1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1000	15.2	0.0	15.0	0.0	15.6	15.1	16.4	
1000	15.5	0.0	15.6	0.0	15.1	15.2	16.4	
1000	16.0	0.0	16.8	0.0	16.2	16.7	16.4	
1000	17.2	0.0	16.8	0.0	16.0	16.3	16.4	
1000	17.0	0.0	16.8	0.0	16.0	16.3	16.4	
1000	16.6	0.0	16.4	0.0	16.0	15.7	16.4	

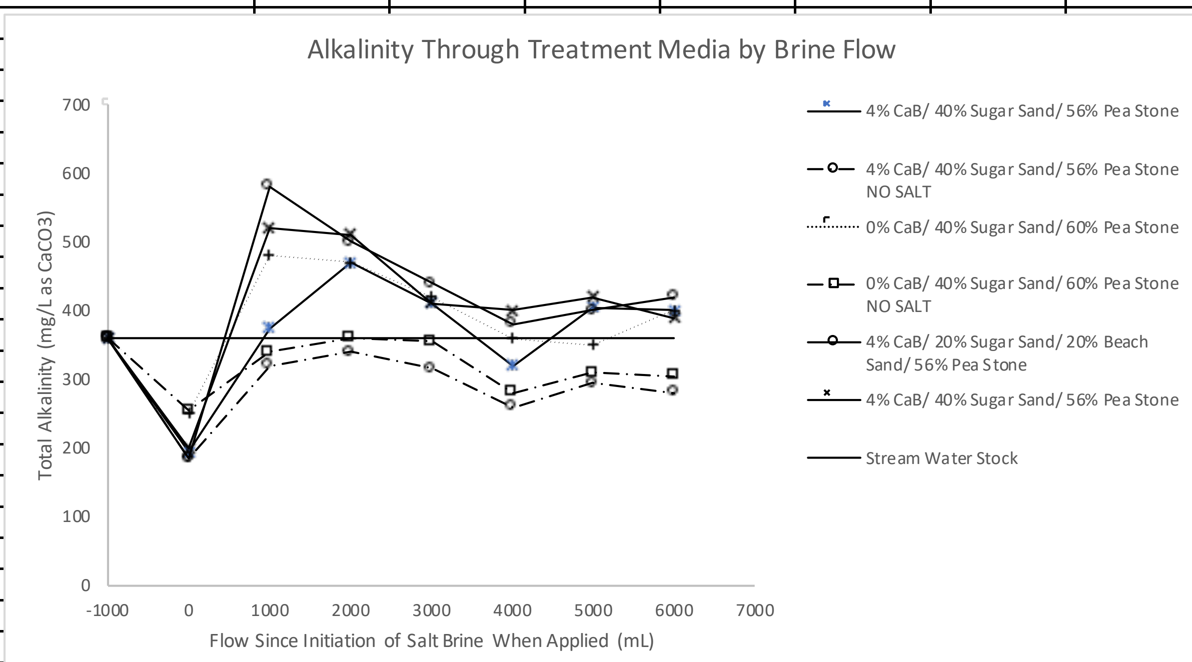
	Chloride Cumulative Mass (g)							
Flow (mL) after Salt Brine Initiation	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	4% CaB/ 20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Chloride Brine Stock	
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1000	15.2	0.0	15.0	0.0	15.6	15.1	16.4	
2000	30.7	0.0	30.6	0.0	30.7	30.3	32.8	
3000	46.7	0.0	47.4	0.0	46.9	47.0	49.1	
4000	63.9	0.0	64.2	0.0	62.9	63.3	65.5	
5000	80.9	0.0	81.0	0.0	78.9	79.6	81.9	
6000	97.5	0.0	97.4	0.0	94.9	95.3	98.3	




Cumulative Chloride Mass Through Treatment Media by Brine Flow
Chloride (g/L)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-1000
0
1000
2000
3000
4000
5000
6000
7000
Flow Since Initiation of Salt Brine When Applied (mL)
4% CaB/ 40% Sugar Sand/ 56% Pea Stone
4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT
0% CaB/ 40% Sugar Sand/ 60% Pea Stone
0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT
4% CaB/ 20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone
4% CaB/ 40% Sugar Sand/ 56% Pea Stone
Chloride Brine Stock

Salt Waterways			SEVENTH PACK				
Column Study: Permeability and Chloride Capture							
December 13, 2023							
					brine avg	16,380	ppm
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less		
Column	1	2	3	4	5	6	Filled Dec 13th
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Pea Stone Proportion	56%	56%	60%	60%	56%	56%	
Sugar Sand Proportion	40%	40%	40%	40%	20%	40%	
Beach Sand Proportion	0%	0%	0%	0%	20%	0%	
Ca-B %	4%	4%	0%	0%	4%	4%	
Length (cm)	32	32	32	32	32	32	
Height of support layer	5	5	5	5	5	5	

	Alkalinity Measurements (mg/L as $CaCO_3$)						
Flow (mL) after Salt Brine Initiation	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone NO SALT	0% CaB/ 40% Sugar Sand/ 60% Pea Stone	0% CaB/ 40% Sugar Sand/ 60% Pea Stone NO SALT	20% Sugar Sand/ 20% Beach Sand/ 56% Pea Stone	4% CaB/ 40% Sugar Sand/ 56% Pea Stone	Stream Water Stock
-1000	360	360	360	360	360	360	360
0	195	185	250	255	185	200	360
1000	375	320	480	340	580	520	360
2000	470	340	470	360	500	510	360
3000	410	315	420	355	440	410	360
4000	320	260	360	280	380	400	360
5000	405	295	350	310	400	420	360
6000	400	280	400	305	420	390	360



Salt Waterways			
Column Study: Permeability and Chloride Capture			
December 13, 2023			
Stock Measurements			
First batch	16,100	ppm	
First batch	15,800		
Second batch	15,200		
Second batch	15,000		
Third batch	17,800		
Third batch	16,700		
Fifth batch	16,400		
Fifth batch	17,000		
Fifth batch	17,100	replicates of Stock 3	
Fifth batch	16,800	replicates of Stock 3	
Fifth batch	16,300	replicates of Stock 3	
Fifth batch	16,500	replicates of Stock 3	
Fifth batch	16,400	replicates of Stock 3	
Fifth batch	16,100	replicates of Stock 3	
Fifth batch	16,500	replicates of Stock 3	
		STD DEV =	330
AVG	16,380	ppm	
Count	15		

Appendix D:
Eighth Filter Pack Log and Analyses

Salt Waterways			EIGHTH PACK					
Column Study: Permeability and Chloride Capture								
December 21, 2023								
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm		
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/							
		inside area =	21.23	cm^2				
Oakton Conductivity Meter								
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)		
From Chloride Columns calibration study								/
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 20th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	Hydrated maybe 500 mL	
Fine Filter Sand %	95%	96%	96%	100%	97%	96%	Dumped with no meas	
Ca-B %	5%	4%	4%	0%	3%	4%	effluent from first hydr	
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
							Dec 20th at 4:40 pm	
							Second hydration run thro	
Stream Water uS/cm	53	53	53	53	53	53	No salt just water	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	maybe 700 mL	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		
Stock Vol (mL)	500	500	500	500	500	500		
Stock Chloride Meas (g/L)	0	0	0	0	0	0	assumed	
Chloride Mass Challenged (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Effluent Chloride	BDL	BDL	BDL	BDL	BDL	BDL	assumed	
Effluent Chloride Dup	0	0	0	0	0	0	assumed	
Effluent Total Alk (ppm as Ca	132	220	235	280	250	245	Dec 21: second hydr run	
Effluent Cond (uS/cm)								
AVG Effl Cond	0	0	0	0	0	0	assumed	
Effluent Vol (mL)	505	735	765	870	755	770	Dec 21 at 12:40 pm	
Effluent Conc Meas (g/L)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass in Effluent (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured/Mass Challenged (%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
							Dec 21st, 12:40 pm	
Starting Level (cm)	70	70	70	70	70	70	Third hydration run throug	
Ending Level (cm)	66.2	45.7	52.1	49.5	49.0	44.0		
Flow Volume (mL)	80.7	515.9	380.1	435.3	445.9	552.0		
Elapsed Time (s)	9240	9240	1710	630	1520	1541		
Flow Velocity (seconds per mL)	2431.58	380.25	95.53	30.73	72.38	59.27		
Flow Velocity (minutes per mL)	40.53	6.34	1.59	0.51	1.21	0.99		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		

Head at end (cm) = dist above end of treatment media	61.2	40.7	47.1	44.5	44.0	39.0		
Permeability (cm/s)	0.00021	0.0016	0.0060	0.019	0.0082	0.011		
Permeability (cm/s)	2.1E-04	1.6E-03	6.0E-03	1.9E-02	8.2E-03	1.1E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	19	147	1467	102	686	148		
delta time (sec)	9221	9093	243	528	834	1393		
delta time (min)	153.7	151.5	4.1	8.8	13.9	23.2		
Stream Water uS/cm	53	53	53	53	53	53	Dec 21st, 12:40 pm	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	Third hydration run throug	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Chloride Meas (g/L)	0	0	0	0	0	0	assumed	
Chloride Mass Challenged (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Effluent Chloride	BDL	BDL	BDL	BDL	BDL	BDL	assumed	
Effluent Chloride Dup	0	0	0	0	0	0	assumed	
Effluent Total Alk (ppm as Ca	180	240	250	300	255	260	Dec 21 at 3:30 pm: third h	
Effluent Cond (uS/cm)								
AVG Effl Cond	0	0	0	0	0	0		
Effluent Vol (mL)	100	515	700	730	720	705		
Effluent Conc Meas (g/L)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass in Effluent (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured (g)	0.0	0.0	0.0	0.0	0.0	0.0		
Mass Captured/Mass Challenged (%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
							Dec 21st at 3:40 pm	
Starting Level (cm)	70	70	70	70	70	70	First Brine Batch	
Ending Level (cm)	48	66.1	58.0	42.5	57.2	55.6		
Flow Volume (mL)	467.1	82.8	254.8	583.9	271.8	305.7		
Elapsed Time (s)	76620	1130	1030	830	840	750		
Flow Velocity (seconds per mL)	3482.73	289.74	85.83	30.18	65.63	52.08		
Flow Velocity (minutes per mL)	58.05	4.83	1.43	0.50	1.09	0.87		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	43.0	61.1	53.0	37.5	52.2	50.6		
Permeability (cm/s)	0.00017	0.0018	0.0063	0.021	0.0084	0.011		
Permeability (cm/s)	1.7E-04	1.8E-03	6.3E-03	2.1E-02	8.4E-03	1.1E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	132	19	890	145	382	72		
delta time (sec)	76488	1111	140	685	458	678		
delta time (min)	1274.8	18.5	2.3	11.4	7.6	11.3		
Stream Water uS/cm	53	53	53	53	53	53	Dec 21st at 3:40 pm	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	First Brine Batch	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	

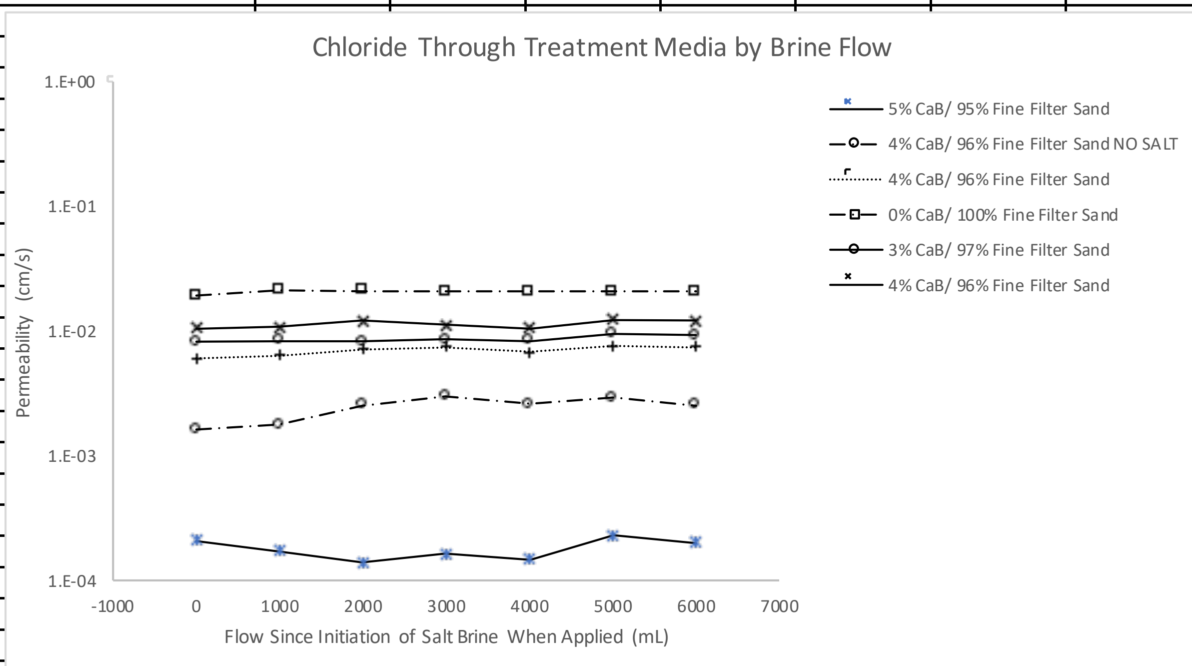
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Chloride Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas of Seventh	
Chloride Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	13,400	BDL	15,400	14,200	15,000	15,200	Sampled Dec 23rd 11 am	
Effluent Chloride Dup	12,300	0					First Brine Batch	
Effluent Total Alk (ppm as Ca	1000	260	800	1000	1000	950		
Effluent Cond (uS/cm)								
AVG Effl Cond	12,850	0	15,400	14,200	15,000	15,200		
Effluent Vol (mL)	905	1100	1015	1015	1015	1010		
Effluent Conc Meas (g/L)	12.9	0.0	15.4	14.2	15.0	15.2		
Mass in Effluent (g)	11.6	0.0	15.6	14.4	15.2	15.4		
Mass Captured (g)	4.8	0.0	0.7	-14.4	1.2	1.0		
Mass Captured/Mass Challenged (%)	29%	#DIV/0!	5%	#DIV/0!	7%	6%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
							Dec 23rd 10:35 am	
Starting Level (cm)	70	70	70	70	70	70	Second Brine Batch	
Ending Level (cm)	49.0	67.3	64.2	57.0	63.8	62.4		
Flow Volume (mL)	445.9	57.3	123.1	276.0	131.6	161.4		
Elapsed Time (s)	89520	540	420	340	390	330	Col 1 tbd	
Flow Velocity (seconds per mL)	4262.86	200.00	72.41	26.15	62.90	43.42		
Flow Velocity (minutes per mL)	71.05	3.33	1.21	0.44	1.05	0.72		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	44.0	62.3	59.2	52.0	58.8	57.4		
Permeability (cm/s)	0.00014	0.0025	0.0071	0.021	0.0082	0.012		
Permeability (cm/s)	1.4E-04	2.5E-03	7.1E-03	2.1E-02	8.2E-03	1.2E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	125	13	368	59	176	36		
delta time (sec)	89395	527	52	281	214	294		
delta time (min)	1489.9	8.8	0.9	4.7	3.6	4.9		
Stream Water uS/cm	53	53	53	53	53	53	when	
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL	what	
Stream Water Total Alk	360	360	360	360	360	360	avg of 350 & 370	
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	0.0%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Chloride Meas (g/L)	16,380	0	16,380	0	16,380	16,380	avg of 15 meas of Seventh	
Chloride Mass Challenged (g)	16.4	0.0	16.4	0.0	16.4	16.4		
Effluent Chloride	16,000	BDL	16,000	16,400	16,100	16,000	Dec 26 sample	
Effluent Chloride Dup	15,600	0						
Effluent Total Alk (ppm as Ca	850	330	850	720	950	800		
Effluent Cond (uS/cm)								
AVG Effl Cond	15,800	0	16,000	16,400	16,100	16,000		
Effluent Vol (mL)	1050	1000	1005	1005	1005	1000		
Effluent Conc Meas (g/L)	15.8	0.0	16.0	16.4	16.1	16.0		
Mass in Effluent (g)	16.6	0.0	16.1	16.5	16.2	16.0		
Mass Captured (g)	-0.2	0.0	0.3	-16.5	0.2	0.4		

Mass Captured/Mass Challenged (%)	-1%	#DIV/0!	2%	#DIV/0!	1%	2%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Starting Level (cm)	70	70	70	70	70	70	Third brine batch	
Ending Level (cm)	46.0	67.5	64.0	55.0	63.4	61.4	3 L and 75 g total	
Flow Volume (mL)	509.6	53.1	127.4	318.5	140.1	182.6		
Elapsed Time (s)	90330	420	420	406	400	407		
Flow Velocity (seconds per mL)	3763.75	168.00	70.00	27.07	60.61	47.33		
Flow Velocity (minutes per mL)	62.73	2.80	1.17	0.45	1.01	0.79		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	41.0	62.5	59.0	50.0	58.4	56.4		
Permeability (cm/s)	0.00016	0.0030	0.0074	0.021	0.0086	0.011		
Permeability (cm/s)	1.6E-04	3.0E-03	7.4E-03	2.1E-02	8.6E-03	1.1E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	147	12	370	70	185	41		
delta time (sec)	90183	408	50	336	215	366		
delta time (min)	1503.0	6.8	0.8	5.6	3.6	6.1		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	2.5%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	16,380	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	16.4	16.4	16.4		
Effluent Chloride	16000	BDL	15700	16200	16000	16000	Sampled Dec 28th	
Effluent Chloride Dup	16100	0						
Effluent Total Alk (ppm as Ca	670	280	600	500	600	600		
Effluent Cond (uS/cm)								
AVG Effl Cond	16,050	0	15,700	16,200	16,000	16,000		
Effluent Vol (mL)	860	995	1005	890	1000	1000		
Effluent Conc Meas (g/L)	16.1	0.0	15.7	16.2	16.0	16.0		
Mass in Effluent (g)	13.8	0.0	15.8	14.4	16.0	16.0		
Mass Captured (g)	2.6	0.0	0.6	2.0	0.4	0.4		
Mass Captured/Mass Challenged (%)	16%	#DIV/0!	4%	12%	2%	2%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Starting Level (cm)	70	70	70	70	70	70	Fourth brine batch	
Ending Level (cm)	47.2	66.3	60.5	47	58	55	4 L and 100 g total	
Flow Volume (mL)	484.1	78.6	201.7	488.3	254.8	318.5		
Elapsed Time (s)	94380	720	741	682	780	805		
Flow Velocity (seconds per mL)	4139.47	194.59	78.00	29.65	65.00	53.67		
Flow Velocity (minutes per mL)	68.99	3.24	1.30	0.49	1.08	0.89		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		

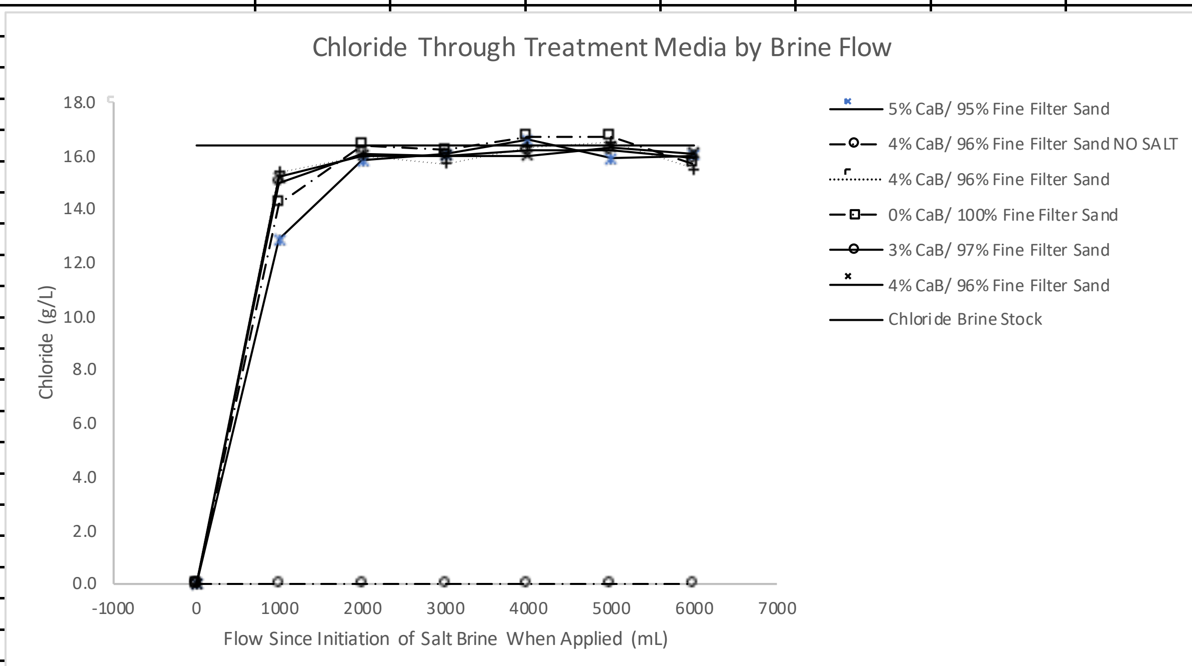
Head at end (cm) = dist above end of treatment media	42.2	61.3	55.5	42.0	53.0	50.0		
Permeability (cm/s)	0.00015	0.003	0.007	0.020491	0.008	0.01043		
Permeability (cm/s)	1.5E-04	2.6E-03	6.8E-03	2.0E-02	8.4E-03	1.0E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	138	18	646	116	355	76		
delta time (sec)	94242	702	95	566	425	729		
delta time (min)	1570.7	11.7	1.6	9.4	7.1	12.1		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	2.5%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	16,380	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	16.4	16.4	16.4		
Effluent Chloride	16600	0	16300	16700	16200	16000	Sampled Jan 3rd	
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	460	300	500	420	490	480		
Effluent Cond (uS/cm)								
AVG Effl Cond	16,600	0	16,300	16,700	16,200	16,000		
Effluent Vol (mL)	1160	1000	885	1000	1000	990	Jan 3rd meas	
Effluent Conc Meas (g/L)	16.6	0.0	16.3	16.7	16.2	16.0		
Mass in Effluent (g)	19.3	0.0	14.4	16.7	16.2	15.8		
Mass Captured (g)	-2.9	0.0	2.0	-0.3	0.2	0.5		
Mass Captured/Mass Challenged (%)	-18%	#DIV/0!	12%	-2%	1%	3%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Starting Level (cm)	70	70	70	70	70	70	Fifth brine batch	
Ending Level (cm)	41.3	64.6	57	44	54	50	5 L and 125 g total	
Flow Volume (mL)	609.4	114.7	276.0	552.0	339.7	424.6	Jan 3rd start	
Elapsed Time (s)	80940	960	940	787	954	962		
Flow Velocity (seconds per mL)	2820.21	177.78	72.31	30.27	59.63	48.10		
Flow Velocity (minutes per mL)	47.00	2.96	1.21	0.50	0.99	0.80		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	36.3	59.6	52.0	39.0	49.0	45.0		
Permeability (cm/s)	0.00023	0.00289	0.00760	0.021	0.0095	0.012		
Permeability (cm/s)	2.3E-04	2.9E-03	7.6E-03	2.1E-02	9.5E-03	1.2E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	186	27	831	135	464	105		
delta time (sec)	80754	933	109	652	490	857		
delta time (min)	1345.9	15.6	1.8	10.9	8.2	14.3		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	2.5%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	16,380	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	16.4	16.4	16.4		

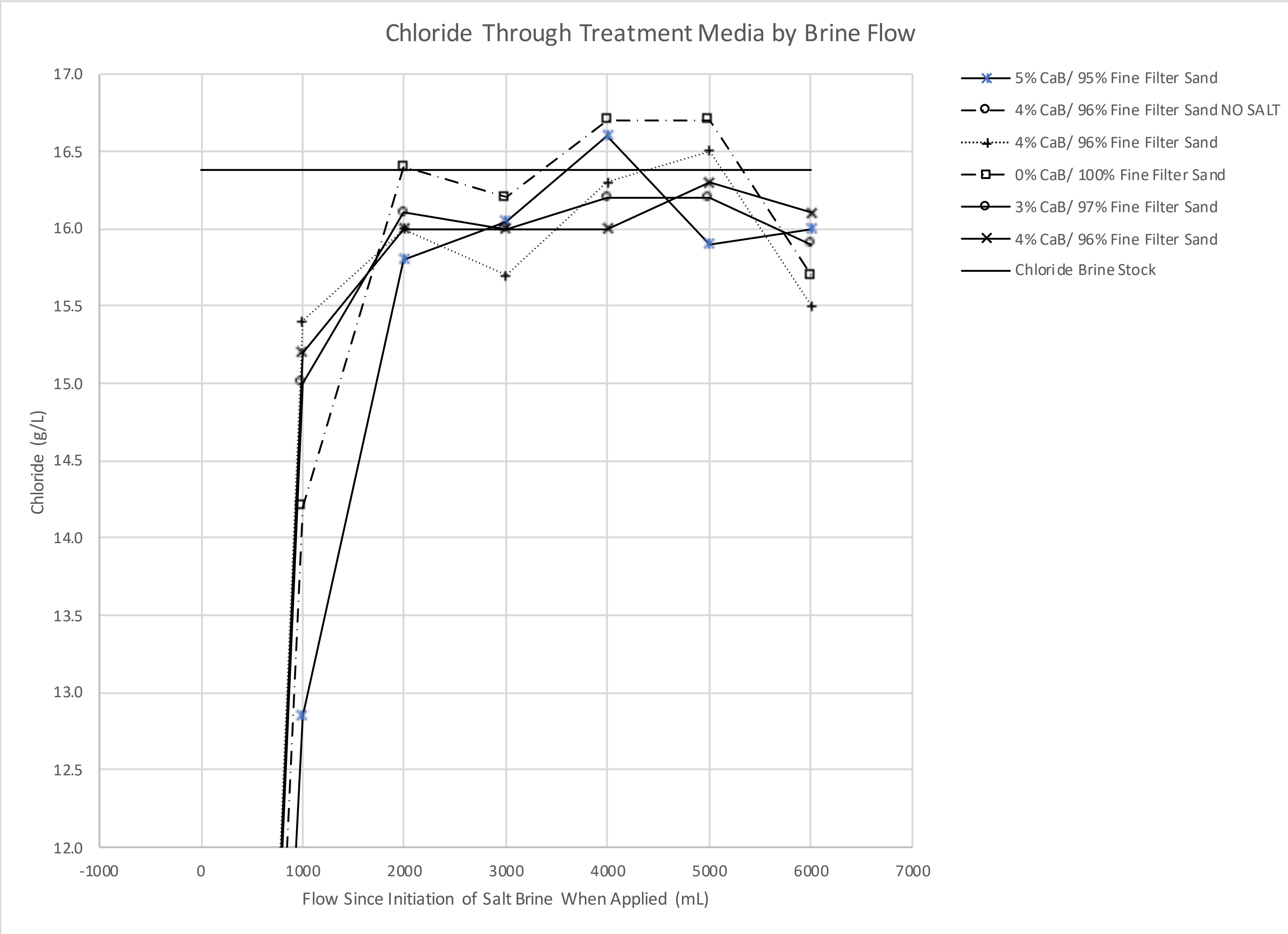
Effluent Chloride	15900	0	16500	16700	16200	16300	Sampled Jan 8th	
Effluent Chloride Dup								
Effluent Total Alk (ppm as $CaCO_3$)								
Effluent Cond (uS/cm)								
AVG Effl Cond	15,900	0	16,500	16,700	16,200	16,300		
Effluent Vol (mL)	985	860	975	985	985	995		
Effluent Conc Meas (g/L)	15.9	0.0	16.5	16.7	16.2	16.3		
Mass in Effluent (g)	15.7	0.0	16.1	16.4	16.0	16.2		
Mass Captured (g)	0.7	0.0	0.3	-0.1	0.4	0.2		
Mass Captured/Mass Challenged (%)	4%	#DIV/0!	2%	0%	3%	1%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		
Starting Level (cm)	70	70	70	70	70	70	Sixth brine batch	
Ending Level (cm)	45.6	49.5	52	44	48	50	6 L and 150 g total	
Flow Volume (mL)	518.1	435.3	382.2	552.0	467.1	424.6		
Elapsed Time (s)	74790	4740	1405	792	1429	972		
Flow Velocity (seconds per mL)	3065.16	231.22	78.06	30.46	64.95	48.60		
Flow Velocity (minutes per mL)	51.09	3.85	1.30	0.51	1.08	0.81		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	40.6	44.5	47.0	39.0	43.0	45.0		
Permeability (cm/s)	0.00020	0.0026	0.0074	0.021	0.0093	0.012		
Permeability (cm/s)	2.0E-04	2.6E-03	7.4E-03	2.1E-02	9.3E-03	1.2E-02		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	150	118	1237	135	687	105		
delta time (sec)	74640	4622	168	657	742	867		
delta time (min)	1244.0	77.0	2.8	10.9	12.4	14.5		
Stream Water uS/cm	53	53	53	53	53	53		
Stream Water Chloride	BDL	BDL	BDL	BDL	BDL	BDL		
Stream Water Total Alk	360	360	360	360	360	360		
Stream Water g/L	0.3	0.3	0.3	0.3	0.3	0.3		
Stock Conc (g/L) Mix	2.5%	0.0%	2.5%	2.5%	2.5%	2.5%		
Stock Vol (mL)	1000	1000	1000	1000	1000	1000		
Stock Conc Meas (g/L)	16,380	0	16,380	16,380	16,380	16,380	avg of 15 meas	
Mass Challenged (g)	16.4	0.0	16.4	16.4	16.4	16.4		
Effluent Chloride	16000	0	15500	15700	15900	16100	Sampled Jan 11	
Effluent Chloride Dup								
Effluent Total Alk (ppm as Ca	380	265	460	360	470	460		
Effluent Cond (uS/cm)	59.50	53.10	62.30	58.20	60.30	56.60		
AVG Effl Cond	16,000	0	15,500	15,700	15,900	16,100		
Effluent Vol (mL)	1005	1000	1000	1000	1000	870		
Effluent Conc Meas (g/L)	16.0	0.0	15.5	15.7	15.9	16.1		
Mass in Effluent (g)	16.1	0.0	15.5	15.7	15.9	14.0		
Mass Captured (g)	0.3	0.0	0.9	0.7	0.5	2.4		
Mass Captured/Mass Challenged (%)	2%	#DIV/0!	5%	4%	3%	14%		
Captured/CaB (g/g)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!		

Salt Waterways			EIGHTH PACK						
Column Study: Permeability and Chloride Capture									
December 28, 2023									
	DATA FROM EIGHTH PACK								
					brine avg	16,380	ppm		
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less				
Column	1	2	3	4	5	6	Filled Dec 20th		
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	Hydrated maybe 500 mL		
Fine Filter Sand %	95%	96%	96%	100%	97%	96%	Dumped with no meas		
Ca-B %	5%	4%	4%	0%	3%	4%	effluent from first hydr		
Length (cm)	32	32	32	32	32	32			
Height of support layer	5	5	5	5	5	5			
	Permeability Measurements (cm/s)								
Flow (mL) after Salt Brine Initiation	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand			
0	0.00021	0.0016	0.0060	0.0192	0.0082	0.0106			
1000	0.00017	0.0018	0.0063	0.021	0.0084	0.011			
2000	0.00014	0.0025	0.0071	0.0210	0.0082	0.0121			
3000	0.00016	0.0030	0.0074	0.0207	0.0086	0.0112			
4000	0.00015	0.0026	0.0068	0.0205	0.0084	0.0104			
5000	0.00023	0.0029	0.0076	0.0208	0.0095	0.0122			
6000	0.00020	0.0026	0.0074	0.0206	0.0093	0.0121			



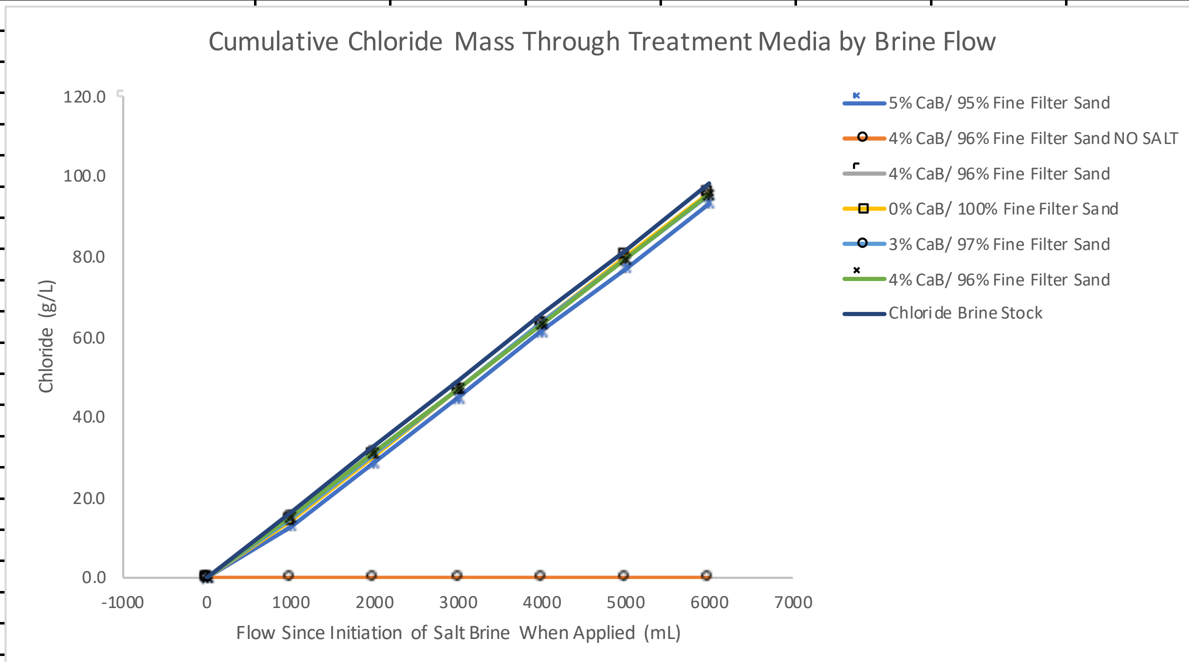
Salt Waterways			EIGHTH PACK					
Column Study: Permeability and Chloride Capture								
December 28, 2023								
	DATA FROM EIGHTH PACK							
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 20th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	Hydrated maybe 500 mL	
Fine Filter Sand %	95%	96%	96%	100%	97%	96%	Dumped with no meas	
Ca-B %	5%	4%	4%	0%	3%	4%	effluent from first hydr	
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
	Chloride Measurements (g/L)							
Flow (mL) after Salt Brine Initiation	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand	Chloride Brine Stock	
0	0.0	0.0	0.0	0.0	0.0	0.0	16.38	
1000	12.9	0.0	15.4	14.2	15.0	15.2	16.38	
2000	15.8	0.0	16.0	16.4	16.1	16.0	16.38	
3000	16.05	0.0	15.7	16.2	16.0	16.0	16.38	
4000	16.6	0.0	16.3	16.7	16.2	16.0	16.38	
5000	15.9	0.0	16.5	16.7	16.2	16.3	16.38	
6000	16	0	15.5	15.7	15.9	16.1	16.38	



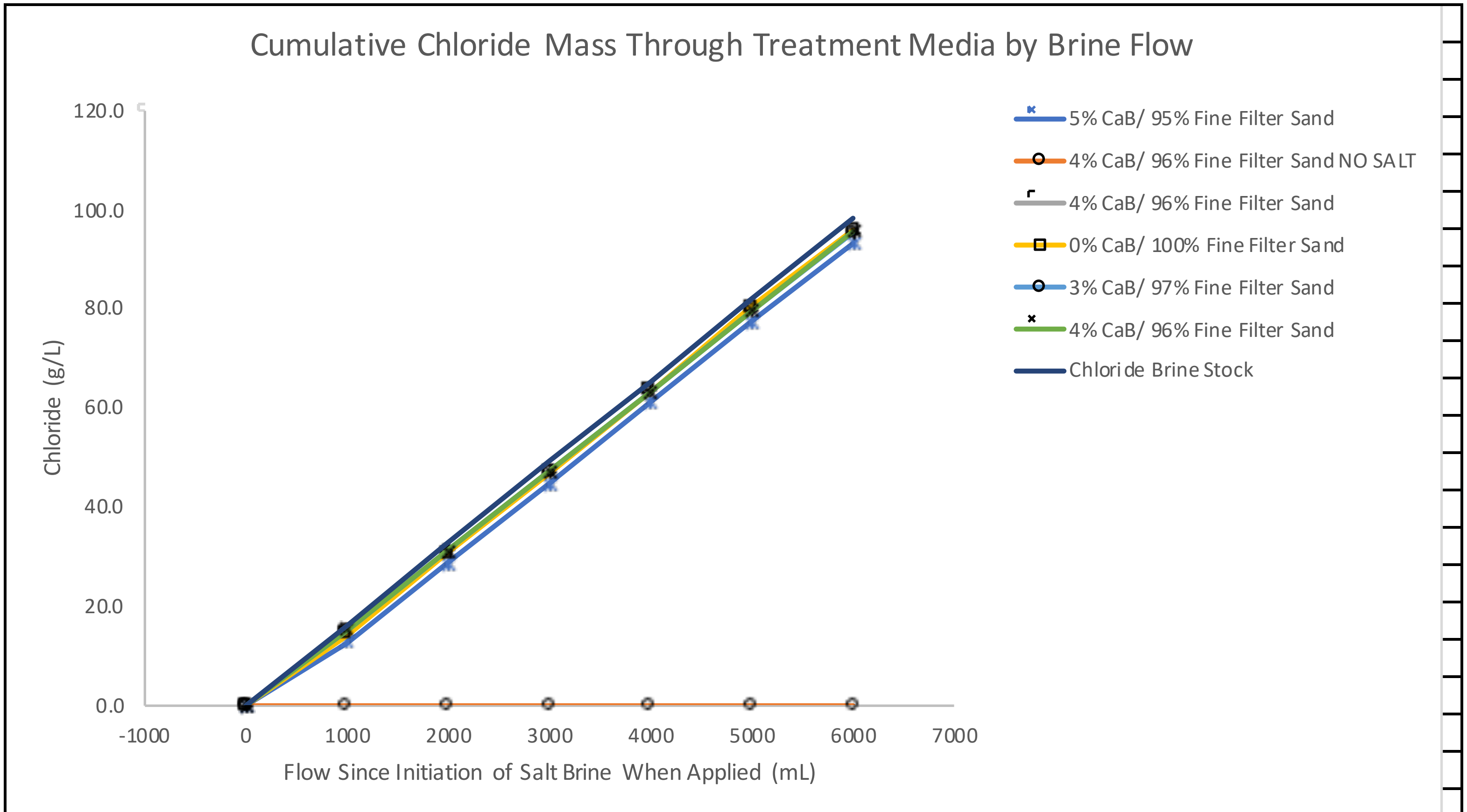


Chloride Through Treatment Media by Brine Flow
Chloride (g/L)
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
-1000
0
1000
2000
3000
4000
5000
6000
7000
Flow Since Initiation of Salt Brine When Applied (mL)
5% CaB/ 95% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand NO SALT
4% CaB/ 96% Fine Filter Sand
0% CaB/ 100% Fine Filter Sand
3% CaB/ 97% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand
Chloride Brine Stock

Salt Waterways			EIGHTH PACK					
Column Study: Permeability and Chloride Capture								
December 28, 2023								
	DATA FROM EIGHTH PACK							
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 20th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	Hydrated maybe 500 mL	
Fine Filter Sand %	95%	96%	96%	100%	97%	96%	Dumped with no meas	
Ca-B %	5%	4%	4%	0%	3%	4%	effluent from first hydr	
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
	Chloride Measurements (g/L)							
Flow (mL) after Salt Brine Initiation	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand	Chloride Brine Stock	
0	0.0	0.0	0.0	0.0	0.0	0.0	16.38	
1000	12.9	0.0	15.4	14.2	15.0	15.2	16.38	
2000	15.8	0.0	16.0	16.4	16.1	16.0	16.38	
3000	16.05	0.0	15.7	16.2	16.0	16.0	16.38	
4000	16.6	0.0	16.3	16.7	16.2	16.0	16.38	
5000	15.9	0.0	16.5	16.7	16.2	16.3	16.38	
6000	16	0	15.5	15.7	15.9	16.1	16.38	
	Chloride Mass (Conc x Flow Volume) (g)							
Flow (mL) between Measurement Steps	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand	Chloride Brine Stock	
1000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1000	12.9	0.0	15.4	14.2	15.0	15.2	16.4	
1000	15.8	0.0	16.0	16.4	16.1	16.0	16.4	
1000	16.1	0.0	15.7	16.2	16.0	16.0	16.4	
1000	16.6	0.0	16.3	16.7	16.2	16.0	16.4	
1000	15.9	0.0	16.5	16.7	16.2	16.3	16.4	
1000	16.0	0.0	15.5	15.7	15.9	16.1	16.4	
	Chloride Cumulative Mass (g)							
Flow (mL) after Salt Brine Initiation	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand	Chloride Brine Stock	
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
1000	12.9	0.0	15.4	14.2	15.0	15.2	16.4	
2000	28.7	0.0	31.4	30.6	31.1	31.2	32.8	
3000	44.7	0.0	47.1	46.8	47.1	47.2	49.1	
4000	61.3	0.0	63.4	63.5	63.3	63.2	65.5	
5000	77.2	0.0	79.9	80.2	79.5	79.5	81.9	
6000	93.2	0.0	95.4	95.9	95.4	95.6	98.3	

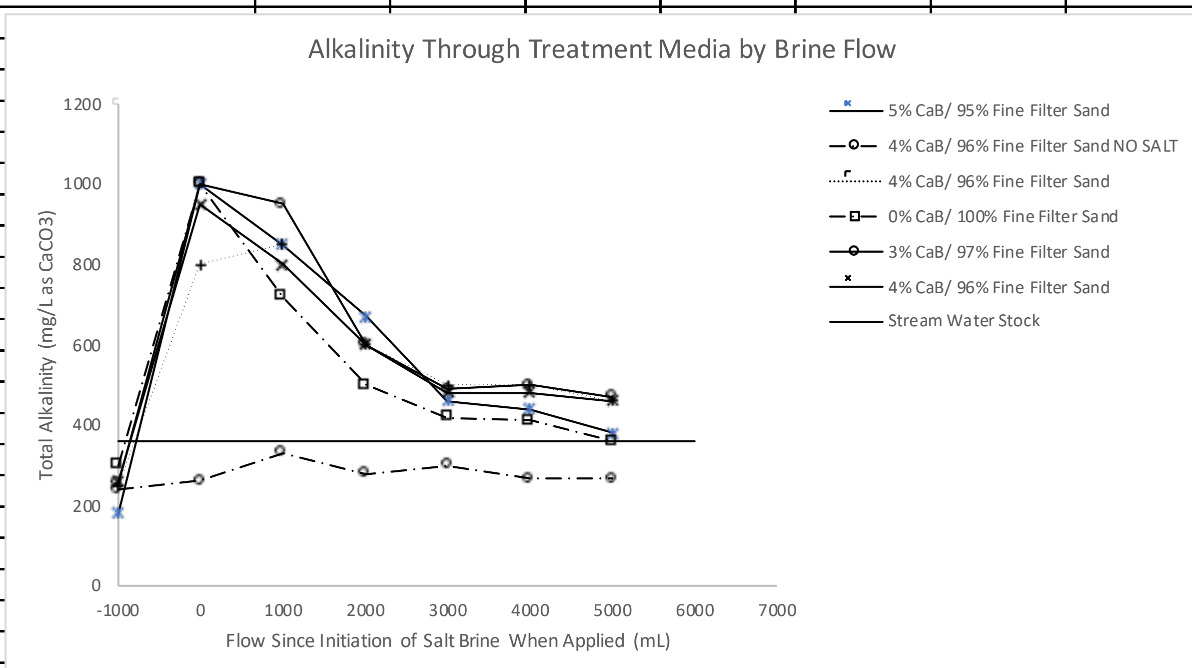


Cumulative Chloride Mass Through Treatment Media by Brine Flow
Chloride (g/L)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-1000
0
1000
2000
3000
4000
5000
6000
7000
Flow Since Initiation of Salt Brine When Applied (mL)
5% CaB/ 95% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand NO SALT
4% CaB/ 96% Fine Filter Sand
0% CaB/ 100% Fine Filter Sand
3% CaB/ 97% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand
Chloride Brine Stock



Cumulative Chloride Mass Through Treatment Media by Brine Flow
5% CaB/ 95% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand NO SALT
4% CaB/ 96% Fine Filter Sand
0% CaB/ 100% Fine Filter Sand
3% CaB/ 97% Fine Filter Sand
4% CaB/ 96% Fine Filter Sand
Chloride Brine Stock
Chloride (g/L)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
-1000
0
1000
2000
3000
4000
5000
6000
7000
Flow Since Initiation of Salt Brine When Applied (mL)

Salt Waterways			EIGHTH PACK					
Column Study: Permeability and Chloride Capture								
December 13, 2023								
	DATA FROM EIGHTH PACK							
					brine avg	16,380	ppm	
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride less			
Column	1	2	3	4	5	6	Filled Dec 20th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	Hydrated maybe 500 mL	
Fine Filter Sand %	95%	96%	96%	100%	97%	96%	Dumped with no meas	
Ca-B %	5%	4%	4%	0%	3%	4%	effluent from first hydr	
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
	Alkalinity Measurements (mg/L as $CaCO_3$)							
Flow (mL) after Salt Brine Initiation	5% CaB/ 95% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand NO SALT	4% CaB/ 96% Fine Filter Sand	0% CaB/ 100% Fine Filter Sand	3% CaB/ 97% Fine Filter Sand	4% CaB/ 96% Fine Filter Sand	Stream Water Stock	
-1000	132	220	235	280	250	245	360	
0	180	240	250	300	255	260	360	
1000	1000	260	800	1000	1000	950	360	
2000	850	330	850	720	950	800	360	
3000	670	280	600	500	600	600	360	
4000	460	300	500	420	490	480	360	
5000	440	265	500	410	500	480	360	
6000	380	265	460	360	470	460	360	



Salt Waterways							
Column Study: Permeability and Chloride Capture							
December 28, 2023							
Stock Measurements		ppm					
First batch	16,700	Stock 1	120 mL taken		480	mg/L as $CaCO_3$	
First batch	16,700	Stock 1			500	mg/L as $CaCO_3$	
Second batch		Stock 4	120 mL taken	<17600	400		
Second batch	16,400	Stock 4			430		
Third batch	16,000	Stock 3	120 mL taken		400		
Third batch	16,000	Stock 3			380		
Fifth batch	15,700	Stock 5	120 mL taken		285		
Fifth batch	15,600	Stock 5			375		
Sixth batch	16,000	Stock 6	120 mL taken		320		
Sixth batch	16,000	Stock 6			350		
		STD DEV =	396			STD DEV =	67
AVG	16,122	ppm			392	ppm	
Count	9						

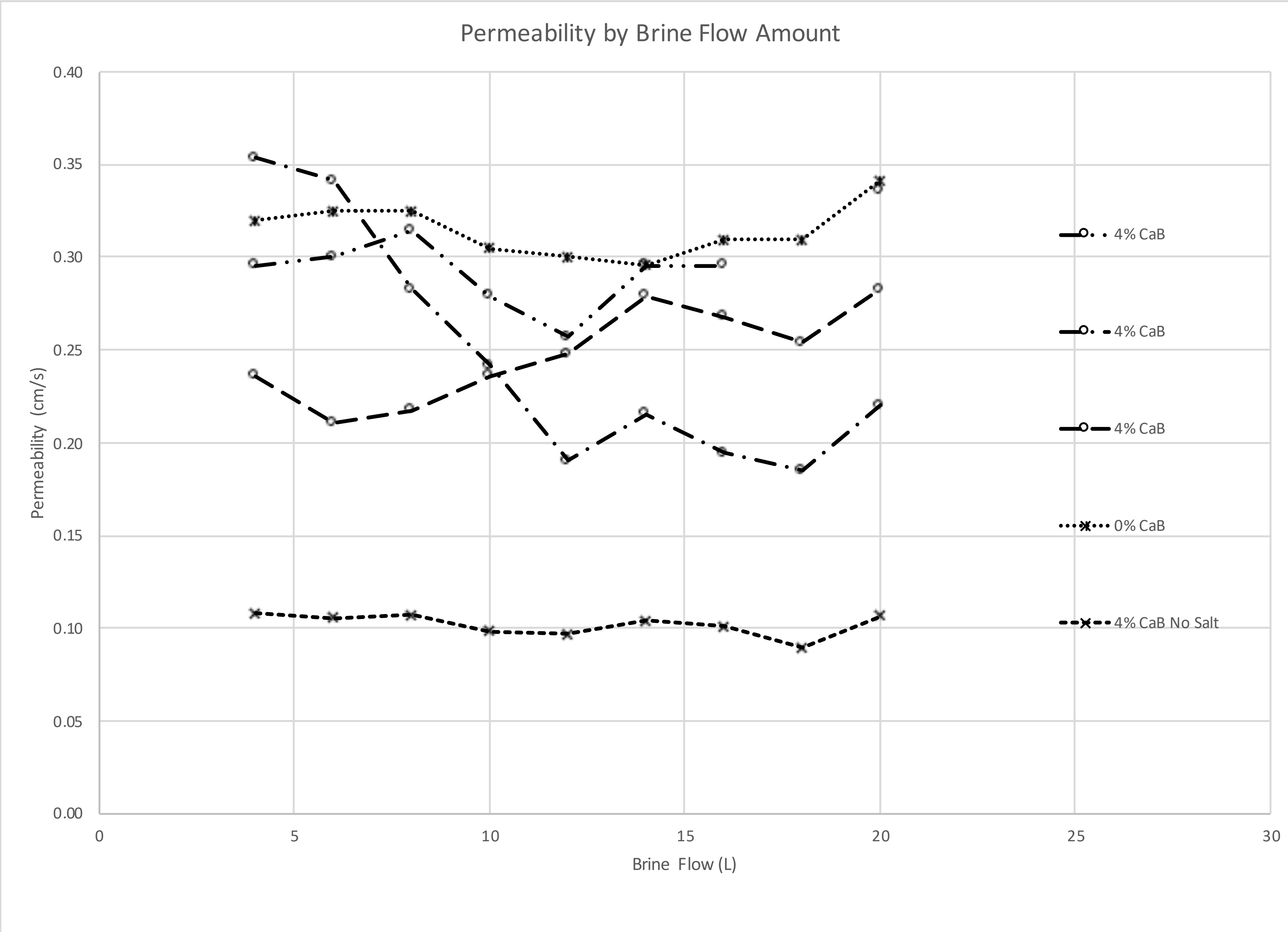
Salt Waterways				
Column Study: Permeability and Chloride Capture				
December 21, 2023				
			Total Alkalinity	
Stream Water Measurements				
Seventh pack	350	mg/L as $CaCO_3$		
Seventh pack	370			
Eighth pack	360			
Eighth pack	355			
		STD DEV =	9	
AVG	359	ppm		
Count	4			

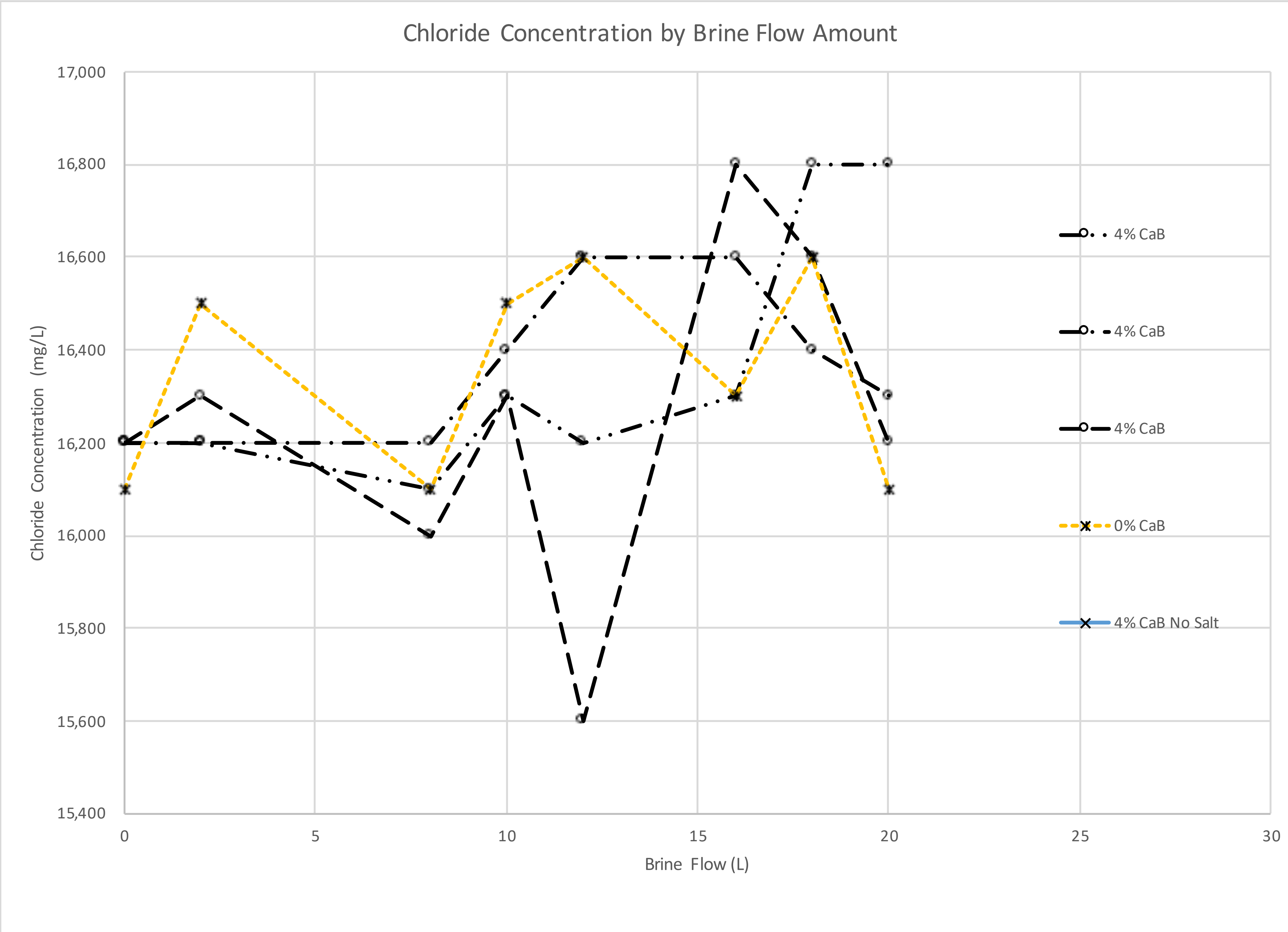
Appendix E:

Data and Graphs of the Permeability and the Chloride Concentration Measurements for the Retreatment of Treated Effluent Experiment

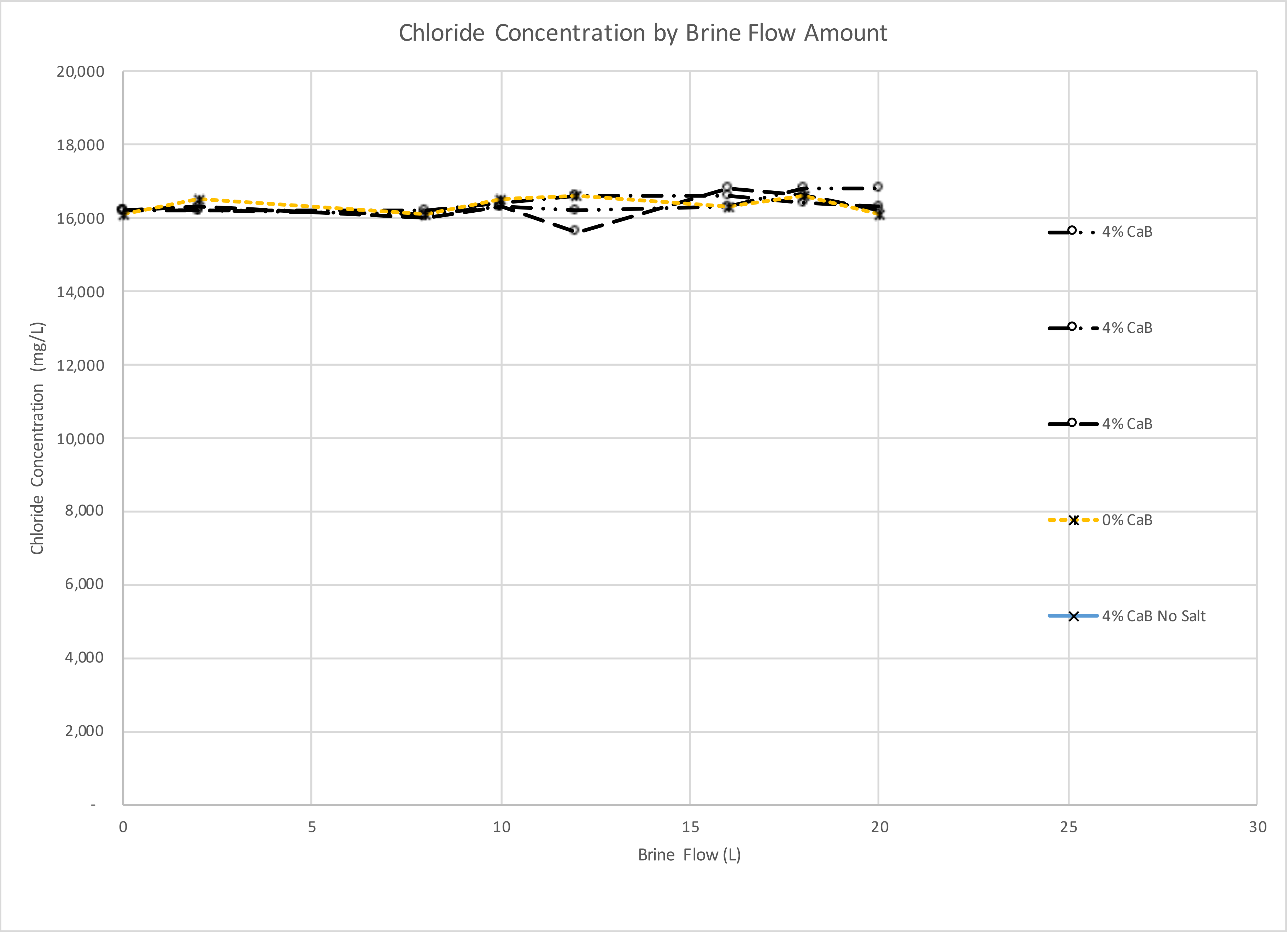
Salt Waterways				NINTH PACK			
Column Study: Permeability and Chloride Capture							
April 24, 2024							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimens						
		inside area =	21.23	cm^2			
Oakton Conductivity Meter							
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)	
From Chloride Columns calibration study							/
					brine avg	16,380	ppm
Temp	72	deg F			25 g in 1000 mL so 2.5%....but chloride le		
Column	1	2	3	4	5	Filled April 8th	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	Hydrated 2000 mL	
Sugar Sand %	40%	40%	40%	40%	40%	First Cycle with no perm n	
Pea Stone %	56%	56%	56%	60%	56%		
Ca-B %	4%	4%	4%	0%	4%	effluent from first hydr	
Length (cm)	32	32	32	32	32		
Height of support layer	5	5	5	5	5		
Starting Level (cm)	70	70	70	70	70		
Ending Level (cm)	40	40	40	40	40.0		
Flow Volume (mL)	637.0	637.0	637.0	637.0	637.0		
Elapsed Time (s)	9240	9240	1710	630	1520		
Flow Velocity (seconds per mL)	308.00	308.00	57.00	21.00	50.67		
Flow Velocity (minutes per mL)	5.13	5.13	0.95	0.35	0.84		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	35.0	35.0	35.0	35.0	35.0		
	Permeation time (sec)						
Brine Flow (L)	4% CaB	4% CaB	4% CaB	0% CaB	4% CaB No Salt		
4	67	56	84	62	183	Cycle 2	
6	66	58	94	61	188	Cycle 3	
8	63	70	91	61	185	Cycle 4	
10	71	82	84	65	201	Cycle 5	
12	77	104	80	66	205	Cycle 6	
14	67	92	71	67	190	Cycle 7	
16	67	102	74	64	196	Cycle 8	
18		107	78	64	221	Cycle 9	

20	59	90	70	58	186	Cycle 10	
	Permeability (cm/s)						
Brine Flow (L)	4% CaB	4% CaB	4% CaB	0% CaB	4% CaB No Salt		
4	0.30	0.35	0.24	0.32	0.11	Cycle 2	
6	0.30	0.34	0.21	0.32	0.11	Cycle 3	
8	0.31	0.28	0.22	0.32	0.11	Cycle 4	
10	0.28	0.24	0.24	0.30	0.10	Cycle 5	
12	0.26	0.19	0.25	0.30	0.10	Cycle 6	
14	0.30	0.22	0.28	0.30	0.10	Cycle 7	
16	0.30	0.19	0.27	0.31	0.10	Cycle 8	
18		0.19	0.25	0.31	0.09	Cycle 9	
20	0.34	0.22	0.28	0.34	0.11	Cycle 10	
	Chloride Concentration (mg/L)						
Brine Flow (L)	4% CaB	4% CaB	4% CaB	0% CaB	4% CaB No Salt		
0	16,200	16,200	16,200	16,100		Cycle 0	
2	16,200	16,200	16,300	16,500		Cycle 1	
4						Cycle 2	
6						Cycle 3	
8	16,100	16,200	16,000	16,100		Cycle 4	
10	16,300	16,400	16,300	16,500		Cycle 5	
12	16,200	16,600	15,600	16,600		Cycle 6	
14						Cycle 7	
16	16,300	16,600	16,800	16,300		Cycle 8	
18	16,800	16,400	16,600	16,600		Cycle 9	
20	16,800	16,300	16,200	16,100		Cycle 10	


Permeability by Brine Flow Amount
Permeability (cm/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
5
10
15
20
25
30
Brine Flow (L)
4% CaB
4% CaB
4% CaB
0% CaB
4% CaB No Salt



Chloride Concentration by Brine Flow Amount
17,000
16,800
16,600
16,400
16,200
16,000
15,800
15,600
15,400
Chloride Concentration (mg/L)
0
5
10
15
20
25
30
Brine Flow (L)
4% CaB
4% CaB
4% CaB
0% CaB
4% CaB No Salt



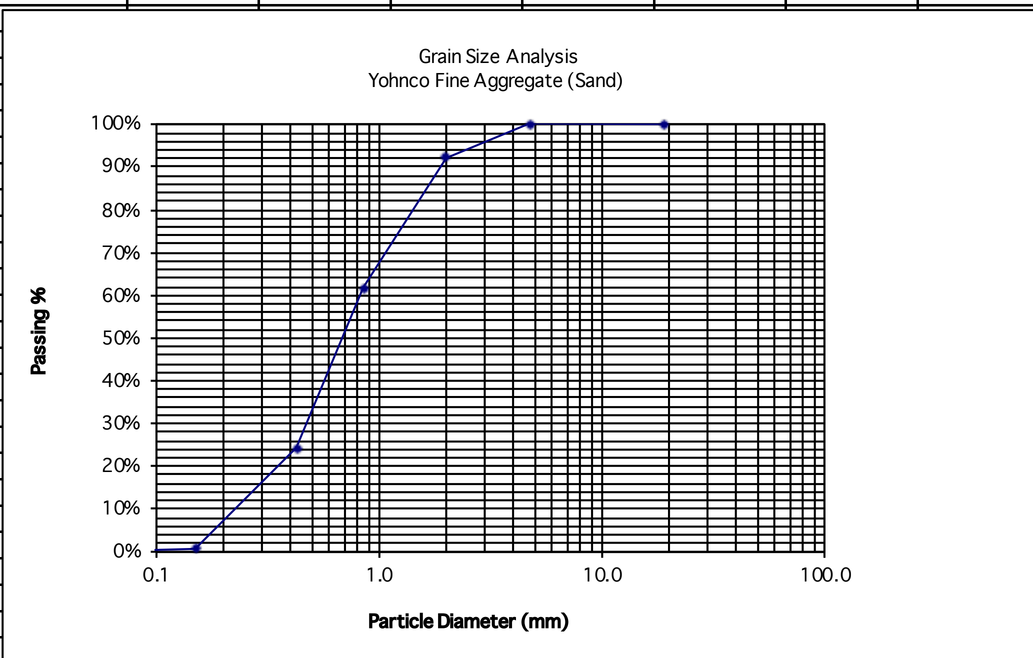
Chloride Concentration by Brine Flow Amount
Chloride Concentration (mg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
-
0
5
10
15
20
25
30
Brine Flow (L)
4% CaB
4% CaB
4% CaB
0% CaB
4% CaB No Salt

Appendix F:

Grain Size Analyses for Treatment Media Components

Yohnco Fine Aggregate (Sand) Grain Size Analysis

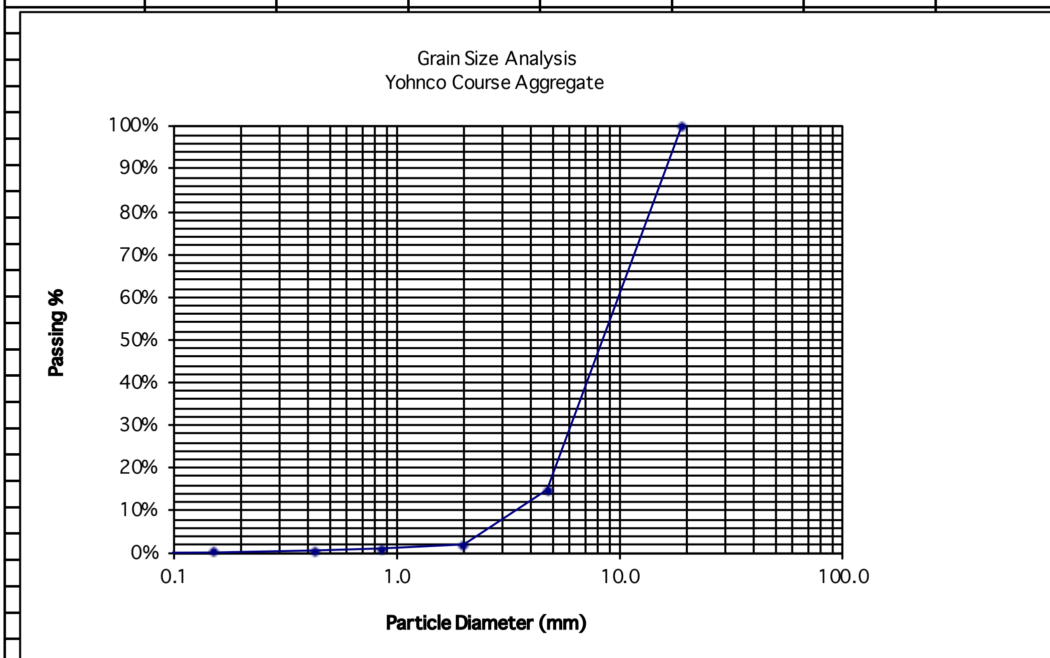
Field Study: Treatment Media Mix Design							
Salt Waterways							
August 20, 2024							
Initial Dry Mass of Sample		403.7	g	Material:	Fine Aggregate	USCS Char =	SP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	526.0	0.3	0%	403.4	100%
#10	2	488.1	518.9	30.8	8%	372.6	92%
#20	0.85	420.3	543.9	123.6	31%	249	62%
#40	0.425	372.9	524.1	151.2	37%	97.8	24%
#120	0.15	350.8	445.6	94.8	23%	3	1%
#200	0.075	336.3	338.2	1.9	0%	1.1	0%
pan		371.9	373.0	1.1	0%		0%
total =				403.7	100%		
						pan	0



	D_{10} =	0.22	mm				
	D_{30} =	0.47	mm				
	D_{60} =	0.82	mm				
Coefficient of Uniformity	C_u =	3.73		Coefficient of Curvature	C_c =	1.22	

Yohnco Course Aggregate Grain Size Analysis

Field Study: Treatment Media Mix Design							
Salt Waterways							
August 20, 2024							
Initial Dry Mass of Sample		399.36	g	Material:	Course Aggregate	USCS Char =	GP
Sieve	Size (mm)	Mass of Sieve Empty (g)	Mass of Sieve & Retained Soil	Retained Mass	Retained % of Whole Sample	Mass of Sample Passing	Passing % of Whole Sample
3 inch	75						
2 inch	50						
1-1/2 inch	37.5						
1 inch	25						
3/4 inch	19						100%
#4	4.75	525.7	865.7	340	85%	59.36	15%
#10	2	488.1	539.6	51.5	13%	7.86	2%
#20	0.85	420.3	423.9	3.6	1%	4.26	1%
#40	0.425	372.9	374.9	2	1%	2.26	1%
#120	0.15	350.8	352.1	1.26	0%	1	0%
#200	0.075	336.3	336.8	0.5	0%	0.5	0%
pan		371.9	372.4	0.5	0%		0%
total =				399.36	100%		
						pan	0



	D_{10} =	3.4	mm				
	D_{30} =	6.0	mm				
	D_{60} =	9.8	mm				
Coefficient of Uniformity	C_u =	2.88		Coefficient of Curvature	C_c =	1.08	

UNIFIED SOIL CLASSIFICATION

FIELD INDENTIFICATON PROCEDURES (EXCLUDING PARTICLES LARGER THAN 3 in. AND BASING FRACTIONS ON ESTIMATED WEIGHTS)				GROUP SYMBOLS a	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA
COARSE-GRAINED SOILS MORE THAN HALF OF MATERIAL IS *LARGER* THAN NO. 200 SIEVE SIZE b	GRAVELS MORE THAN HALF OF COARSE FRACTION IS LARGER THAN NO. 4 SIEVE SIZE	CLEAN GRAVELS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZE AND SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZES	*GW*	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GIVE TYPICAL NAME: INDICATE APPROXIMATE PERCENTAGES OF SAND AND GRAVEL; MAXIMIZE SIZE; ANGULARITY, SURFACE CONDITION, AND HARDNESS OF THE COARSE GRAINS; LOCAL OR GEOLOGIC NAME AND OTHER PERTINENT DESCRIPTIVE INFORMATION; AND SYMBOLS IN PARENTHESES	$C_U = \frac{D_{60}}{D_{10}}$ GREATER THAN 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3
			PREDOMINANTLY ONE SIZE OR A RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING	*GP*	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENT FOR *GW*
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	NONPLASTIC FINES (FOR IDENTIFICATION PROCEDURES, SEE *ML* BELOW)	*GM*	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW "A" LINE OR *PI* LESS THAN 4
			PLASTIC FINES (FOR IDENTIFICATION PROCEDURES, SEE *CL* BELOW)	*GC*	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES	FOR UNDISTURBED SOILS ADD INFORMATION ON STRATIFICATION, DEGREE OF COMPACTNESS, CEMENTATION, MOISTURE CONDITIONS AND DRAINAGE CHARACTERISTICS	ATTERBERG LIMITS ABOVE "A" LINE OR *PI* GREATER THAN 7. ABOVE "A" LINE WITH *PI* BETWEEN 4 AND 7 ARE *BORDERLINE* CASES REQUIRING USE OF DUAL SYMBOLS
	SANDS MORE THAN HALF OF COARSE FRACTION IS SMALLER THAN NO. 4 SIEVE SIZE (FOR VISUAL CLASSIFICATION, THE 1/4 IN. SIZE MAY BE USED AS EQUIVALENT TO THE NO. 4 SIEVE SIZE)	CLEAN SANDS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZES AND SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICLE SIZES	*SW*	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	EXAMPLE: *SILTY SAND,* GRAVELLY: ABOUT 20% HARD, ANGULAR GRAVEL PARTICLES 1/2-IN. MAXIMUM SIZE; ROUNDED AND SUBANGULAR SAND GRAINS COARSE TO FINE, ABOUT 15% NON-PLASTIC FINES WITH LOW DRY STRENGTH; WELL COMPACTED AND MOIST IN PLACE; ALLUVIAL SAND; (*SM*)	$C_U = \frac{D_{60}}{D_{10}}$ GREATER THAN 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3
			PREDOMINANTLY ONE SIZE OR A RANGE OF SIZES WITH SOME INTERMEDIATE SIZES MISSING	*SP*	POORLY GRADED SANDS, GRAVELLY SANDS , LITTLE OR NO FINES		NOT MEETING ALL GRADATION REQUIREMENT FOR *SW*
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	NONPLASTIC FINES (FOR IDENTIFICATION PROCEDURES, SEE *ML* BELOW)	*SM*	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES		ATTERBERG LIMITS BELOW "A" LINE OR *PI* LESS THAN 4
			PLASTIC FINES (FOR IDENTIFICATION PROCEDURES, SEE *CL* BELOW)	*SC*	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES		ATTERBERG LIMITS ABOVE "A" LINE WITH *PI* GREATER THAN 7. ABOVE "A" LINE WITH *PI* BETWEEN 4 AND 7 ARE *BORDERLINE* CASES REQUIRING USE OF DUAL SYMBOLS

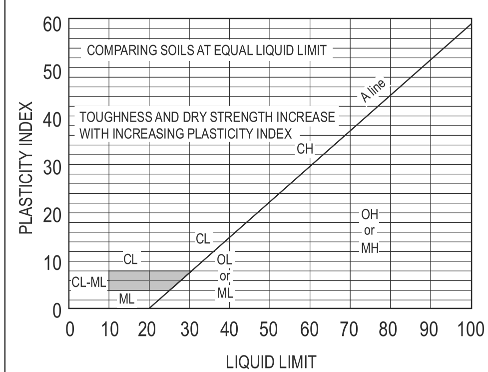
(THE NO. 200 SIEVE SIZE IS ABOUT THE SMALLEST PARTICLE VISIBLE TO THE NAKED EYE)

USE GRAIN SIZE CURVE IN IDENTIFYING THE FRACTIONS AS GIVEN UNDER FIELD IDENTIFICATION

DETERMINE PERCENTAGES OF GRAVEL AND SAND FROM GRAIN SIZE CURVE DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN NO. 200 SIEVE SIZE) COARSE GRAINED SOILS ARE CLASSIFIED AS FOLLOWS:
LESS THAN 5% — *GW, GP, SW, SP*
MORE THAN 12% — *GM, GC, SM, SC*
5% TO 12% — *BORDERLINE* CASES REQUIRING USE OF DUAL SYMBOLS

IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN NO. 40 SIEVE SIZE

		DRY STRENGTH (CRUSHING CHARACTER-ISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GROUP SYMBOLS a	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS
FINE-GRAINED SOILS MORE THAN HALF OF MATERIAL IS *SMALLER* THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS LIQUID LIMIT LESS THAN 50	NONE TO SLIGHT	QUICK TO SLOW	NONE	*ML*	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS WITH SLIGHT PLASTICITY	GIVE TYPICAL NAME: INDICATE DEGREE AND CHARACTER OF PLASTICITY, AMOUNT AND MAXIMUM SIZE OF COARSE GRAINS; COLOR IN WET CONDITION, ODOR IF ANY, LOCAL OR GEOLOGIC NAME AND OTHER PERTINENT DESCRIPTIVE INFORMATION; AND SYMBOLS IN PARENTHESES
		MEDIUM TO HIGH	NONE TO VERY SLOW	MEDIUM	*CL*	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS	
		SLIGHT TO MEDIUM	SLOW	SLIGHT	*OL*	ORGANIC SILTS AND ORGANIC SILT-CLAYS OF LOW PLASTICITY	FOR UNDISTURBED SOILS ADD INFORMATION ON STRUCTURE, STRATIFICATION, CONSISTENCY IN UNDISTURBED AND REMOLDED STATES, MOISTURE AND DRAINAGE CONDITIONS
	SILTS AND CLAYS LIQUID LIMIT GREATER THAN 50	SLIGHT TO MEDIUM	SLOW TO NONE	SLIGHT TO MEDIUM	*MH*	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	
		HIGH TO VERY HIGH	NONE	HIGH	*CH*	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	EXAMPLE; *CLAYEY SILT*, BROWN; SLIGHTLY PLASTIC; SMALL PERCENTAGE OF FINE SAND; NUMEROUS VERTICAL ROOT HOLES; FIRM AND DRY IN PLACE; LOSS; (*ML*)
		MEDIUM TO HIGH	NONE TO VERY SLOW	SLIGHT TO MEDIUM	*OH*	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY	
HIGHLY ORGANIC SOILS		READILY IDENTIFIED BY COLOR, ODOR, SPONGY FEEL AND FREQUENTLY BY FIBROUS TEXTURE			*Pt*	PEAT AND OTHER HIGHLY ORGANIC SOILS	



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

Lambe and Whitman, *Soil Mechanics*, Wiley, 1969.

Appendix G:
Permeability Analyses of Treatment Media

Salt Waterways					
Field Study: Permeability and Treatment Media Design					
September 6, 2024					
Objective: Evaluation of permeability (k) as a function of Yohnco's Fine and Course Aggregates mixed in different combinations with Calcium Bentonite (CaB) at 4% proportion. Media was hydrated before tests.					
Filter Pack Size: 1000g in all columns.					
Permeant: Stream water with no salt.					
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
4% CaB	4% CaB	4% CaB	4% CaB	4% CaB	4% CaB
80% Sand	70% Sand	60% Sand	50% Sand	40% Sand	30% Sand
16% Gravel	26% Gravel	36% Gravel	46% Gravel	56% Gravel	66% Gravel
k = 0.00775 cm/s	k = 0.00244 cm/s	k = 0.00231 cm/s	k = 0.00393 cm/s	k = 0.0561 cm/s	k = 0.124 cm/s
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
4% CaB	4% CaB	4% CaB	4% CaB	4% CaB	4% CaB
35% Sand	30% Sand	25% Sand	20% Sand	15% Sand	10% Sand
61% Gravel	66% Gravel	71% Gravel	76% Gravel	81% Gravel	86% Gravel
k = 0.114 cm/s	k = 0.0995 cm/s	k = 0.275 cm/s	k = 0.550 cm/s	k = 0.900 cm/s	k = 1.04 cm/s
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
4% CaB	4% CaB	4% CaB	4% CaB	4% CaB	4% CaB
35% Sand	30% Sand	25% Sand	20% Sand	25% Sand	25% Sand
61% Gravel	66% Gravel	71% Gravel	76% Gravel	71% Gravel	71% Gravel
k = 0.130 cm/s	k = 0.108 cm/s	k = 0.287 cm/s	k = 0.583 cm/s	k = 0.0492 cm/s	k = 0.109 cm/s
	by media mixtures				
	Average 25%	0.1484	Permeability (cm/s)		
	Average 25% wo	0.1980	Permeability (cm/s)		
	Average ALL 25%	0.1801	Permeability (cm/s)		

Salt Waterways								
Field Study: Permeability and Treatment Media Design								
September 6, 2024								
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm		
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dimensions/							
		inside area =	21.23	cm^2				
Oakton Conductivity Meter								
Conc (g/L) =	0.0000004	[Conductivity (ms/cm)]^2		+	0.0052	Conductivity (ms/cm)		
From Chloride Columns calibration study								/
					brine avg	0	ppm	
Temp	72	deg F						
Column	1	2	3	4	5	6		
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000		
Sand	80%	70%	60%	50%	40%	30%		
Gravel	16%	26%	36%	46%	56%	66%		
Ca B	4%	4%	4%	4%	4%	4%		
Length (cm)	32	32	32	32	32	32		
Height of support layer	5	5	5	5	5	5		
							Sep 3rd, 1:30 pm	
Starting Level (cm)	70	70	70	70	70	70		
Ending Level (cm)	53.6	64.3	64.6	43.8	40.0	40.0		
Flow Volume (mL)	348.2	121.0	114.7	556.3	637.0	637.0		
Elapsed Time (s)	1200	1200	1200	420	353	160		
Flow Velocity (seconds per mL)	73.17	210.53	222.22	16.03	11.77	5.33		
Flow Velocity (minutes per mL)	1.22	3.51	3.70	0.27	0.20	0.09		
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0		
Head at end (cm) = dist above end of treatment media	48.6	59.3	59.6	38.8	35.0	35.0		
Permeability (cm/s)	0.00775	0.0024	0.0023	0.039	0.0561	0.124		
Permeability (cm/s)	7.8E-03	2.4E-03	2.3E-03	3.9E-02	5.6E-02	1.2E-01		
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1		
Amt of time for increment	86	29	838	119	300	89		
delta time (sec)	1114	1171	362	301	53	71		
delta time (min)	18.6	19.5	6.0	5.0	0.9	1.2		

Salt Waterways							
Field Study: Permeability and Treatment Media Design							
September 6, 2024							
Columns are 2 inch Sch 40		inside diam =	2.047	inch	5.20	cm	
	https://www.commercial-industrial-supply.com/resource-center/pvc-pipe-and-fittings-dime						
		inside area =	21.23	cm^2			
Column	1	2	3	4	5	6	
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	
Sand	35%	30%	25%	20%	15%	10%	
Gravel	61%	66%	71%	76%	81%	86%	
Ca B	4%	4%	4%	4%	4%	4%	
Length (cm)	32	32	32	32	32	32	
Height of support layer	5	5	5	5	5	5	
							Sep 4th,
Starting Level (cm)	70	70	70	70	70	70	11:00 am
Ending Level (cm)	40	40	40	40	40.0	40.0	
Flow Volume (mL)	637.0	637.0	637.0	637.0	637.0	637.0	
Elapsed Time (s)	174	199	72	36	22	19	
Flow Velocity (seconds per mL)	5.80	6.63	2.40	1.20	0.73	0.63	
Flow Velocity (minutes per mL)	0.10	0.11	0.04	0.02	0.01	0.01	
Head at start (cm) = dist above end of treatment media	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist above end of treatment media	35.0	35.0	35.0	35.0	35.0	35.0	
Permeability (cm/s)	0.11385	0.0995	0.2751	0.550	0.9004	1.043	
Permeability (cm/s)	1.1E-01	1.0E-01	2.8E-01	5.5E-01	9.0E-01	1.0E+00	
increment of permeability	0.1	0.1	0.001	0.1	0.01	0.1	
Amt of time for increment	93	99	72	30	22	17	
delta time (sec)	81	100	0	6	0	2	
delta time (min)	1.4	1.7	0.0	0.1	0.0	0.0	
Column	1	2	3	4	5	6	Sep 4th,
Trmt Media Mass (g)	1000	1000	1000	1000	1000	1000	12:00 pm
Sand	35%	30%	25%	20%	25%	25%	
Gravel	61%	66%	71%	76%	71%	71%	
Ca B	4%	4%	4%	4%	4%	4%	
Length (cm)	32	32	32	32	32	32	
Height of support layer	5	5	5	5	5	5	

Starting Level (cm)	70	70	70	70	70	70	
Ending Level (cm)	40	40	40	40	40	40	
Flow Volume (mL)	637.0	637.0	637.0	637.0	637.0	637.0	
Elapsed Time (s)	152.0	184.0	69.0	34.0	403.0	182.0	
Flow Velocity (seconds per m	5.1	6.1	2.3	1.1	13.4	6.1	
Flow Velocity (minutes per m	0.1	0.1	0.0	0.0	0.2	0.1	
Head at start (cm) = dist abo	65.0	65.0	65.0	65.0	65.0	65.0	
Head at end (cm) = dist abov	35.0	35.0	35.0	35.0	35.0	35.0	
Permeability (cm/s)	0.1303	0.1077	0.2871	0.5826	0.0492	0.1088	
Permeability (cm/s)	1.30E-01	1.08E-01	2.87E-01	5.83E-01	4.92E-02	1.09E-01	
increment of permeability	0.1	0.1	0.0	0.1	0.0	0.1	
Amt of time for increment	86.0	95.4	68.8	29.0	334.9	94.9	
delta time (sec)	66.0	88.6	0.2	5.0	68.1	87.1	
delta time (min)	1.1	1.5	0.0	0.1	1.1	1.5	
			by media mixtures				
			Average 25%	0.1484	Permeability (cm/s)		
			Average 25%	0.1980	Permeability (cm/s)		
			Average ALL	0.1801	Permeability (cm/s)		

Appendix H:
Safety Plan – Field Testing

Safety Plan
S. Druschel
September 8, 2019
Revised September 24, 2019 to incorporate MSU Safety Officer Review Comments
Revised September 10, 2024 to pivot to new MnDOT contracts

Purpose: Faculty and student researchers will be in the field during winter conditions to:
1. Install and tend instruments (time lapse cameras, conductivity meters, light and weather recorders) that are monitoring roadway ditch snowmelt runoff conditions; and,
2. Sampling in-ditch snowmelt runoff water.

Instruments and sampling locations are proposed to be placed in ditch and on ditch side slope up to the Right of Way (ROW) line, approximately 40 or more feet from the traffic way.

Tending involves removing a "bird house" front, removing and replacing both a camera and a weather logger, then reading meters/logger by Bluetooth. Initial instrument sets will involve pounding in a fence pole and bolting instruments or bird house to pole, and will be done during October. Instrument removal will include bird house and post removal, and will likely be done during April.

Sampling involves filling sample containers (likely less than 200 mL in volume) for snowmelt and possibly taking tube snow samples.

Support for tending and sampling involves driving to sites, parking along a side road, walking or snowshoeing into the location.

Sites proposed for study are along:
- East-west oriented highways including US 14, MN 30, MN 68 and MN 19 in South Central and Southwest Minnesota;
- North-south oriented highways including MN 22, MN 83 and MN 15 in South Central Minnesota, and US 59, US 71, US 75 and MN 4 in Southwest Minnesota.
- All highways proposed for study are constructed and maintained by MnDOT.
- Highways have been selected for low-volume characteristics.

September 2024 update: Sites now include only MN 30 locations in the vicinity of Amboy and Mapleton, MN, and a test track at Fort Ripley (Minnesota) that does not have public access. Additionally, new work items are proposed that involve working near heavy construction equipment and snow plows; see section at end.

Safety Procedures:

1. Sites are approved for winter study by MnDOT after proposal by MSU Mankato.
2. Personnel wear Hi-Vis safety vests at all times when approaching or at sites, plus construction or snow boots. Insect repellant and sun lotion available for researcher personnel, if needed.
3. Personnel wear vehicle seat belts at all times the vehicle is moving.
4. Vehicle uses LED flashing bar light installed on top of car with lights turned on.
5. As vehicle approaches site, vehicle turns right off main (US or MN) highway onto near-side cross road, then pulls off to right on cross road. Checking behind and ahead for a no-traffic condition, turn signal is turned on and vehicle executes a three-point turn to turn around and become facing main highway.
    a. If site is accessible from side road (preferred), vehicle then parks along right side of side road with flashers activated (flashing bar already activated).
    b. If site must be accessed from main highway (mid-block drop off & pick up):
        i. Vehicle waits on side road until no traffic approaching on highway, then turns right and pulls out onto highway.
        ii. Vehicle then uses turn signal (flashing bar light already activated) and pulls onto right shoulder to stop and park, leaving vehicle running to support flashing bar operation. Passengers and gear discharge at instrument location, working from off-highway side. Gear is placed on side slope of roadway, beyond shoulder.
            1. Work then proceeds in ditch line, typically including installing or removing fence posts, installing or removing mounted instruments, changing batteries, downloading data, and water or snow sampling.
            2. When done, materials and samples are brought to off-highway side of vehicle, keeping vehicle between workers and highway. Loading is then done from adjacent to the vehicle into the vehicle from the off-highway side.
            3. Upon completion, driver checks for no nearby traffic (within 1 mile oncoming either direction), then when clear walks around car to enter driver's side front door.
        iii. Vehicle then checks for oncoming traffic, and when none, uses left turn signal to reenter the highway lane.
        iv. If necessary to reverse direction:
            1. Vehicle then drives to next crossroad, turns left, then when clear of traffic on side road executes a three-point turn.
            2. Vehicle then approaches main highway with right turn signal on and turns right when clear of oncoming traffic.

6. Researchers outside of vehicle will stay back and away from highway lanes until support vehicle stopped along roadway for pickup. Researchers on foot will be cognizant that

movement by them can cause traffic reactions, and such will not approach traffic lanes until pickup moment.

7. There will be no crossing of main highways on foot.
8. Winter gear provided to researchers who go into the field:
    a. Insulated boots, made for snow not construction conditions.
    b. Insulated hats (two per person)
    c. Insulated gloves (three pairs per person)
    d. Long underwear base layers, bottom and tops, for under clothes
    e. Wool sox
    f. Microfiber fleece mid layer
    g. Hooded sweatshirt
    h. Insulated warm up jacket, functions as wind shell over sweatshirt and fleece
    i. Hi Vis safety vest
    j. Snow pants, insulated
    k. Snowshoes with quick release bindings
9. Vehicle to be outfitted with snow shovel, GPS, and cell phone for winter navigation and ability to telephone a tow truck. GPS and cell phone chargers will be available, to keep electronics powered up. Flash lights/head lamps will be available.
10. Vehicle to be outfitted with winter snow tires from mid-November to early March, or longer, depending on temperatures. "All season tires" will not be allowed when daytime frost or roadway ice conditions are likely to occur.
11. Safety plan review will occur before setting out every field day. Items to be specifically reviewed will include:
    a. Driving technique;
    b. Highway safety with particular attention to turning, signaling, and observations of oncoming traffic;
    c. Pedestrian safety with particular attention to safety clothing, pedestrian movement, and pedestrian-traffic interaction; and,
    d. Winter safety with particular attention to slip and fall protection, and cold protection.

Figure 1. Typical location proposed for study; Sterling South Study Location: MN 30 about 5 miles east of Amboy. Treatment media and instrument location proposed for approximately 150 feet in front of camera location, beside small hill on right.

Figure 2. Typical off-highway parking at location proposed for study: MN 30 Eastbound about 4 miles west of US 169 (5 miles west of Amboy). View east from along MN 30 Eastbound side.

12. Should there be a medical situation needing attention, support vehicle may be used to transport person requiring care (because locations may be so far from MSU Mankato or likely available medical transport).
13. Locations and addresses of medical clinics in the areas of study:
    a. Mankato Clinic, 1230 East Main Street, Mankato
    b. Madelia Community Hospital, 121 Drew Avenue SE, Madelia

Work activities proposed (September 2024)

Salt Waterways project involves placing about 75 flow-through bags, each containing about 50 pounds of a treatment media, in a chevron formation across a stormwater ditch. Four locations are proposed (two installations each at two separate highway locations). Bags need to be filled, tied, loaded, then lifted to near installation, and installed. Removal will work in reverse order during the Spring. Specific activities include:

- Transporting 50 lb bags of clay to concrete redi mix plant;
- Observing and documenting mixing of treatment media in redi mix truck;
- Guiding location of discharge from redi mix truck (to be done at a MnDOT truck station material yard);
- Guiding MnDOT-operated payloader to pick up treatment media and load into MnDOT-operated hydraulic sand bag filler;
- Holding geotextile (flow-through) bags open under chute of hydraulic sand bag filler while filling (typically 50 lbs media);
- Moving filled bags to storage location, then tying with wire tie closure;
- Loading bucket of parked MnDOT-operated payloader with treatment media bags;
- Guiding placement of treatment media bags into MnDOT-operated dump truck;
- Guiding unloading of treatment media bags from MnDOT-operated dump truck to MnDOT-operated hydraulic excavator for lifting into ditch bottom;
- Guiding cast of treatment media bags from MnDOT-operated hydraulic excavator into ditch bottom.
- Arrangement of treatment media bags in ditch bottom to be conducive for treatment and flow.

During all operations with MnDOT-operated heavy equipment, personnel are to wear Hi-Vis safety vests at all times, leather gloves, Type II hard hats and construction boots. Wire tie tool is a "Kraft Tool GG310 Professional Tie Wire Twister with Wood Handle" designed to prevent repetitive motion issues. Work is proposed for October – November timeframe, such that ordinary work clothes will suffice.

Salt IV: Know Before The Snow project involves monitoring deicing of pavement using time lapse photography and digital thermography from before treatment to 3 hours after treatment.

Specific activities include: placement of cameras adjacent to test track, photographing of snow plow operation from location approximately 200 feet away from operation (clear of snow discharge and cast), and recovery of cameras. Work is proposed for -25 to -30 deg F ambient air conditions. See Item 8 above for cold weather personal protection equipment and procedures appropriate to proposed conditions.

Appendix I:
Instrumentation Plan

Instrumentation and Sampling Plan – Salt Waterways Project
S. Druschel
September 15, 2024

1.0. Overview

The field testing of the Salt Waterways project involves placing about 75 flow-through bags, each containing about 50 pounds of a treatment media, in a chevron formation across a stormwater ditch. The installed treatment-bag chevron will likely measure 6 to 9 inches high (above ditch bottom), 3 to 4 feet across (direction of ditch flow), and 25 to 30 feet long (ditch bottom plus side slopes). Four locations are proposed (two installations each at two separate highway locations) for Winter 2024-25, each location with a separate treatment-bag chevron.

To prevent damage to roadway slope turf and vegetation, the research team and MnDOT have agreed on a procedure to lift the treatment bags over the side slope and set them in the ditch bottom. Specifically, a MnDOT-operated hydraulic excavator will lift bags over the side slope from a MnDOT-operated dump truck parked on the highway shoulder. Research personnel will then arrange treatment media bags in ditch bottom to be conducive for treatment and flow. Removal will work in reverse order during the Spring (likely late March; dates set by timing of snow melt flows).

Bags will be filled, tied, loaded at an off-highway location (MnDOT Madelia truck station). Treatment media consists of a calcium-bentonite clay mixed with sand and gravel (fine and course aggregates).

2.0. Instrumentation and Sampling

Instruments are proposed to be placed in ditch bottom and on outside ditch side slope up to the Right of Way (ROW) line, approximately 40 or more feet from the traffic way. Instruments proposed include: time lapse cameras, conductivity meters, light and weather recorders to monitor roadway ditch snowmelt runoff conditions. Instrument tending will involve removing a "bird house" front, removing and replacing both a camera and a weather logger, then reading meters/logger by Bluetooth. Initial instrument sets will involve pounding in a fence pole and bolting instruments or bird house to pole, and will be done during October. Instrument removal will include bird house and post removal, and will likely be done during April.

Sampling locations are proposed for ditch bottom. Sampling involves filling sample containers (likely less than 200 mL in volume) for snowmelt and possibly taking tube snow samples.

Support for tending and sampling involves driving to sites, parking along a side road, walking or snowshoeing into the location. See safety procedures listed in Section 5 of this plan.

3.0. Sample Site Locations

Sites include four locations along MN 30 in the vicinity of Amboy and Mapleton (Figures 1 to 4).

1. Willow Creek: MN 30, Mile 127, approximately five miles west of Amboy, MN; Pleasant Mound Township, Blue Earth County. AADT 698 (2022).
    a. East location: South side of MN 30, approximately 2075 feet east of CSAH 40/499th Avenue crossroad. 43° 53' 41.31" N, 94° 15' 39.63" W. Estimated elevation 1021 feet. Figure 1.
    b. West location: South side of MN 30, approximately 1015 feet east of CSAH 40/499th Avenue crossroad. 43° 53' 41.28" N, 94° 15' 54.40" W. Estimated elevation 1023 feet. Figure 2.
2. Sterling: MN 30, Mile 137, approximately five miles east of Amboy, MN and six miles west of Mapleton, MN. Sterling Township, Blue Earth County. AADT 1118 (2023)
    a. North location: North side of MN 30, approximately 1685 feet southwest of County Road 151/119th Street crossroad and approximately 4700 feet northeast of CSAH 1/550th Avenue. 43° 53' 40.40" N, 94° 03' 45.75" W. Estimated elevation 995 feet. Figure 3.
    b. South location: South side of MN 30, approximately 1685 feet southwest of County Road 151/119th Street crossroad and approximately 4700 feet northeast of CSAH 1/550th Avenue. 43° 53' 44.88" N, 94° 03' 34.80" W. Estimated elevation 989 feet. Figure 4.

Figure 1. Willow Creek East Study Location: MN 30 about 5 miles west of Amboy. View east from eastbound side ditch line. Treatment media and instrument location proposed for space directly in front of second utility pole, approximately 500 feet from photographer location.

Figure 2. Willow Creek West Study Location: MN 30 about 5 miles west of Amboy. View east from eastbound side ditch line. Treatment media and instrument location proposed for space directly in front of camera location.

Figure 3. Sterling North Study Location: MN 30 about 5 miles east of Amboy. View east from westbound side ditch line. Treatment media and instrument location proposed for approximately 75 feet in front of camera location, beside small hill on left.

Figure 4. Sterling South Study Location: MN 30 about 5 miles east of Amboy. View east from eastbound side ditch line. Treatment media and instrument location proposed for approximately 150 feet in front of camera location, beside small hill on right.

4.0. Installation

Proposed Instrument Installation/Post Placement Procedures:

1. Gopher State One Call (GSOC) (Dig Safe) will be called to clear each location before any posts are driven below the ground. Researchers will maintain a conservative approach at all locations proposed, meaning utilities including buried telecom cables and perhaps water or gas pipelines are expected at each location until marked otherwise.
    a. Locations will be marked using triple pin flags wrapped with white flagging tape, to be easily identified as proposed MSU Mankato research location.
    b. GSOC will be directed using the mileage posts for the highways as well as cross streets and approximate offsets from pavement (or centerline, if desired).
2. Instruments will be mounted on U-post (fence posts) located within approximately 8 feet of the ROW line, typically 10 or more feet <u>beyond</u> (outside) the main highway ditch line.
3. U-posts will be installed as two pieces, each 6 feet long: a lower anchor piece driven to about 36 inches above grade, then an upper piece bolted to the lower piece. Total height will be about 8 feet above grade. Additional pieces may be bolted on to gain further height should snow drifts become deep.
4. One or two posts will be installed at each location, depending upon the need for cameras. If two posts are proposed, they will be located within approximately 10 feet of each other.
5. Cameras will be mounted within a "bird house" with a removable front, taking pictures through a "bird access hole". Cameras will be tended by removing the bird house front, attached with four Torx screws.
6. Weather loggers will be mounted on the back of the post, near ground level, using carabiners.
7. Light meter/loggers will be mounted horizontally, bolted down to a shelf bracket off the back of the post.
8. Conductivity meters will be set in the ditch line with a simple pin flag/wire anchor.
9. Initial instrument sets will involve pounding in a fence pole and bolting the upper post section, bird house and instruments to the pole, likely done during October.
10. Instrument removal will include bird house and post removal, specifically including lower sections, which will be jacked out of the ground using a hydraulic jack and a reaction block (4 x 4 x 12 inch wood block) if necessary. Removal will likely be done during April once frost is out of the ground.
11. Safety procedures approved for the research work will be followed at all times; a summary of key activities is provided below.

Appendix J:

Weather Record for Winter 2024 – 25

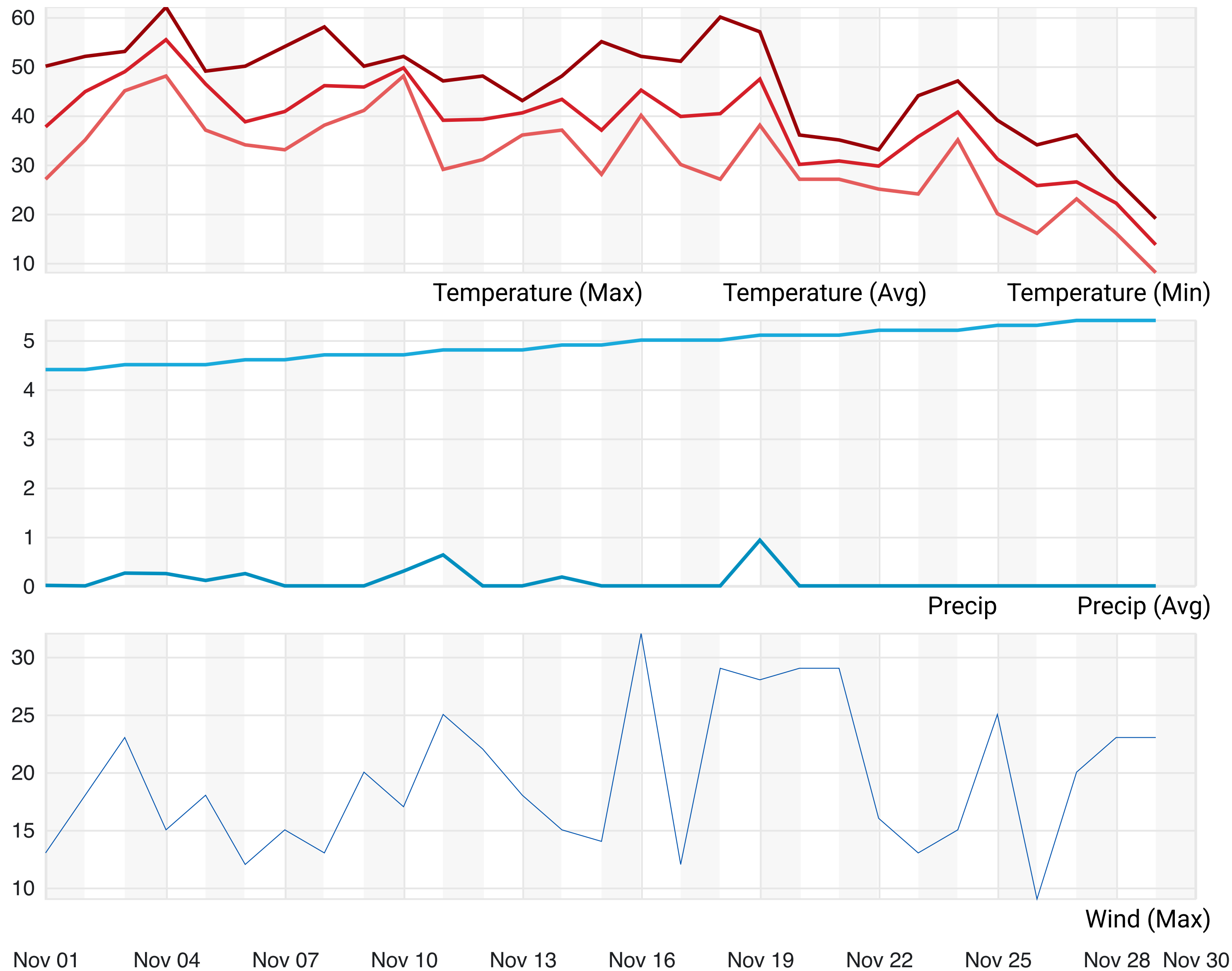
43.13 °N, **93.38** °W

Clear Lake, IA Weather History

48° MASON CITY MUNICIPAL AIRPORT STATION (/DASHBOARD/PWS/KIACLEAR32?CM_VEN=LOCALWX_PWSDASH) | CHANGE

November

2024



Summary

Temperature (°F)	Max	Average	Min	
Max Temperature	62	46.24	19	
Avg Temperature	55.39	38.33	13.68	
Min Temperature	48	31.14	8	
Dew Point (°F)	Max	Average	Min	
Dew Point	58	33.81	1	
Precipitation (in)	Max	Average	Min	Sum

Precipitation	0.93	0.10	0.00	2.92
Snowdepth	0.00	0.00	0.00	0.00
Wind (mph)	Max	Average	Min	▲
Wind	32	11.99	0	
Gust Wind	45	6.86	0	
Sea Level Pressure (in)	Max	Average	Min	▲
Sea Level Pressure	29.05	28.67	27.85	

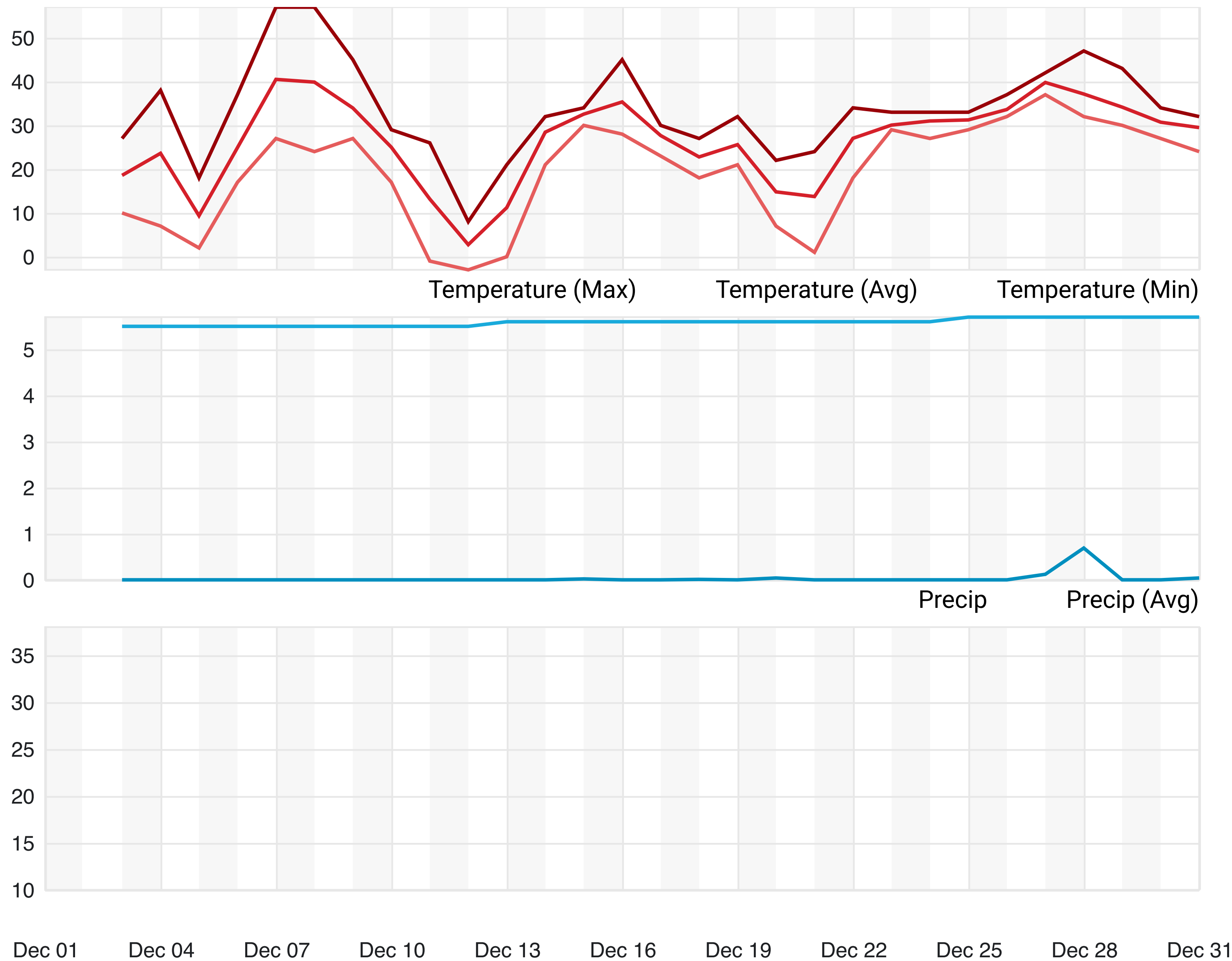
Daily Observations

Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)			
Nov	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	M
1	50	37.6	27	38	31.9	24	96	80.7	59	13	6.1	0	2
2	52	44.8	35	45	38.6	31	93	79.0	68	18	11.6	7	2
3	53	48.9	45	53	48.1	44	100	97.0	93	23	13.9	7	2
4	62	55.4	48	58	53.5	46	100	93.8	82	15	9.4	6	2
5	49	46.4	37	47	44.4	35	97	93.2	86	18	12.4	6	2
6	50	38.7	34	40	36.7	33	100	93.2	66	12	5.1	0	2
7	54	40.8	33	43	37.3	33	100	88.4	57	15	6.0	0	2
8	58	46.0	38	42	37.9	36	93	74.7	49	13	7.0	0	2
9	50	45.8	41	46	42.3	36	97	88.2	76	20	13.5	5	2
10	52	49.7	48	49	46.6	43	100	89.5	77	17	10.7	0	2
11	47	39.0	29	42	32.7	27	93	78.8	59	25	14.5	3	2
12	48	39.2	31	37	32.4	26	89	77.2	66	22	16.3	8	2

13	43	40.5	36	42	38.4	34	100	92.1	89	18	11.2	0	2
14	48	43.3	37	42	40.6	35	100	90.5	76	15	9.7	0	2
15	55	37.0	28	44	34.5	27	100	91.7	64	14	6.5	0	2
16	52	45.1	40	43	40.8	37	93	85.2	71	32	18.1	9	2
17	51	39.8	30	42	34.8	29	100	83.6	61	12	7.3	0	2
18	60	40.4	27	58	39.4	26	100	96.5	90	29	9.7	0	2
19	57	47.4	38	54	42.3	27	96	82.7	65	28	19.2	13	2
20	36	30.0	27	28	23.9	19	89	78.1	64	29	20.8	15	2
21	35	30.7	27	29	26.5	23	93	84.7	76	29	22.6	15	2
22	33	29.7	25	29	27.2	23	96	90.6	85	16	9.2	0	2
23	44	35.7	24	35	31.0	23	96	83.9	68	13	5.1	0	2
24	47	40.7	35	39	36.0	32	93	83.7	73	15	9.7	6	2
25	39	31.1	20	37	26.2	13	96	82.5	61	25	18.4	8	2
26	34	25.7	16	23	17.3	12	84	71.2	52	9	5.6	0	2
27	36	26.5	23	24	20.6	19	88	78.8	61	20	11.8	3	2
28	27	22.1	16	19	15.0	7	85	74.4	65	23	17.1	12	2
29	19	13.7	8	10	3.5	1	77	64.7	50	23	19.5	16	2

December

2024



Summary

Temperature (°F)	Max	Average	Min
Max Temperature	57	33.69	8
Avg Temperature	40.5	26.49	2.75
Min Temperature	37	19.34	-3

Dew Point (°F)	Max	Average	Min
Dew Point	42	21.04	-11

Precipitation (in)	Max	Average	Min	Sum
Precipitation	0.69	0.03	0.00	0.92

Snowdepth	0.00	0.00	0.00	0.00

Wind (mph)	Max	Average	Min
Wind	38	12.11	0
Gust Wind	56	5.94	0

Sea Level Pressure (in)	Max	Average	Min
Sea Level Pressure	29.23	28.76	28.19

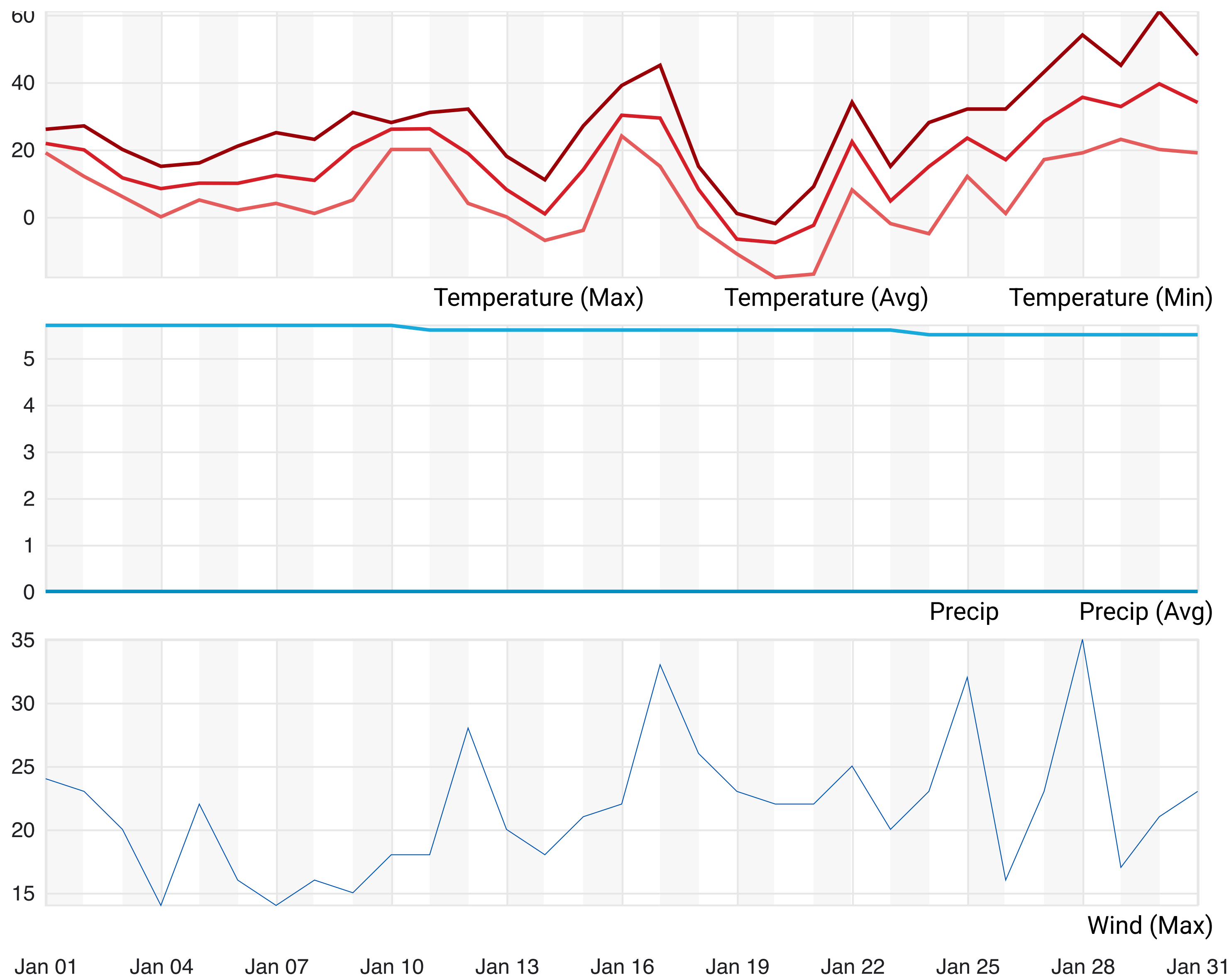
Daily Observations

Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)		
Dec	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
3	27	18.6	10	19	13.2	7	88	80.0	71	17	10.6	5
4	38	23.6	7	31	15.5	-3	89	71.7	58	38	26.8	14
5	18	9.4	2	7	2.0	-3	80	72.5	62	26	13.1	0
6	37	24.9	17	16	12.0	7	75	59.0	41	15	9.2	3
7	57	40.5	27	29	24.4	19	72	54.3	34	20	13.1	6
8	57	39.9	24	39	29.1	20	88	67.1	41	24	10.9	0
9	45	34.0	27	29	24.8	20	89	70.6	46	32	18.0	9
10	29	25.0	17	22	18.5	13	88	76.6	69	28	12.1	0
11	26	13.2	-1	22	5.0	-9	88	70.3	51	31	19.7	7
12	8	2.8	-3	-6	-8.9	-11	69	59.0	48	16	7.6	0
13	21	11.2	0	7	-2.5	-8	72	55.5	40	22	14.2	5
14	32	28.4	21	32	26.2	12	100	91.3	68	21	14.6	6
15	34	32.6	30	34	32.1	30	100	98.1	92	20	10.7	0

16	45	35.4	28	36	31.2	24	100	86.1	60	26	13.8	8
17	30	27.7	23	27	23.6	19	92	84.6	72	25	10.2	3
18	27	22.8	18	24	18.7	14	96	84.8	74	16	11.9	0
19	32	25.6	21	30	22.7	16	96	88.8	81	28	15.8	0
20	22	14.8	7	19	10.2	2	89	82.0	77	24	13.7	3
21	24	13.7	1	18	9.5	-3	89	83.2	73	12	6.5	0
22	34	27.0	18	29	22.5	15	92	83.2	78	22	14.4	9
23	33	30.1	29	29	26.1	25	89	85.4	79	18	11.7	0
24	33	31.0	27	28	26.5	24	89	83.3	75	14	5.8	0
25	33	31.2	29	32	29.5	25	100	93.4	82	16	10.6	6
26	37	33.6	32	37	33.1	30	100	98.1	93	12	7.9	5
27	42	39.8	37	42	39.4	37	100	98.5	93	12	7.4	0
28	47	37.2	32	42	36.5	32	100	97.8	83	17	10.1	0
29	43	34.2	30	38	33.2	29	100	96.5	82	10	5.3	0
30	34	30.7	27	34	29.6	26	100	95.3	88	17	5.7	0
31	32	29.5	24	31	26.1	17	100	87.5	66	26	20.0	10

Clear Lake, IA Weather History ★ 🏠

January | 2025



Summary

Temperature (°F)	Max	Average	Min
Max Temperature	61	27.42	-2
Avg Temperature	39.5	16.85	-7.64
Min Temperature	24	6.1	-18

Dew Point (°F)	Max	Average	Min
Dew Point	32	7.08	-26

Precipitation (in)	Max	Average	Min	Sum

Precipitation	0.00	0.00	0.00	0.00
Snowdepth	0.00	0.00	0.00	0.00
Wind (mph)	Max	Average	Min	▲
Wind	35	13.37	0	
Gust Wind	48	6.85	0	
Sea Level Pressure (in)	Max	Average	Min	▲
Sea Level Pressure	29.25	28.81	28.21	

Daily Observations

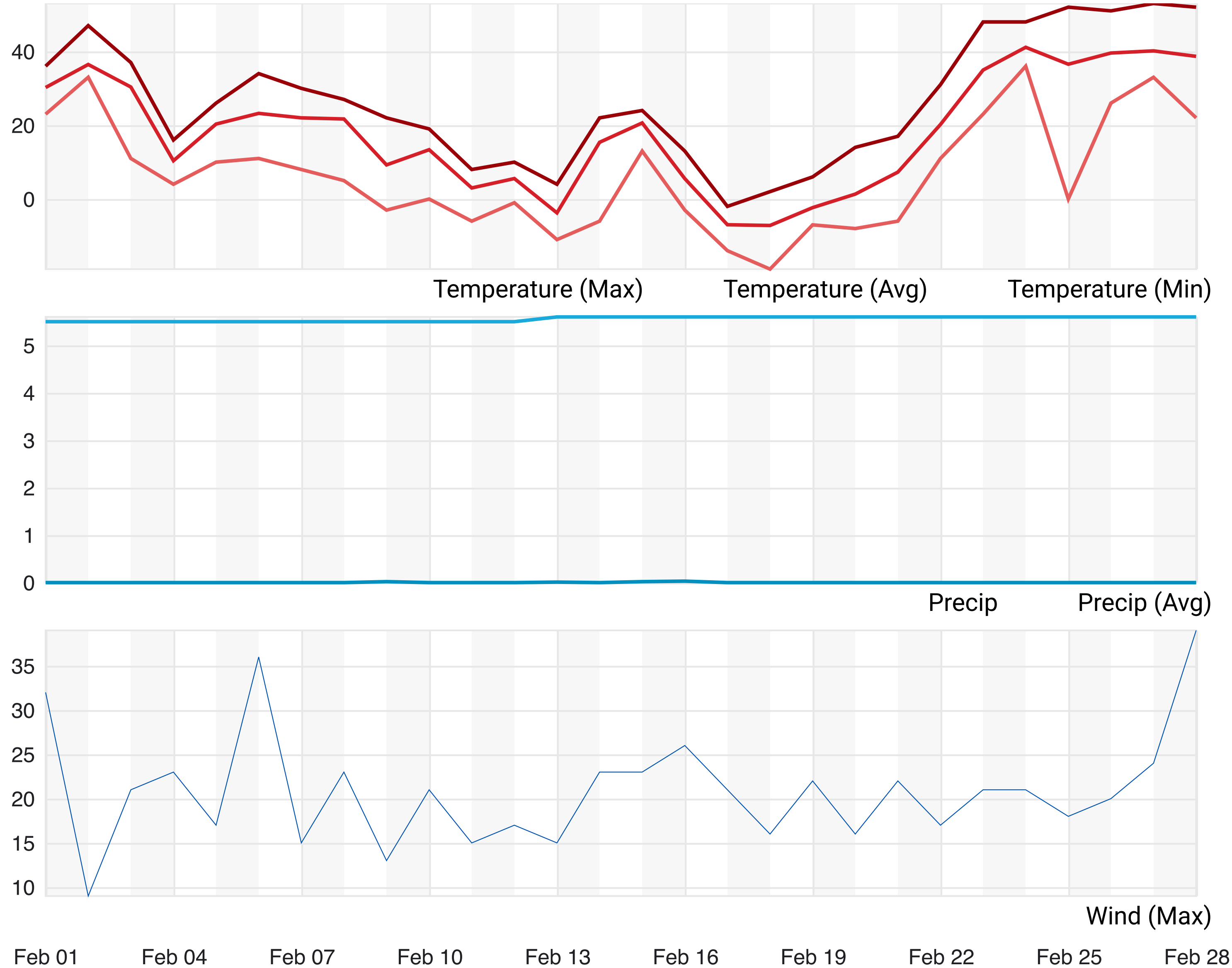
Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)		
Jan	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
1	26	21.8	19	18	14.3	11	81	73.1	65	24	13.8	3
2	27	19.9	12	16	13.0	6	84	75.1	56	23	10.7	3
3	20	11.6	6	6	4.0	0	81	72.3	55	20	15.5	12
4	15	8.4	0	1	-1.3	-5	83	66.0	51	14	10.8	7
5	16	10.0	5	2	-4.6	-9	62	52.0	39	22	15.2	10
6	21	10.0	2	6	-0.4	-5	80	63.7	48	16	10.8	5
7	25	12.3	4	10	2.1	-4	80	65.0	42	14	7.0	3
8	23	10.8	1	7	2.5	-4	84	70.3	48	16	8.7	6
9	31	20.4	5	23	15.2	2	88	80.8	64	15	9.9	6
10	28	26.0	20	25	20.6	13	92	80.2	71	18	11.5	6
11	31	26.1	20	25	19.0	13	82	74.8	63	18	10.1	0
12	32	18.8	4	29	12.0	-3	93	74.8	59	28	20.0	10

13	18	8.1	0	6	-0.5	-6	81	68.9	50	20	13.6	7
14	11	0.9	-7	-1	-6.4	-13	80	72.0	59	18	10.5	0
15	27	14.0	-4	22	6.7	-8	84	73.3	57	21	12.4	0
16	39	30.2	24	25	23.1	19	91	75.8	55	22	14.4	3
17	45	29.3	15	30	20.6	7	85	70.5	49	33	20.9	9
18	15	8.2	-3	7	-3.9	-12	77	59.5	36	26	23.0	15
19	1	-6.6	-11	-11	-15.8	-18	74	65.0	47	23	16.0	6
20	-2	-7.6	-18	-11	-17.4	-26	75	62.7	49	22	14.5	6
21	9	-2.5	-17	-4	-15.2	-25	75	56.7	38	22	14.2	7
22	34	22.3	8	22	13.9	0	85	70.5	56	25	15.6	8
23	15	4.7	-2	1	-5.2	-11	80	65.3	41	20	12.1	0
24	28	14.9	-5	18	6.5	-12	81	70.0	55	23	9.5	0
25	32	23.4	12	20	13.0	5	85	66.0	43	32	18.3	10
26	32	17.0	1	9	3.9	-3	88	59.8	32	16	10.3	3
27	43	28.3	17	21	10.9	4	81	50.7	25	23	16.2	10
28	54	35.5	19	26	21.3	17	92	61.6	28	35	18.2	5
29	45	32.8	23	24	21.0	16	81	63.3	40	17	10.3	0
30	61	39.5	20	32	24.4	15	88	58.5	27	21	8.2	0
31	48	34.0	19	26	22.3	15	85	65.0	36	23	12.5	0

Clear Lake, IA Weather History

February

2025



Summary

Temperature (°F)	Max	Average	Min
Max Temperature	53	26.68	-2
Avg Temperature	41.13	18.11	-7.17
Min Temperature	36	6.61	-19

Dew Point (°F)	Max	Average	Min
Dew Point	39	10.25	-24

Precipitation (in)	Max	Average	Min	Sum

	Max	Average	Min	
Precipitation	0.03	0.00	0.00	0.08
Snowdepth	0.00	0.00	0.00	0.00

Wind (mph)	Max	Average	Min
Wind	39	12.79	0
Gust Wind	60	4.6	0

Sea Level Pressure (in)	Max	Average	Min
Sea Level Pressure	29.33	28.83	28.28

Daily Observations

Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)		
Feb	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
1	36	30.2	23	31	24.1	19	96	78.4	62	32	19.0	8
2	47	36.5	33	36	33.4	31	100	89.4	66	9	5.6	0
3	37	30.4	11	34	26.3	3	93	85.1	70	21	16.4	7
4	16	10.4	4	0	-3.5	-8	70	54.3	41	23	15.5	10
5	26	20.3	10	25	13.5	-1	96	75.5	56	17	11.1	6
6	34	23.2	11	24	13.8	1	92	70.2	32	36	17.1	8
7	30	22.0	8	10	5.4	1	73	50.3	36	15	7.3	0
8	27	21.7	5	21	14.9	-1	88	75.8	51	23	13.9	5
9	22	9.3	-3	10	1.6	-7	82	71.7	58	13	7.2	0
10	19	13.4	0	14	7.8	-5	84	78.6	68	21	10.4	0
11	8	3.0	-6	3	-6.2	-14	80	65.8	60	15	10.2	0
12	10	5.5	-1	3	-0.3	-6	84	77.1	69	17	13.4	8

13	4	-3.8	-11	-5	-10.3	-16	83	74.0	60	15	9.9	6
14	22	15.4	-6	19	10.2	-12	89	80.3	70	23	15.8	5
15	24	20.6	13	19	16.6	8	92	84.7	74	23	13.1	6
16	13	5.5	-3	7	-2.1	-8	80	71.1	61	26	19.1	10
17	-2	-7.0	-14	-8	-15.8	-20	79	65.8	56	21	15.4	9
18	2	-7.2	-19	-9	-15.2	-24	78	68.5	60	16	11.6	7
19	6	-2.3	-7	-5	-10.5	-14	72	68.3	60	22	14.9	12
20	14	1.3	-8	4	-5.3	-14	83	74.0	64	16	9.6	0
21	17	7.3	-6	2	-2.5	-10	83	65.6	49	22	11.8	0
22	31	20.2	11	24	13.3	2	89	74.8	64	17	9.8	5
23	48	35.0	23	36	27.9	19	88	75.9	63	21	10.0	3
24	48	41.1	36	39	34.4	30	89	77.4	68	21	11.0	0
25	52	36.5	0	36	30.0	0	96	71.2	0	18	9.4	3
26	51	39.6	26	39	32.7	24	92	77.4	61	20	9.9	0
27	53	40.2	33	31	28.2	25	85	65.2	37	24	14.9	6
28	52	38.7	22	33	24.5	14	72	57.7	43	39	24.6	15

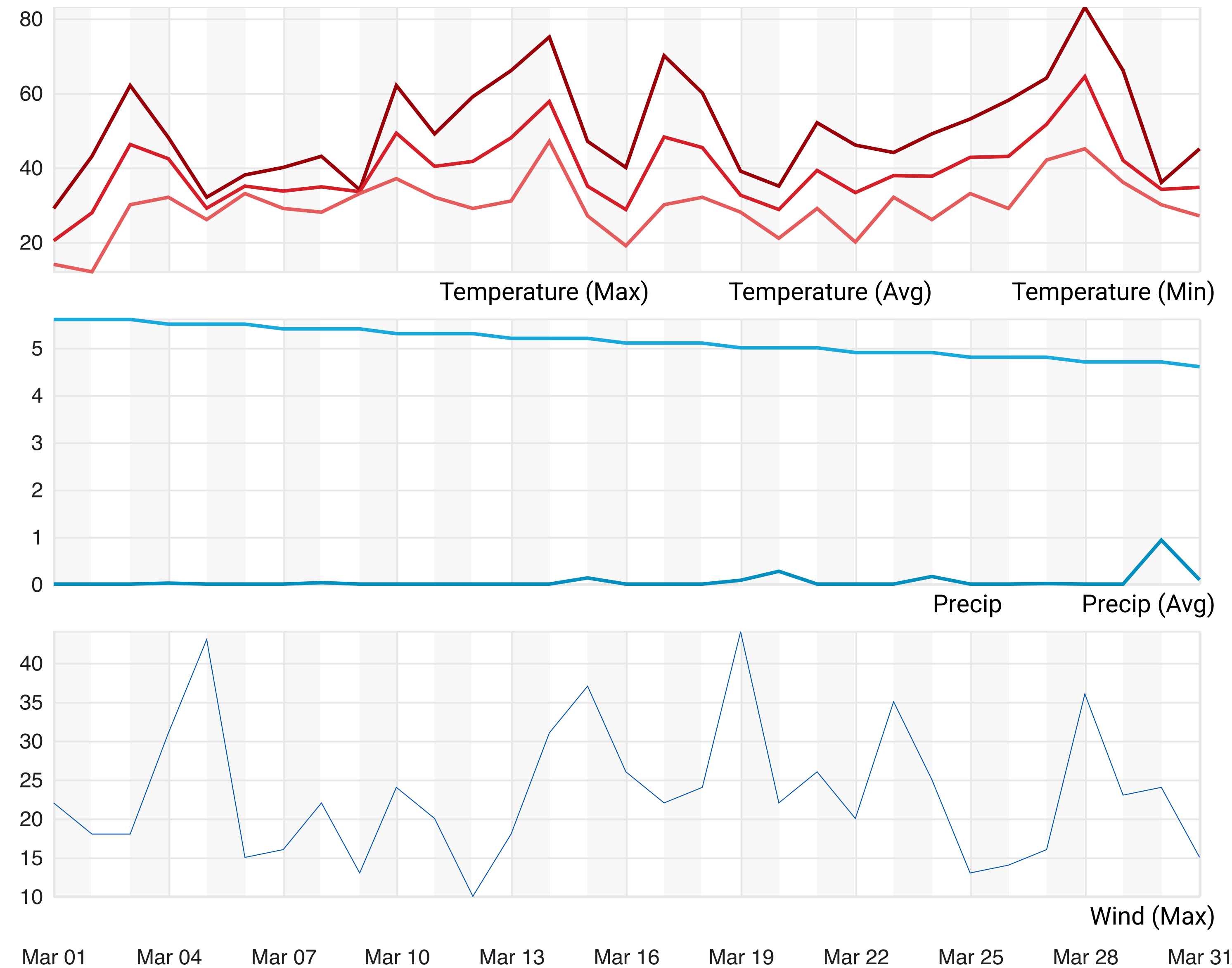
43.13 °N, **93.38** °W

Clear Lake, IA Weather History ★

51° MASON CITY MUNICIPAL AIRPORT STATION (/DASHBOARD/PWS/KIACLEAR32?CM_VEN=LOCALWX_PWSDASH) | CHANGE

March

2025



Summary

Temperature (°F)	Max	Average	Min	▲
Max Temperature	83	50.55	29	
Avg Temperature	64.38	39.29	20.35	
Min Temperature	47	29.65	12	

Dew Point (°F)	Max	Average	Min	▲
Dew Point	55	29.66	-1	

Precipitation (in)	Max	Average	Min	Sum	▲

Precipitation	0.93	0.06	0.00	1.72
Snowdepth	0.00	0.00	0.00	0.00
Wind (mph)	Max	Average	Min	▲
Wind	44	14.45	0	
Gust Wind	55	9.67	0	
Sea Level Pressure (in)	Max	Average	Min	▲
Sea Level Pressure	28.96	28.5	27.68	

Daily Observations

Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)		
Mar	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
1	29	20.4	14	14	6.3	-1	81	57.4	29	22	11.1	0
2	43	27.8	12	17	12.2	5	84	55.6	31	18	9.7	0
3	62	46.2	30	39	30.4	17	80	55.2	41	18	12.8	7
4	48	42.3	32	46	39.5	30	97	90.1	76	31	13.6	3
5	32	29.1	26	30	26.8	24	96	91.1	88	43	35.7	29
6	38	35.0	33	31	28.6	26	89	77.9	68	15	5.8	0
7	40	33.7	29	34	30.2	23	96	87.8	65	16	8.4	0
8	43	34.8	28	31	26.2	21	79	71.4	55	22	15.3	10
9	34	33.5	33	28	28.0	28	82	80.5	79	13	12.5	12
10	62	49.2	37	44	37.5	30	82	65.2	44	24	12.4	5
11	49	40.3	32	39	28.5	25	85	64.3	43	20	12.1	6
12	59	41.6	29	42	29.7	22	79	64.5	41	10	4.5	0

13	66	48.0	31	46	37.5	29	92	69.5	47	18	9.5	0
14	75	57.7	47	51	47.3	41	97	70.9	40	31	16.4	6
15	47	35.0	27	47	29.4	18	100	80.4	69	37	22.0	5
16	40	28.7	19	23	17.2	12	78	63.5	45	26	16.3	3
17	70	48.2	30	39	29.4	20	79	51.0	30	22	15.2	7
18	60	45.3	32	39	33.3	28	92	65.3	44	24	15.6	3
19	39	32.5	28	31	28.9	19	96	86.7	69	44	29.2	17
20	35	28.7	21	25	20.7	15	79	72.1	61	22	12.9	7
21	52	39.2	29	37	28.4	14	86	65.7	51	26	19.3	10
22	46	33.3	20	31	20.7	12	74	60.2	50	20	11.5	0
23	44	37.8	32	38	30.1	24	89	74.1	62	35	22.4	9
24	49	37.6	26	33	26.7	22	84	66.3	46	25	13.4	0
25	53	42.7	33	36	27.0	19	96	57.8	29	13	7.3	0
26	58	43.0	29	38	32.1	28	96	70.0	36	14	8.3	3
27	64	51.6	42	46	39.9	35	80	65.6	48	16	12.5	0
28	83	64.4	45	55	49.9	43	93	63.9	36	36	18.8	6
29	66	41.9	36	55	39.0	35	97	90.4	68	23	15.4	9
30	36	34.1	30	35	32.3	26	100	93.0	82	24	18.2	14
31	45	34.7	27	28	26.0	25	92	72.3	48	15	10.0	0

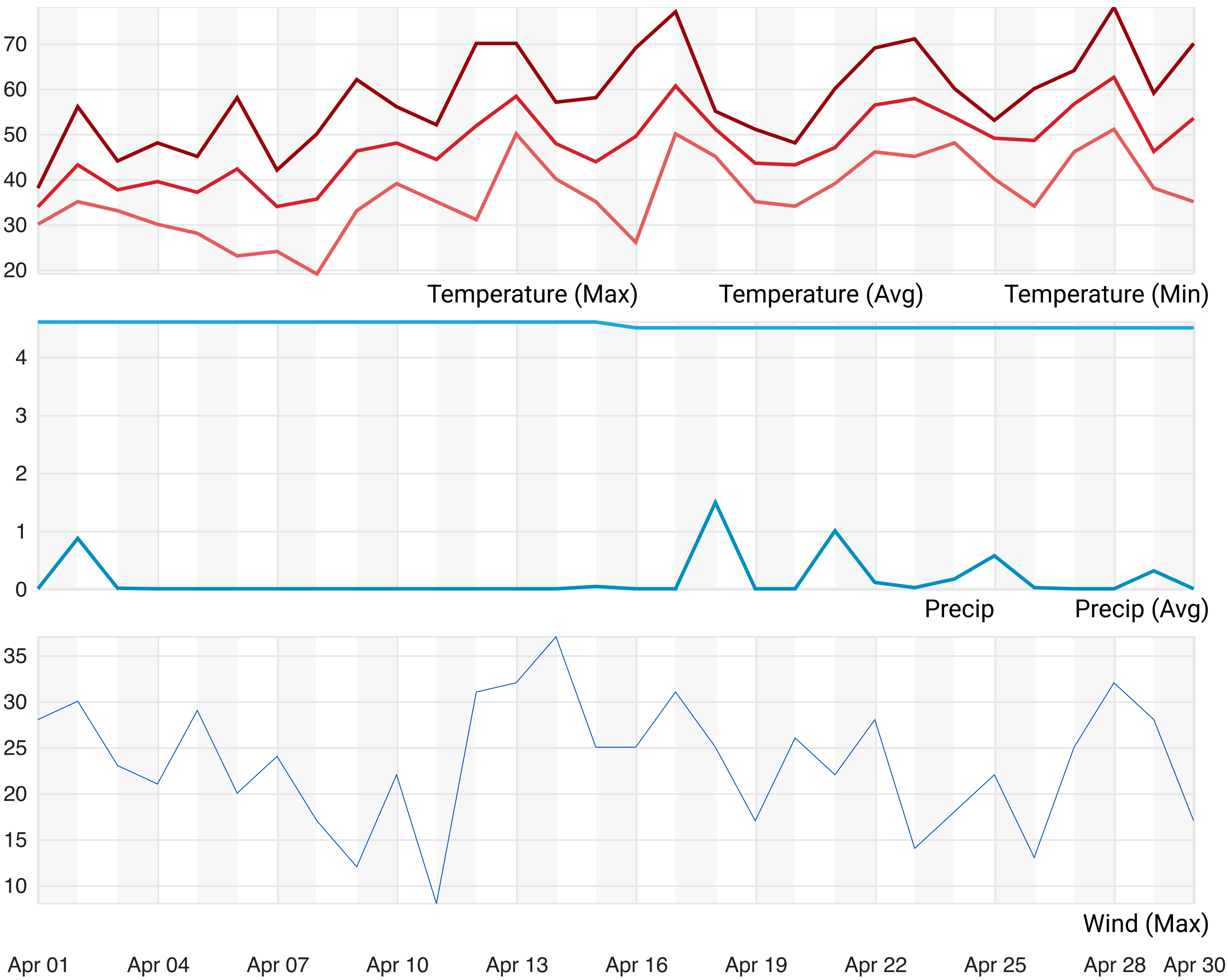
43.13 °N, **93.38** °W

Clear Lake, IA Weather History ★

48° MASON CITY MUNICIPAL AIRPORT STATION (/DASHBOARD/PWS/KIACLEAR32?CM_VEN=LOCALWX_PWSDASH) | CHANGE

April

2025



Summary

Temperature (°F)	Max	Average	Min	▲
Max Temperature	78	58.33	38	
Avg Temperature	62.51	47.39	33.85	
Min Temperature	51	36.57	19	

Dew Point (°F)	Max	Average	Min	▲
Dew Point	66	35.85	8	

Precipitation (in)	Max	Average	Min	Sum	▲

Precipitation	1.49	0.15	0.00	4.61
Snowdepth	0.00	0.00	0.00	0.00
Wind (mph)	Max	Average	Min	▲
Wind	37	13.75	0	
Gust Wind	49	10.75	0	
Sea Level Pressure (in)	Max	Average	Min	▲
Sea Level Pressure	29.03	28.68	27.93	

Daily Observations

Time	Temperature (°F)			Dew Point (°F)			Humidity (%)			Wind Speed (mph)		
Apr	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
1	38	33.9	30	34	29.4	22	96	84.0	66	28	20.5	6
2	56	43.1	35	52	39.5	29	97	87.5	73	30	18.5	3
3	44	37.6	33	33	29.5	27	83	72.7	60	23	13.2	0
4	48	39.4	30	37	32.6	27	92	77.5	61	21	6.8	0
5	45	37.1	28	35	23.7	15	87	62.4	31	29	19.6	5
6	58	42.2	23	27	22.3	17	82	49.3	27	20	10.2	0
7	42	33.9	24	29	14.8	8	73	47.8	26	24	15.8	3
8	50	35.6	19	18	14.1	11	85	46.2	22	17	6.7	0
9	62	46.2	33	33	28.0	19	70	50.5	34	12	7.8	3
10	56	48.0	39	43	38.8	32	83	70.9	60	22	14.5	5
11	52	44.3	35	38	35.5	30	86	72.6	50	8	4.0	0
12	70	51.8	31	40	35.6	27	89	58.9	31	31	15.7	7

13	70	58.3	50	49	42.7	38	63	56.6	46	32	14.5	0
14	57	47.8	40	39	33.6	29	76	59.2	36	37	24.3	12
15	58	43.8	35	33	27.2	19	79	56.8	23	25	17.7	0
16	69	49.4	26	30	26.8	20	81	46.6	22	25	13.5	0
17	77	60.6	50	56	47.1	31	96	63.6	40	31	15.7	0
18	55	51.0	45	52	46.8	32	100	86.2	59	25	15.8	0
19	51	43.5	35	35	30.2	27	83	61.7	39	17	9.7	3
20	48	43.1	34	44	39.5	29	96	87.4	60	26	16.6	0
21	60	47.0	39	46	40.3	36	96	79.5	51	22	14.8	3
22	69	56.4	46	52	45.6	40	89	70.3	36	28	10.7	0
23	71	57.8	45	55	48.3	40	87	72.1	45	14	6.9	0
24	60	53.6	48	53	46.4	41	93	77.2	67	18	11.5	6
25	53	49.0	40	47	45.0	37	93	86.3	71	22	15.3	5
26	60	48.5	34	41	37.2	31	96	67.4	44	13	9.8	3
27	64	56.6	46	51	44.3	39	81	64.1	51	25	18.5	8
28	78	62.5	51	66	57.2	47	93	83.3	64	32	18.9	5
29	59	46.1	38	42	35.3	31	86	68.9	36	28	15.1	0
30	70	53.5	35	49	38.1	31	89	60.8	30	17	9.9	0

Appendix K:
Ditch Water Chloride Concentration Analyses

CHLORIDE TESTS (Direct Collect)

Date Collected	Duplicate Sample #	Willow Creek West: West Well (Untreated)	Willow Creek West: East Well (Treated)		Willow Creek East: East Well (Untreated)	Willow Creek East: West Well (Treated)		Sterling North: West Well (Untreated)	Sterling North: East Well (Treated)		Sterling South: West Well (Untreated)	Sterling South: East Well (Treated)
3/11/25	1	500	200		150	175		175	175		BDL 50	70
	2										BDL 51	70
	3											
3/20/25	1	Over 500	Over 500									
	2	250	450		Too Dry/No data Collected	Too Dry/No data Collected		75	70		125	150
	3	400										
3/20/2025 Mixed	1	350	500					> 500	65		150	150
For these trials, we created turbelence to	2	Over 500	400					BDL 250				
distributed the sediment that was	3							80				

PAPER TOWEL CHLORIDE TESTS

Paper Towel Weights:	2.3	grams
	2.3	grams
	2.3	grams

		Willow Creek West: West Well (Untreated)	Willow Creek West: East Well (Treated)		Willow Creek East: East Well (Untreated)	Willow Creek East: West Well (Treated)		Sterling North: West Well (Untreated)	Sterling North: East Well (Treated)		Sterling South: West Well (Untreated)	Sterling South: East Well (Treated)
Combined Weight: 3/11/2025 (grams)					275.4	286.8		325.6	325.3		317.7	327.6
Jar Weight Empty (Grams)					151.8	150.5		193.8	193		194.3	192.3
Starting Water (100 Grams)					100	100		100	100		100	100
Paper Towel Weight (2.3 Grams					2.3	2.3		2.3	2.3		2.3	2.3
Water Mass Collected		No sample collected	No sample collected		21.3	34		29.5	30		21.1	33
Total Water Mass					121.3	134		129.5	130		121.1	133
Sample Proportion					17.560%	25.373%		22.780%	23.077%		17.424%	24.812%
Measured Conc					BDL 50	BDL 50		50	50		BDL 50	BDL 50
Corrected Concentration (ppm)					BDL 50	BDL 50		219	217		BDL 50	BDL 50

		Willow Creek West: West Well (Untreated)	Willow Creek West: East Well (Treated)		Willow Creek East: East Well (Untreated)	Willow Creek East: West Well (Treated)		Sterling North: West Well (Untreated)	Sterling North: East Well (Treated)		Sterling South: West Well (Untreated)	Sterling South: East Well (Treated)
Combined Weight: 3/07/2025 (Snowy Samples) (grams)		258.8	282.6		263.8	259.3		279.7	262.2		263.8	260.3
Jar Weight Empty (Grams)		151.4	151.8		151.8	150.8		152	150.8		150	150.3
Starting Water (100 Grams)		100	100		100	100		100	100		100	100
Paper Towel Weight (2.3 Grams		2.3	2.3		2.3	2.3		2.3	2.3		2.3	2.3
Water Mass Collected		5.1	28.5		9.7	6.2		25.4	9.1		11.5	7.7
Total Water Mass		105.1	128.5		109.7	106.2		125.4	109.1		111.5	107.7
Sample Proportion		4.85%	22.18%		8.84%	5.84%		20.26%	8.34%		10.31%	7.15%
Measured Conc		75	500		65	BDL 50		113	65		50	BDL 50
Corrected Concentration (ppm)		1546	2254		735	BDL 50		558	779		485	BDL 50

Chloride Testing of Ditch Waters		
Salt Waterways		
March, 2025		
S. Druschel	Sampling, Testing and Descriptions by Nolan Beckmann and Derek Krumwiede'	
Site Water/Snow Observations		
3/7/25	Upstream	Downstream
Sterling North		
Sterling South		
Willow Creek East		
Willow Creek West		
3/11/25		
Sterling South	Mostly water. Water did not overtop bags. No overflow to sides. Depth of about 9-12" at deepest.	Significantly less water. Water was at grass height, possibly flowing underneath bag.
Sterling North	Mostly Snow with some water; more like slush consistency with some water. Snow overtopped some of the bags, but couldn't destinctly find water overflow.	Equal amount of snow, but less moisture compared to upstream.
Willow Creek East	Mostly Water with about 3/4 depth of snow. Water overflowing through bag like small, partially open faucet. Water flowing around bags on field side	Small amounts of snow and small stream of water. Noticeably less water compared to upstream end.
Willow Creek West	Mostly Snow with Water up to and overflowing bags to Downstream. Flowing Through missing bag in top center. About equal amounts of water on each side of bags	Mostly Snow with water up to and overflowing bags from Upstream. About equal amounts of water on each side of bags
3/20/25		
Sterling South		
Sterling North		
Willow Creek East		
Willow Creek West		