Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 06-R26	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Potential Use of Reverse Osmosis in Managing Saltwater Waste Collected at Road-Salt Storage Facilities		5. Report Date March 2006
		6. Performing Organization Code
7. Author(s) G. Michael Fitch, Vinka O. Craver, and James A. Smith		8. Performing Organization Report No. VTRC 06-R26
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 72990
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	FHWA P.O. Box 10249 Richmond, VA 23240	13. Type of Report and Period Covered Final
		14. Sponsoring Agency Code
15. Supplementary Notes		

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Field and laboratory tests were conducted using RO to treat stormwater containing high levels of NaCl. The results of these tests suggest that RO is a feasible method to reduce the levels of Cl to less than 250 mg/L for nearly all initial levels of NaCl found in VDOT's stormwater ponds. However, the RO system tested would not be capable of reducing Cl levels to 25 mg/L for all NaCl concentrations found throughout the state.

Overall, although RO proved to be quite successful at reducing the levels of Cl, pretreating the stormwater to reduce the turbidity levels of the runoff water before it entered the RO system was very difficult, but achievable.

17 Key Words reverse osmosis, chloride, salt water, runoff		18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

POTENTIAL USE OF REVERSE OSMOSIS IN MANAGING SALTWATER WASTE COLLECTED AT ROAD-SALT STORAGE FACILITIES

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Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

March 2006
VTRC 06-R26

DISCLAIMER

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INTRODUCTION

Background

The Virginia Department of Transportation (VDOT) is responsible for maintaining more than 57,000 miles of roadway. The implementation of VDOT's anti-icing program comprises a large part of this maintenance effort. In fiscal year 2003, VDOT purchased more than 570,000 tons of NaCl. This salt, along with various other anti-icing chemicals, is stored at each VDOT residency and area headquarters, at least one of which is located in every county. In total, salt is stored at more than 300 locations throughout the state. Most of the storage facilities are composed of a building used to stockpile the chemicals, an adjacent impermeable pad that serves as a loading area for trucks, and a stormwater storage pond or collection basin. Figure 1 provides an image of a typical salt storage facility. The pad is designed to contain any chemicals that may be spilled during the loading process; the runoff from this area is directed to and stored in the nearby stormwater pond. The pond itself is designed to be impermeable to prevent infiltration of the water containing varying concentrations of anti-icing chemicals.

Evaporation rates for the ponded water are small compared to the volume of water collected,[1,2] and allowing the stormwater ponds containing saltwater to overtop and infiltrate has obvious adverse environmental implications, ranging from salt stress on surrounding vegetation to groundwater contamination. As a consequence, VDOT has been forced to dispose of the saltwater by one of three methods: (1) connecting directly to a publicly owned treatment works (POTW) system, (2) hiring an outside contractor to pump and remove the salt-laden water, or (3) applying the saltwater to gravel roads. Each option has significant shortcomings. First, most of the state has few gravel roads, thereby all but eliminating the option of road spraying. As for

Figure 1. Typical Salt Storage Structure, Loading Pad, and Stormwater Runoff Collection Pond

the other two options, the associated costs are very high because of expensive connection and disposal fees and hauling rates. In addition, POTW systems (especially the smaller capacity facilities) are becoming increasingly reluctant to accept saltwater because the systems are not designed to remove salt. Large influxes of NaCl can disrupt the sensitive chemical and biological reactions that make these facilities effective at removing more typical wastes.

Earlier Research

To address the problem of saltwater collection and disposal, researchers at the Virginia Transportation Research Council and the University of Virginia undertook a study to define more fully the extent of VDOT's saltwater collection, recommend ways of reducing the volumes collected, and identify potential methods of water treatment.[1] During January, February, and March of 2004, water samples from 45 detention pond facilities in Virginia (five facilities in each of the state's nine transportation districts) were collected and analyzed to quantify chloride-ion concentration, total suspended solids (TSS), and oil and grease. In addition, salt-loading pad areas and pond volumes and surface areas were quantified.

The study[1] found that chloride concentrations were significantly greater than those specified in state and federal regulatory guidelines, with concentrations routinely exceeding 1,600 mg/L (2,636 mg/L NaCl). Average concentrations of TSS and oil and grease were 20 and 9.5 mg/L, respectively. Using historic rainfall and evaporation rate data[2] from 1965 through 2003 and measured impervious pad and pond areas, the quantity of stormwater collected from the loading pads and ponds during the driest, wettest, and an average rainfall year was determined. Approximately 60 MG of salt-contaminated runoff water is generated statewide in an average rainfall year. If only the runoff generated during the 5-month winter maintenance season is considered, the volume of salt-contaminated runoff produced in an average rainfall year is about 30 MG.

Statewide, VDOT was found to pay an average cost of $0.13 per gallon to dispose of the salt-contaminated runoff. For an average rainfall year, this translates into a total annual disposal cost of approximately $7.8 million. This estimate assumes that all the runoff (after accounting for evaporation losses) is treated, which does not always occur. Because of the high disposal cost per gallon and the extremely large volumes of water VDOT was capturing, the researchers recommended that VDOT consider reducing the size of the loading pads where possible to reduce the volume of water captured as runoff. They also recommended that VDOT install diversion valves in the pipes leading from the drains on the loading pads to the stormwater ponds.[1,2] This would enable facility managers to divert water that runs off the loading pads when no salt is present. At a minimum, this would allow for the diversion of runoff from April through October, again significantly reducing the volume of water captured in the ponds.

Even with pad size reduction and the use of diversion valves, the researchers recognized that VDOT would still capture large volumes of water that would require disposal or treatment. Therefore, in addition to the characterization of the water captured at VDOT sites, the earlier research included an evaluation of three treatment alternatives: ion exchange, electrodialysis, and reverse osmosis (RO). The assessment was based on the findings concerning the quantity and quality of the water captured at VDOT's sites. Using this information and an assumed target chloride concentration of 250 mg/L (411 mg/L NaCl), the researchers determined that RO was the only technology that was potentially feasible for use. The other two alternatives were determined not be cost-effective or technologically feasible given the characteristics of the VDOT sites.[1,2]

Reverse Osmosis

RO refers to the process wherein water containing one or more solutes is forced through a membrane that allows the water, but not the dissolved solute(s), to pass. If no external pressure is applied to the water on either side of the membrane, water will flow from the dilute side of the membrane to the concentrated side of the membrane until a pressure differential (equal to the osmotic pressure) is reached and the system is at equilibrium. By application of an external pressure on the concentrate side of the membrane that is greater than the osmotic pressure, water flows from the concentrated side of the membrane to the dilute side. This results in purification of the water and the production of a more concentrated waste solution.

RO systems do not require caustic or acid solutions for membrane regeneration, but they do require occasional cleaning and eventual membrane replacement. RO can achieve 90 to 98 percent removal of dissolved solids. In theory, this removal rate is satisfactory to treat the runoff water to a chloride concentration lower than 250 mg/L, which is the U.S. Environmental Protection Agency's National Secondary Drinking Water Regulation maximum level,[4] yet significantly higher than the Virginia Department of Environmental Quality's 25 mg/L groundwater standard for chloride.[5] However, the concentrate waste-stream discharge rate from the process can range between 20 and 70 percent of the inflow discharges depending on a number of variables, one of the most important of which is the feed stream concentration. For treatment streams with relatively low concentrations of suspended solids and organic constituents, concentrate waste-stream generation is likely to equal 20 to 30 percent of the inflow discharge.[6]

RO has been used extensively for the treatment of water in a variety of settings including the pharmaceutical, semiconductor, power generation, pulp and paper, and chemical and petrochemical industries. The U.S. Bureau of Reclamation has even proposed using RO to treat a portion of the irrigation runoff captured within the San Joaquin Valley.[7] Despite this wide variety of uses, almost no documentation exists regarding the use of RO to treat stormwater runoff and, more specifically, runoff water containing high levels of NaCl. Therefore, although RO appears promising, many issues about its applicability need to be identified before VDOT can incur the capital costs required to use it as a means of treating saltwater on a large scale. Some of these issues include the need and means of pre-filtering, waste and product stream characteristics, percent reduction in treated water volume, and unforeseen maintenance issues.

PURPOSE AND SCOPE

The purpose of this project was to conduct a pilot study of the RO treatment technology to determine if RO treatment was something VDOT should invest in and use at some of its salt storage facilities. A single RO unit was used to treat saltwater in a laboratory setting where all parameters could be controlled and at a VDOT field site.

METHODS

To meet the study objectives, the study team undertook two primary tasks: laboratory testing and field testing of an RO unit.

Laboratory Testing

A 2,000-gpd RO treatment system built by Clean Water Products was initially tested in the laboratory. The unit was built with a female plug receptacle in the back designed to work in conjunction with a float switch. The system uses a 3/4 horsepower pump to push water through a 4- by 40-inch RO membrane at 160 psi.

The experimental setup used to run the laboratory test is presented in Figure 2A. Salt-contaminated water was prepared using an NaCl concentrate solution and was mixed continuously with tap water to achieve the desired NaCl concentration to feed the RO unit. From the mixing tank, the feed solution passed through two pre-filters to remove sediment greater than 5 microns in size and then to the RO filter. On the RO unit, because of the high pressures applied through the RO membrane, low NaCl (product) and high NaCl (reject) concentration streams are generated. Part of the reject stream was used for recirculation.

A total of 13 experimental conditions (varying input NaCl concentrations) were applied for a minimum of 10 hours. Recirculation and reject flows were set on 1 gpm and 2 gpm, respectively, as recommended by the system manufacturer. Table 1 shows the main characteristics of the influent used.

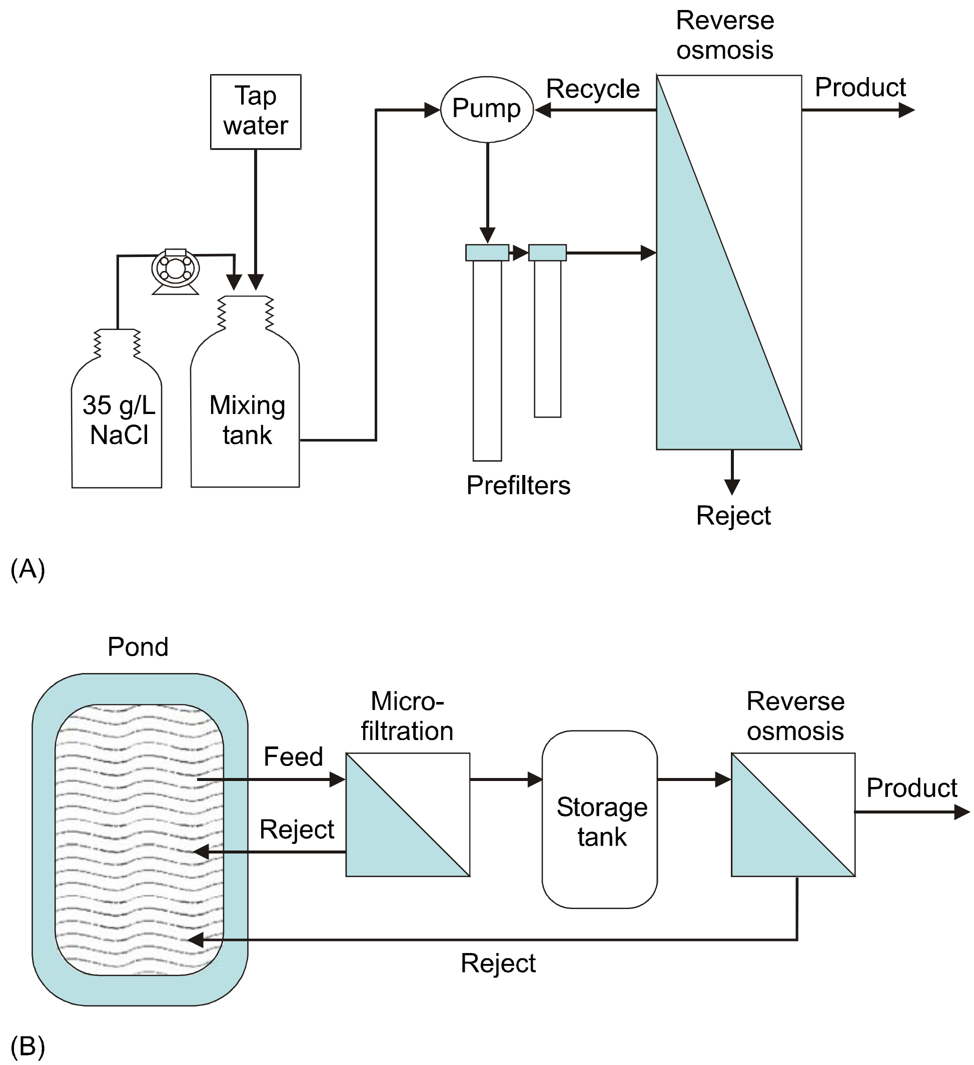

Figure 2. (A) Setup for Laboratory Experiments with Reverse Osmosis Equipment; (B) Layout of Microfiltration/Reverse Osmosis Field Test

Table 1. Feed Solution Characteristics for Conditions Tested

Test	NaCl (mg/L)	Conductivity (mS/cm^2)	Turbidity (NTU)	Cyanide (mg/L)
Low Range	523	0.8	0.21	<0.002
	985	1.3	0.39	<0.002
	1565	2.1	0.45	<0.002
	1653	2.9	0.55	<0.002
	1870	3.2	0.36	<0.002
	2230	3.5	0.59	<0.002
	4076	4.6	0.47	<0.002
	5612	7.5	0.59	0.002
	6701	10.44	0.66	0.002
High Range	11554	18.54	0.88	0.002
	15680	23.69	0.92	0.002
	18319	31.98	0.97	0.004
	24587	44.98	0.99	0.004
Field Test	3594	6.2	7.98	N.D.

Chloride concentrations were measured every 30 min for the feed, product, and reject streams using a chloride-specific ion electrode. Chloride concentration was transformed to a NaCl concentration using a calibration curve. The values of the flows for the feed, product, and reject streams were measured every 30 min. Other parameters determined at each experimental condition were turbidity, conductivity, and cyanide concentration (cyanide was measured by way of the HACH 8029 method and was of interest because of its use as an anti-caking agent for NaCl).

Field Testing

Field testing was conducted using the same RO unit tested in the laboratory. The work was performed at VDOT's Zion Crossroads Area Headquarters in central Virginia. The test site has a stormwater basin with a storage capacity of approximately 45,000 gallons and a loading pad that covers nearly 600 m^2. The loading pad serves a three-bay shed and a much larger salt dome that is used as a storage area for several other area headquarters nearby (see Figure 1).

Water was withdrawn from the stormwater pond using a 3 gpm electric sump pump and directed to the filtration system outfitted with a 2- by 20-inch 5 micron pre-filter and a 4- by 40-inch spiral wound microfiltration (MF) element. The MF step was needed to remove solids greater than approximately 1 micron. The filtered water was then pumped to a 330-gallon polyethylene storage tank. Once this tank was full, the water was pumped back through a 4- by 40-inch spiral wound composite-cellulose acetate RO element (see Figure 2B). The maximum operating pressure for the MF and RO was 130 and 160 psi, respectively. Reject and recirculation flows were varied to maintain the proper pressure conditions but were generally kept at 1 and 3 gpm, respectively, for the MF stage and 1 and 5 gpm for the RO stage. The waste streams from the MF and RO units were pumped back to the stormwater pond. Samples of the reject and the clean product lines were collected hourly and analyzed upon their return to the laboratory.

RESULTS AND DISCUSSION

Laboratory Experiments

Chloride Removal

The chloride removal results are divided into two sets. The first set presents the results obtained when the feed concentration of NaCl was between 585 to 6,701 mg/L (317 to 4066 mg/L Cl). Based on prior field measurements throughout the state,[2] this range was selected to encompass the salt concentrations found in the vast majority of stormwater storage ponds. In a few cases, significantly higher salt concentrations were detected (caused by improper salt storage). Therefore, a second, higher range of salt concentrations (greater than 10,000 mg/L NaCl) was studied.

Figure 3 shows the NaCl concentration on the product and reject streams as a function of the NaCl feed concentration. For this range of feed concentrations, product stream

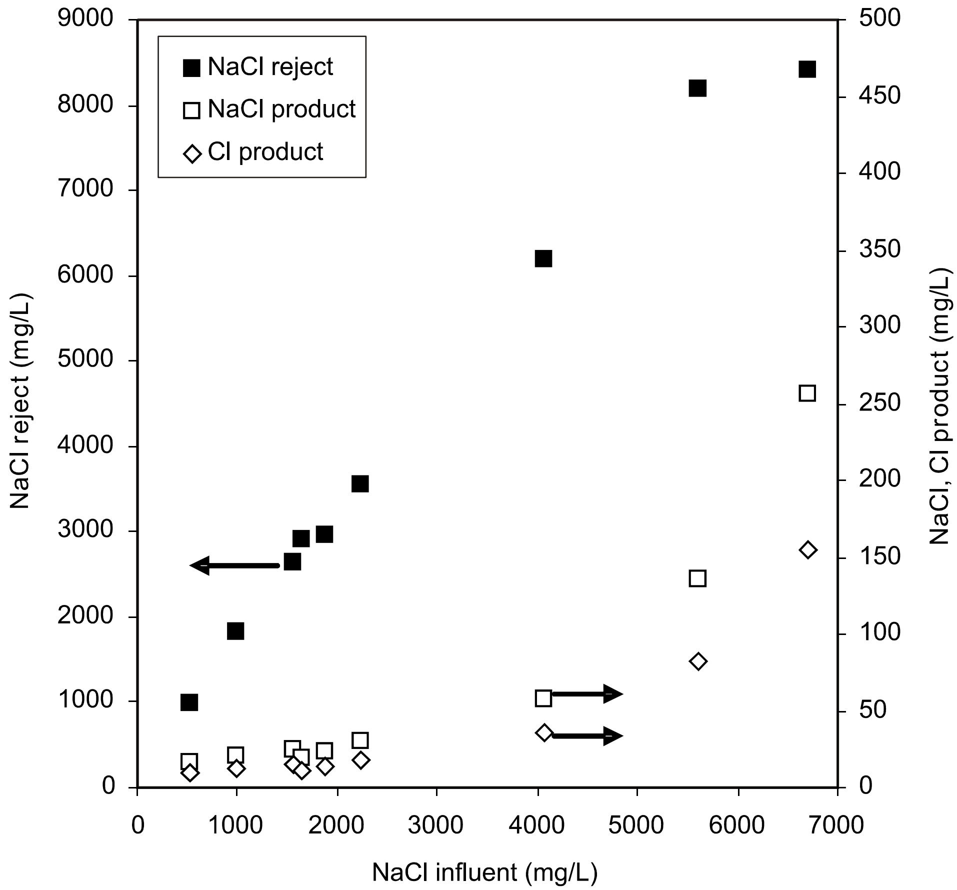

Figure 3. Product and Reject NaCl Concentrations as Function of Feed NaCl Concentration

concentrations were lower than 155 mg/L. For the product streams, NaCl concentration tended to decrease exponentially with decreasing NaCl feed concentration. Reject stream NaCl concentrations decreased linearly with decreasing NaCl concentration in the feed solution. Previous water analyses at a small number of sites in 2004 showed that NaCl concentrations in the stormwater runoff ponds were between 1,483 and 4,284 mg/L. For this range of feed concentrations and based on the removal efficiencies obtained in the laboratory, Cl concentrations of the product stream would be less than 20 mg/L and flow of product higher than 4 L/min. The product flow decreased as the NaCl feed concentration increased (Figure 4) and the flow rate for the reject remained constant.

Figure 5A shows the product NaCl and Cl concentrations and reject NaCl concentration as a function of the NaCl feed concentration during the experiments at high NaCl concentrations. The results reveal a linear increase in Cl concentration in the product stream and the reject stream with increasing feed NaCl concentration. The concentrations of Cl in the product streams for these high concentrations were several times higher than the assumed goal of 250 mg/L. With regard to the product flow, it decreased sharply with the increase in NaCl in the feed, with a minimum flow of 80 mL/min when the feed concentration was 24,000 mg/L NaCl (Figure 4B). From these results, it is apparent that a low flow performance should be expected from the RO unit at high NaCl concentrations. This can be explained by the fact that the maximum

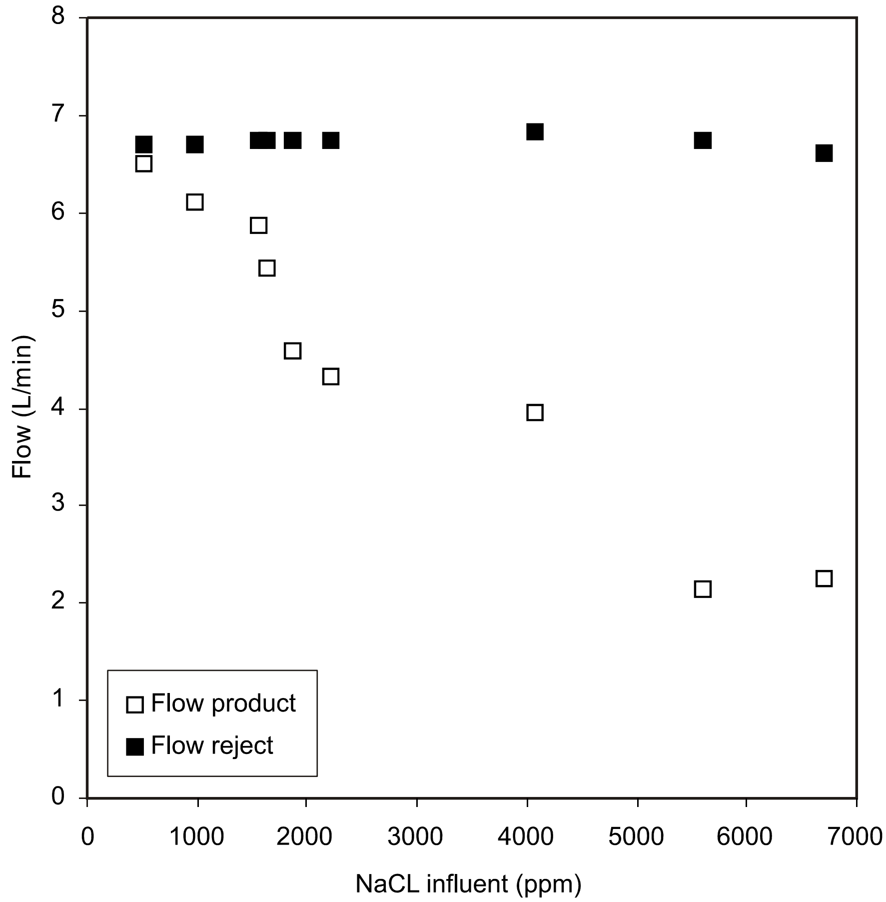

Figure 4. Flows of Product and Reject as Function of NaCl Concentration on Feed During Low Concentration Experiments

operational pressure of the RO unit used in this experiment was 160 psi, which is considered a "low-pressure" RO unit. Low-pressure RO is commonly used to produce drinking water from brackish raw water with NaCl concentrations lower than 12,000 mg/L. High-pressure RO units are able to treat seawater (NaCl >34,000 mg/L) because they can operate at pressures as high as 1,000 psi.[8] Although these high-pressure systems would be able to treat the water with NaCl concentrations as high as 24,000 mg/L, they would be much more expensive to operate than would the low-pressure systems tested.

Percent Recovery

Figure 6 shows the percent recovery and concentration factors for all NaCl feed concentrations tested. The percent recovery and concentration factor were calculated in accordance with Equations 1 and 2, respectively,

$$r = (Q_p/Q_f)*100 \qquad \text{(Eq. 1)}$$
$$CF = (1/(1 - 0.01r)) \qquad \text{(Eq. 2)}$$

where r is percent recovery, Q_p is product flow, Q_f is feed flow, and CF is concentration factor (increase in concentration of the reject flow expressed as a factor of the feed flow). Percent

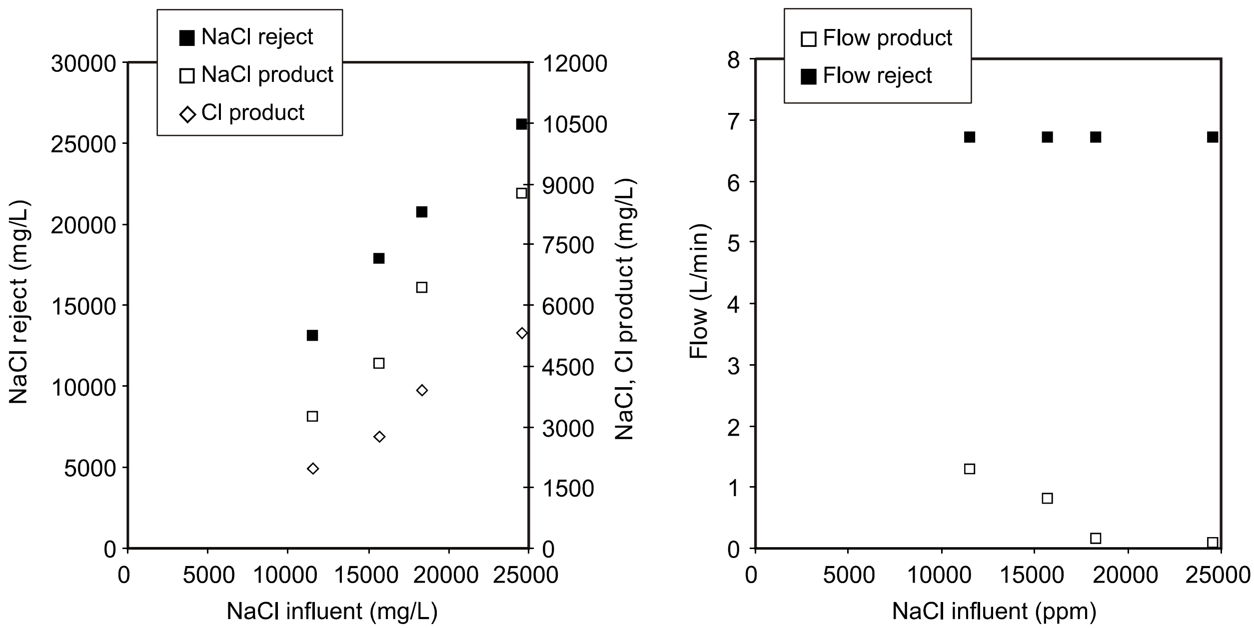

Figure 5. (A) Product and Reject NaCl Concentrations as Function of Feed NaCl Concentration; (B) Flows of Product and Reject as Function of NaCl Concentration on Feed, During High NaCl Concentration Experiments

recovery decreases rapidly with the increase of NaCl in the feed stream. This occurred because the product flow decreased, especially at NaCl concentrations higher than 10,000 mg/L. Common percent recovery values for low-pressure RO systems normally range between 70 and 85 percent.[8] The percent recovery values found here were lower than those found in other studies.[8] It is possible that the values could be increased by altering the reject and recycle flow values used (7.5 and 11.2 L/min, respectively). The concentration factors were also negatively affected by the increase of the NaCl in the feed stream. However in the range of 1,485 to 4,284 mg/L NaCl, the percent recovery was approximately 40 percent and the concentration factors were in the range of 1.5 to 2.0. This indicates that the volume of brackish water can be reduced by half and the concentration of NaCl in the reject can be doubled.

After more than 17,000 gallons of water were treated with the RO unit, no sign of fouling was observed. This was validated by repeating one of the first feed concentrations tested and comparing the values for product flow with the result previously obtained (data not shown).

Cyanide

Cyanide was not detected in the product stream; in the reject stream, the maximum concentration measured was 0.002 mg/L. The low concentrations in both streams were close to the detection limit of the HACH 8029 used (0.002 mg/L), reducing the precision of the results. In future experiments, the digestion of the sample could be considered because cyanide can form a complex with organic matter and other inorganic compounds. The HACH method used in this study can detect cyanide only in its free form and not as a complex with other compounds.

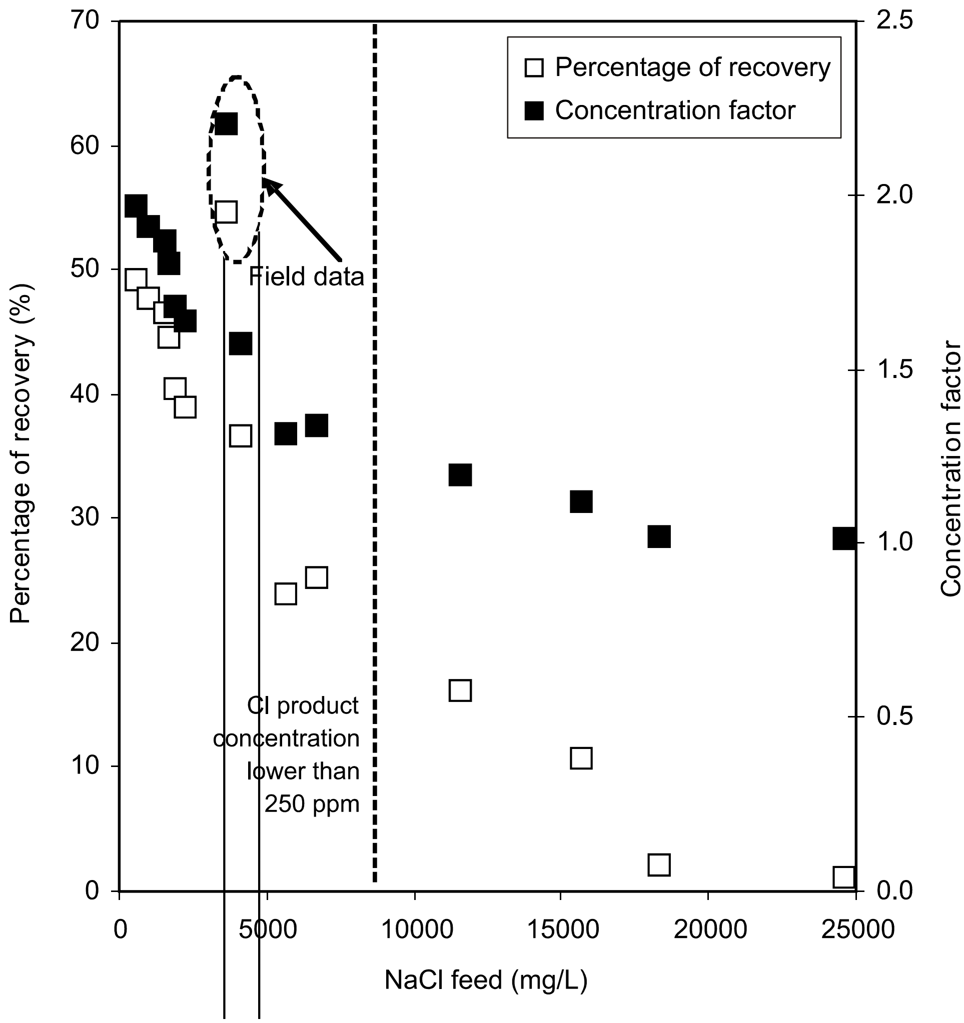

Figure 6. Recovery Percentages of Product and Concentration Factor on Reject Streams at NaCl Feed Concentrations Tested

Conductivity

The conductivity reduction on the product was proportional to the reduction of the NaCl concentration; this result was expected since NaCl was the main source of conductivity in the feed solution.

Field Test

Turbidity Removal

The MF unit was able to remove more than 96 percent of the turbidity originally present in the pond water (7.99 NTU). The average values for the product streams and reject streams were 0.27 and 10.15 NTU, respectively (see Figure 7). During the MF stage, no reduction of the NaCl concentration was observed. In spite of the promising results with regard to turbidity

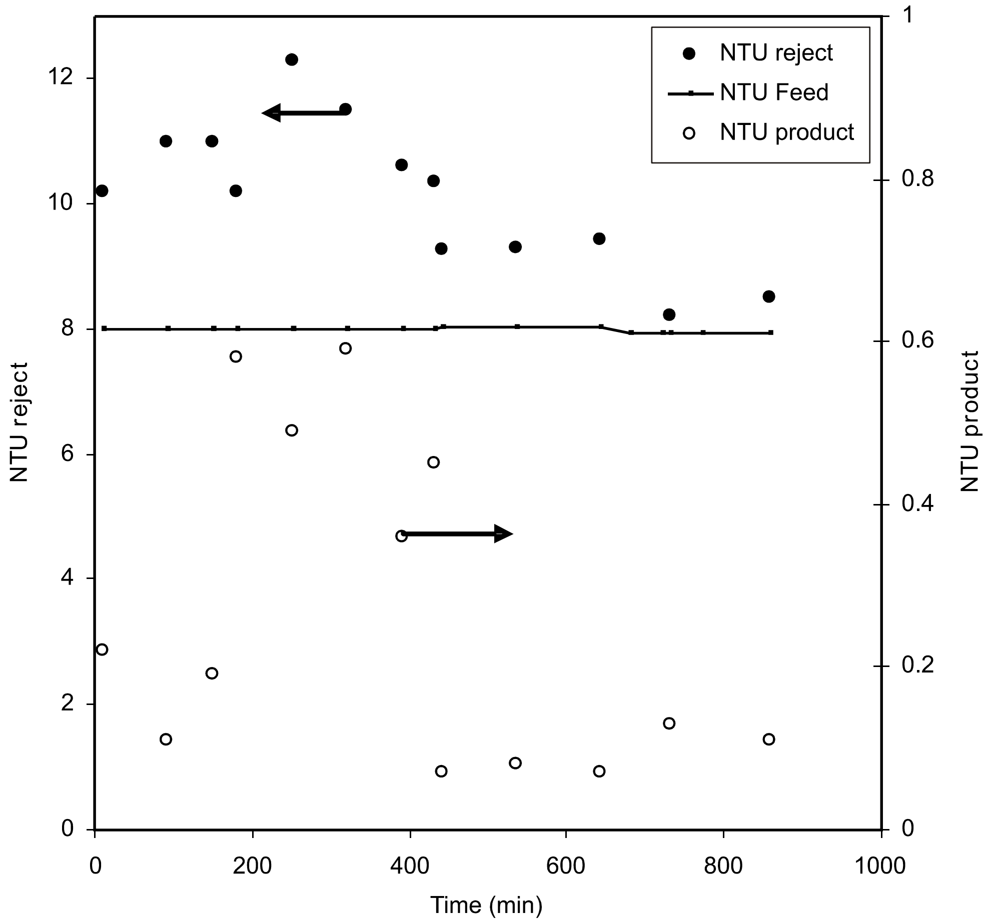

Figure 7. Turbidity Reduction Resulting from Microfiltration Pretreatment (arrows indicate axis to be used for data point types)

removal, a rapid reduction of the product flow was observed for the duration of the field test. Figure 8 shows the flow values for the product and reject streams as a function of time. It is likely the reduction in product flow was related to the fouling of the surface of the membrane. One disadvantage of spiral-wound MF elements is that they cannot be backwashed. The only cleaning procedure possible for this type of filter is a chemical wash. The cleaning procedure consisted of the recirculation of a trisodium phosphate solution for 15 minutes (as recommended by the manufacturer). After every cleaning process, the MF unit product flow increased.

Based on the results obtained in the field test, the MF unit would require cleaning approximately every 3 hours. Cleaning at such frequent intervals is inconvenient and can significantly reduce the volume of saltwater that can be treated during a given time period. To reduce the cleaning frequency, some type of pretreatment would be necessary. The two most common types are coagulant and powdered activated carbon. Metal coagulants are normally injected into the raw water through a feed line, after which the water enters a reservoir for mixing and coagulation. It appears that the coagulation of smaller particles into larger ones reduces the penetration of various materials, including colloidal and larger organic macromolecules, into pores of the membrane.[9] Considering the layout of the typical VDOT salt storage site, the pond could be used as a mixer and coagulant tank. A new set of experiments would need to be conducted to determine the appropriate coagulant to use and its optimal dose.

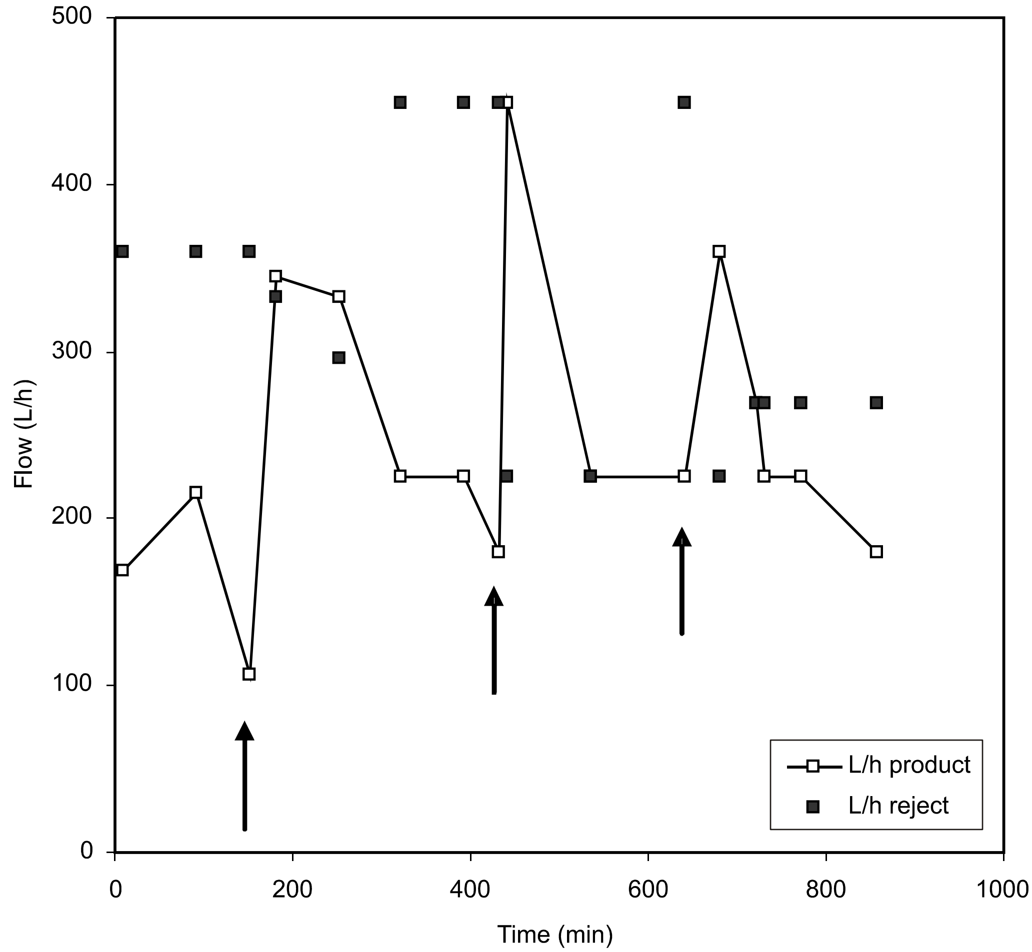

Figure 8. Product and Reject Flows of Microfiltration Stage of Field Tests (arrows indicate timing of a cleaning procedure)

Chloride Removal

With regard to the RO stage, Figure 9 shows the NaCl concentrations of the feed and reject streams and the NaCl and Cl concentrations of the product stream. The small dip in the feed stream NaCl levels, and the corresponding drop in the product and reject NaCl levels, is thought to be due to the precipitation occurring during this time period, resulting in a slight dilution of the NaCl. The overall performance of the RO unit, however, was very stable, and no sign of reduction in the product flow was observed during the experimental period.

Figure 10 shows the principal average values obtained during the field test and the previously plotted laboratory removal rates. The concentration of Cl in the product stream was higher than expected based on the results obtained in the laboratory testing but was still lower than 250 mg/L. This difference may be caused by the presence of other ions, in addition to NaCl, that also contribute to the increase of the osmotic pressure of the pond water. This phenomenon did not occur in the laboratory since the only source of ions was NaCl.

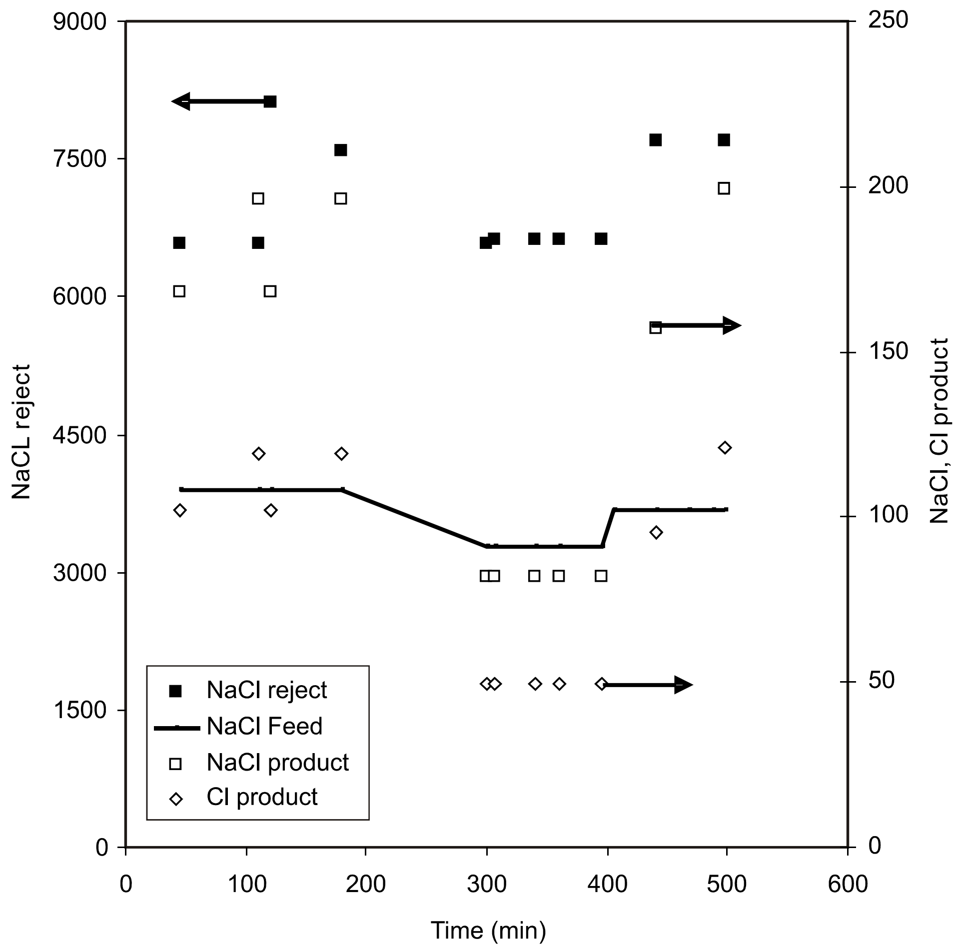

Figure 9. NaCl Concentrations of Feed and Reject Streams and Chloride Concentration of Product Stream on Reverse Osmosis Stage in Field Experiments (arrows indicate axis to be used for data point types)

Percent Recovery

The differences between the laboratory and field data with regard to product and reject flows are related to the different operational conditions tried during the field test. A reject flow of 3.7 L/min (1 gpm) and a recirculation flow of 18.7 L/min (5 gpm) were used. Figure 11 shows an increase in the product flow at the new operational condition tested. The new operational condition also had a positive effect on the percent recovery and concentration factor (see Figure 6).

Fate of Product and Waste Streams

Based on the percent recovery values measured in the laboratory and the field test, and the large volumes of saltwater captured by VDOT, the fate of the product and waste streams must be considered when making a decision regarding the feasibility of RO as a treatment option for VDOT-captured saltwater. There is no clear standard for chloride pertaining specifically to stormwater discharge. Based on values obtained in the initial research, the statewide average value for chlorides in VDOT's stormwater ponds is approximately 1,600 mg/L, with 95 percent

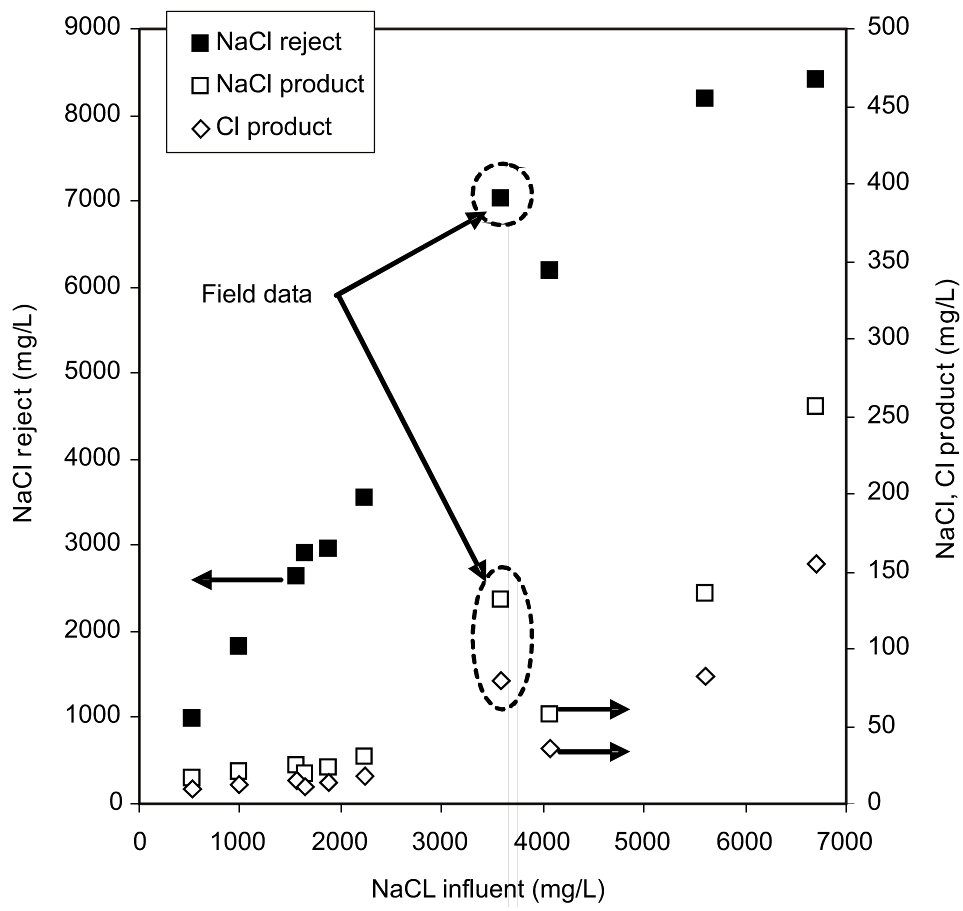

Figure 10. Product and Reject NaCl Concentrations as Function of Feed NaCl Concentration During Low Concentration and Field Experiments (arrows indicate axis to be used for data point types)

of VDOT's sites expected to have chloride values below 3,200 mg/L.[1,2] Given the percent chloride reductions measured in the field, it can be expected that treatment with RO would decrease these values to below 50 and 100 mg/L, respectively. If the state regulatory agencies were to set the chloride discharge limit for VDOT at 250 mg/L (based on the EPA's National Secondary Drinking Water Regulation), low pressure RO treatment would be sufficient for the treatment of nearly all of VDOT's collected saltwater.[4] Conversely, if VDOT's discharge limit is set at 25 mg/L (based on the Virginia Department of Environmental Quality's groundwater standards), more than half of the water would not meet this requirement when treated by RO.[5] This alone would make the use of RO by VDOT infeasible.

The fate of the waste stream produced by RO treatment is not dependent on regulatory interpretation, but it will be determined by whether VDOT begins using salt brine for direct application as a part of its anti-icing program (this is currently being explored at several locations by VDOT). Assuming VDOT does begin to use salt brine for direct application, it seems practical to store the highly concentrated RO waste stream in storage tanks (above ground or under ground) and add additional salt to raise the NaCl concentration to the desired 23 percent.

Specific storage requirements would be dependent on the volume of salt brine applied during the winter maintenance season, the volume and concentration of stormwater captured, and

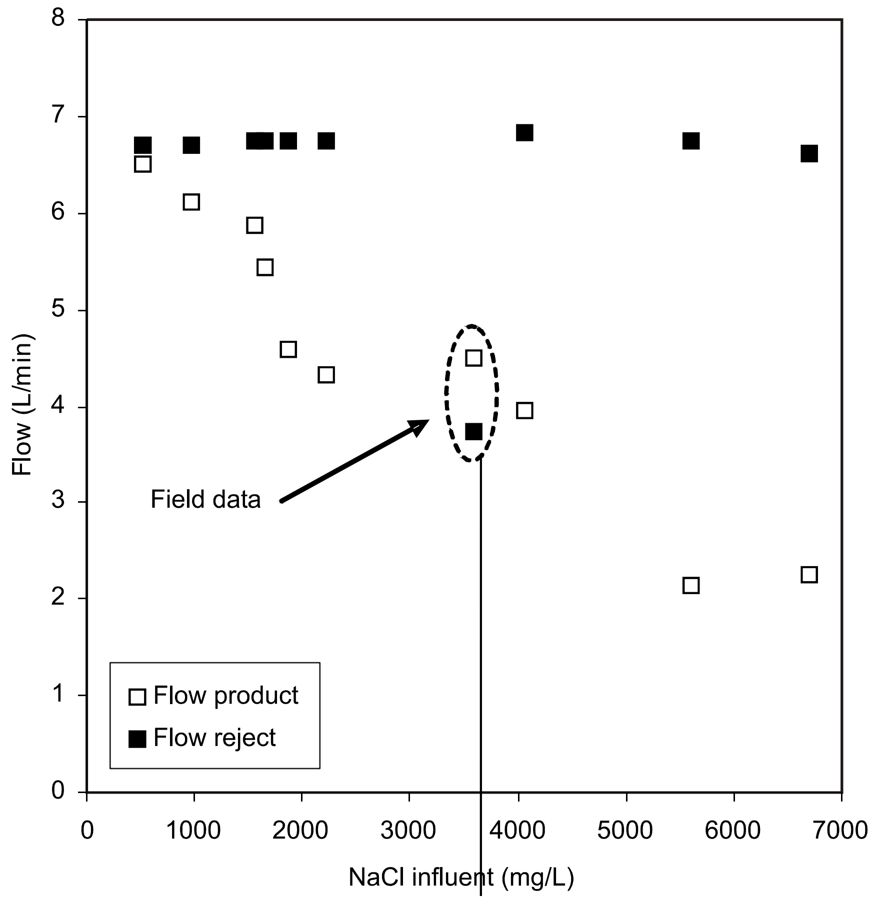

Figure 11. Flows of Product and Reject as Function of NaCl Concentration on Feed During Low Concentration and Field Experiments

the reduction in volume achieved by the RO treatment process. The specific values for each of these variables will vary considerably from site to site, but based on the initial research[1] and the findings of this study, the following can be assumed with regard to the average site:

- The stormwater storage capacity will be 40,000 gallons, which will need to be emptied two times per year.
- The NaCl concentration in the stormwater will be approximately 2,600 mg/L.
- If treated with RO, the volume of stormwater will be reduced approximately 50 percent.

These numbers, in conjunction with salt brine application estimates, would allow the calculation of on-site storage requirements. The obvious advantage of using the RO waste stream is that it is being used as the base for the salt brine, for which VDOT would normally have to pay. Therefore, this type of end use would save money by reducing the costs associated with the disposal of the waste stream and the costs of salt brine production.

Other Concerns

Even though most of the results of this research appear promising, several problems need to be solved before RO can be used extensively to treat saltwater captured by state departments of transportation.

Pre-filtering

A feasible mechanism for pre-filtering must be identified. This may be accomplished through the use of some type of pretreatment, as discussed earlier, or a more advanced pre-filtering system (i.e., one that would allow for the backwashing of the filter) than was used in this study. Because the stormwater runoff ponds seem to be ideal environments for algae growth, it is likely that the relatively high turbidity found in the field test will be found in most of the ponds requiring treatment. Therefore, the turbidity must be reduced before RO filtering can be used.

System Throughput

Throughput volumes must be increased. Because of the large volumes of water captured and the relatively small storage capacity for most ponds, many ponds will require several pump and treat cycles each year. Based on a maximum throughput of 760 gpd as measured in the field for VDOT's average NaCl concentrations, and assuming a conservative statewide treatment volume of 30 MG (this assumes diversion of stormwater will take place from April through October), a total of 300 RO units would need to be purchased and operate at least 26 weeks of the year. This calculation does not take into account downtime due to maintenance or repair and also assumes the previously described problems related to pre-filtration could be overcome. In order to make this more feasible from a system throughput perspective, RO systems capable of treating tens of thousands of gallons per day would be necessary (versus the unit tested, which was rated at 2000 gpd). Though costly, these higher volume systems do exist. Assuming the chloride removal and percent recovery values found in this research are scalable, these larger systems should be feasible treatment options.

Costs

Although obtaining accurate cost information for the purchase and operation of an RO system was not the primary goal of this research, based on limited purchase price information[1,2] and published average operating cost information,[10] total costs associated with RO treatment were postulated to range between $0.05 and $0.08 per gallon. Actual treatment prices would be subject to a number of variables including the number and size of units purchased, the expected usable life of the units, and the volumes and concentrations of the water to be treated. These variables would be dependent on the volumes of water collected and storage capacities of specific sites. In addition, if the reject stream can be stored and used for either pre-wetting or direct brine application, the treatment costs could be further offset by reducing the volumes of common pre-wetting chemicals such as calcium chloride and magnesium chloride.

CONCLUSIONS

- *Given the range of NaCl values found in VDOT's stormwater ponds at its salt storage sites, Cl values in the product stream resulting from RO treatment would be expected to average under 20 mg/L. However, because of the wide variability in NaCl concentrations at ponds throughout the state, a number of these sites could have Cl values above 25 mg/L.*

- *Treatment of stormwater containing salt in the range of 2,000 to 3,000 mg/L NaCl with a low pressure RO system will result in a total volume reduction of approximately 50 percent* (i.e., approximately 50 percent of the volume will be "clean" and the remaining volume will exit the system as reject).

- *Removing turbidity by way of pre-filtering will likely be difficult with RO.* Turbidity levels were quite high in most of the stormwater ponds examined. This coupled with the inability to backwash the spiral-wound MF filter commonly used for low pressure RO systems causes significant system downtime and decreased system throughput volumes.

- *In addition to the problems related to the pre-filtering step, the feasibility of RO use by VDOT will likely hinge on the Cl levels allowed by the Virginia environmental regulatory agencies for surface water discharge.* If this level is set near the 250 mg/L secondary drinking water standard, low pressure RO is still potentially a feasible means of saltwater treatment for VDOT (with respect to the Cl removal efficiency).

- *Use of the RO reject (i.e., concentrated waste) could potentially be used in the creation of brine used for pre-wetting dry NaCl and/or direct brine application.* This would reduce the volume of waste to be disposed of and further offset the costs associated with RO treatment. It may be even more efficient to simply use the saltwater collected (prior to RO treatment) to use for brine creation.

- *The Virginia Transportation Research Council is in the initial stages of gathering additional information to assess the potential to use the saltwater VDOT collects as the base stock for the creation of 23 percent salt brine solution that can be used to pre-wet and/or directly apply brine*. It appears that using the reduced volume of water collected by VDOT would not only save money with respect to disposal costs but would also potentially be of benefit in the creation of brine.

RECOMMENDATIONS

1. *VDOT's Asset Management Division should not purchase RO units for treatment of saltwater collected at salt storage facilities*. This is based on the small total volume reduction that would be achieved, the small throughput volumes that could be expected, and the likelihood of encountering pre-filtering problems.

2. *VDOT's Asset Management Division should continue to implement the previously stipulated recommendations of reducing the size of the loading pads and installing diversion valves*. The full implementation of these two practices would result in significantly greater saltwater volume reduction than would treatment by way of RO.

COSTS AND BENEFITS ASSESSMENT

The cost estimate for treating VDOT's saltwater with RO based on information in Phase I of the research study was approximately $0.05 per gallon.[1] This estimate assumed an RO reject rate of 25 percent, which would require normal disposal at a cost of $0.13 per gallon. Given the reject percentages measured in the field component of this study, this reject value would need to be increased to at least 50 percent. Following the earlier assumption that this volume would require disposal, the revised cost of treatment by way of RO would be approximately $0.08 per gallon. This revised value for RO treatment costs does not reflect the increased costs that would likely be incurred due to the more frequent MF cleaning found to be necessary in the field. It is assumed that this would contribute significantly to the overall costs of RO, raising the per gallon treatment costs well above $0.08.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the help of E. Wallingford and S. Long in VDOT's Environmental Division and D. Roosevelt at VTRC for their guidance in conducting this research. The authors also thank the staff at VDOT's Zion Crossroads Area Headquarters for their permission and support in conducting the field component of the study. Finally, the authors express their appreciation for the work of VTRC's L. Evans in developing the final document.

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