FINAL REPORT

CHARACTERIZATION AND ENVIRONMENTAL MANAGEMENT OF STORMWATER RUNOFF FROM ROAD-SALT STORAGE FACILITIES

G. Michael Fitch
Senior Research Scientist
Virginia Transportation Research Council

James A. Smith, Ph.D., P.E.
Associate Professor
Department of Civil Engineering
University of Virginia

Shannon Bartelt-Hunt, Ph.D.
Research Associate
Department of Civil Engineering
North Carolina State University

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DISCLAIMER

ABSTRACT

The Virginia Department of Transportation (VDOT) is responsible for maintaining more than 57,000 miles of roadway. A large part of this maintenance effort comprises the implementation of VDOT's snow removal and ice control program. In fiscal year 2003, VDOT purchased more than 570,000 tons of sodium chloride. This salt, along with various other deicing chemicals, is stored at each VDOT residency and area headquarters, for a total of 292 locations throughout the state. Most of the storage facilities comprise a building to stockpile the chemicals, an adjacent impermeable pad that serves as a loading area for trucks, and a stormwater storage pond or collection basin.

The objectives of this study were to assess the quantity and quality of salt-contaminated water generated from stormwater runoff at VDOT's salt storage facilities and to evaluate management/treatment alternatives to reduce costs and better protect the environment. To achieve the first objective, data regarding detention pond surface area and volume, runoff area, and several key water quality constituents were collected from five randomly selected storage facilities in each of VDOT's nine districts, for a total of 45 sampling sites.

Chloride concentrations were significantly greater than state and federal regulatory guidelines for drinking water and surface water quality criteria, with values routinely exceeding 2000 mg/L. Concentrations of total suspended solids and oil and grease were less than expected, with averages of 20 and 2 mg/L, respectively. The quantity of stormwater collected was higher than anticipated, with approximately 60 MG of contaminated runoff water being generated in an average rainfall year. Even if only the runoff generated during the 5-month winter maintenance season is considered, the volume of salt-contaminated water is in excess of 30 MG.

To achieve the second objective, two alternatives to VDOT's disposal practices were examined: (1) management strategies to reduce the volume of salt-contaminated stormwater runoff generated at each facility, and (2) treatment of the runoff to remove the salt and subsequent release of the runoff back to the environment. Currently, VDOT disposes of the salt water by one of three methods: (1) connecting directly to a publicly owned treatment works system, (2) pumping and transporting the salt water to such a system by tank truck, or (3) applying the salt water to gravel roads to suppress dust temporarily.

The average per gallon cost of VDOT's current method of pumping and transporting to a publicly owned treatment works system is approximately \$0.13. If VDOT used a mobile ultrafiltration/reverse osmosis system, this cost would be cut by more than half. The \$0.047 per gallon cost is also 58% of the \$0.08 per gallon cost VDOT pays to use the wastewater for dust control. For a statewide annual treatment volume of 58.6 MG, this would result in an annual cost savings of \$1.9 million to \$4.9 million. It appears that the reverse osmosis treatment technology is worthy of additional exploration to ensure that operation problems and costs do not preclude its use by VDOT.

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INTRODUCTION

The Virginia Department of Transportation (VDOT) is responsible for maintaining more than 57,000 miles of roadway. A large part of this maintenance effort comprises the implementation of VDOT's snow removal and ice control program. In fiscal year 2003, VDOT purchased more than 570,000 tons of NaCl. This salt, along with various other deicing chemicals, is stored at each of VDOT's residencies and area headquarters, at least one of which is located in every county. In total, salt is stored at 292 locations throughout the state. Most of the storage facilities are comprised 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. 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 runoff containing varying concentrations of deicing chemicals. The majority of the ponds VDOT constructs are deliberately wide and shallow to facilitate evaporation (see Figure 1). Unfortunately, this design also increases the volume of water captured during a precipitation event. Assuming the evaporation rate of the water in the pond is greater than the runoff and direct precipitation inflow rate, the ponds are relatively effective in containing the salt-laden water. However, at many VDOT storage facilities, the holding capacities of the ponds are exceeded by the combination of runoff from the loading pad and direct precipitation to the pond surface.

Allowing the stormwater ponds containing salt water to overtop and infiltrate has obvious environmental implications. As a consequence, VDOT has been forced to dispose of the salt water by one of three methods: (1) connecting directly to a publicly owned treatment works (POTW) system, (2) pumping and transporting the salt water to a POTW system by tank truck,

Figure 1. Typical Salt Water Collection Basin Found at VDOT Salt Storage Facilities.

or (3) applying the salt water to gravel roads (the hygroscopic nature of the NaCl provides temporary dust suppression). Each option has significant shortcomings. Many parts of the state have few gravel roads, thereby all but eliminating the option of road spraying. The associated costs of the other two disposal systems 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 salt water because their 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 sanitary and industrial wastewater streams.

Numerous studies have reported on the adverse environmental effects of road salt distributed onto highways during winter maintenance periods. Road salt has been shown to contaminate groundwater (Dennis, 1973; Howard and Beck, 1993; Labadia and Buttle, 1996) and surface water (Rosenberry et al., 1999; Bubeck et al., 1971; Demers and Sage, 1990; Mason et al., 1999), and it can have adverse effects on roadside vegetation (Hughes et al., 1975). A smaller number of studies have addressed point-source environmental contamination from snow-dumping sites. During winter months, some municipalities transport snow that has accumulated along roadsides and in parking lots to snow dump sites. As this snow melts, deicing agents and other pollutants are released to the environment (Scott, 1980; Scott and Wylie, 1980; Pierstorff and Bishop, 1980). Although these and numerous other studies have examined the environmental effects of salt used by transportation agencies, virtually no data exist on how to dispose of, use, or treat the salt water properly captured and stored by these agencies, although contamination from salt storage facilities is a potential source of environmental contamination.

At present, there is a paucity of data on the quality and quantity of the stormwater runoff at salt storage facilities. The volume of contaminated water, which approximately equals the annual precipitation that falls on the loading pad and the pond minus the annual evaporation volume from the pond, is unknown. Further, typical concentrations or concentration ranges of salt ions, suspended solids, and organics in this runoff water are also unknown. This information is necessary for making appropriate environmental management decisions regarding the treatment and/or discharge options for the captured water.

PURPOSE AND SCOPE

The purpose of this project was to determine the feasibility of treating the salt water captured and stored in the stormwater basins at VDOT's salt storage facilities in order to minimize the risks of environmental contamination and reduce the costs associated with current disposal methods. Treatment in this case constitutes removing sufficient concentrations of NaCl such that the treated water does not pose a contamination hazard to nearby surface water or groundwater sources, particularly underground sources of drinking water. Treatments by way of portable reverse osmosis units, electrodialysis units, or ion-exchange resins were the primary methods considered. More specifically, based on a complete chemical characterization of the water captured in the ponds and a more thorough understanding of the water capture, storage, and disposal problem, the practicality of portable treatment units using reverse osmosis (RO), electrodialysis, and/or ion-exchange resins was evaluated from both a technical and a financial perspective.

METHODS

To meet the study objectives, four primary tasks were undertaken by the study team:

1. The literature on the management of contaminated stormwater runoff from salt storage facilities was reviewed.

2. A number of state department of transportations (DOTs) and municipalities were surveyed by email with regard to the methods they use to capture, store, treat, and/or dispose of water captured at their salt storage facilities.

3. Facility information and water quality data from a subset of VDOT's 292 salt storage locations were collected. These data along with regional rainfall and evaporation estimates were used to predict water treatment volumes.

4. Based on the results of the data collection and analysis effort, alternative management and treatment options that would reduce current costs and increase environmental protection were examined.

Literature Review

A literature review was conducted to determine methods and technologies used for sodium chloride removal and to gain a better understanding of the levels of chlorides that would be acceptable in the effluent following treatment.

Survey of Transportation Entities

An e-mail survey was conducted by use of the Snow-Ice Mailing List sponsored by the University of Iowa Institute of Hydraulic Resources. This mailing list serves a variety of geographically dispersed groups of public and private transportation professionals who are interested in winter maintenance. The purpose of the survey was to identify environmental management approaches being implemented by other state DOTs and municipalities to minimize and treat runoff water collected at salt storage facilities. In addition , a number of DOTs, consultants, and Canadian provinces were contacted in person, by telephone, and by e-mail.

Assessment of Quality and Quantity of Salt-Contaminated Water

To determine the quality and quantity of water from the detention ponds at VDOT's salt storage facilities, data regarding surface area and volume, runoff area, and several key water quality constituents were collected from five randomly selected storage facilities in each of VDOT's nine districts, for a total of 45 sampling sites. Figure 2 shows the district boundaries, the location of salt storage facilities, and the sites chosen for sampling.

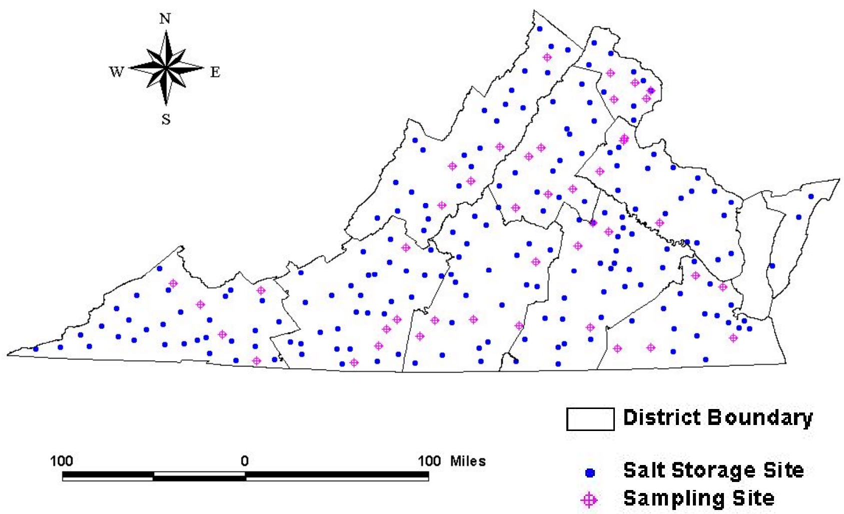

Figure 2. Distribution of Sampled Salt Storage Locations in Virginia.

Water Quality Constituents

Data were collected from the sampling sites from December 2003 through March 2004. One grab sample was taken from each pond and analyzed in the laboratory for chloride ion concentration and total suspended solids (TSS). An additional sample was collected from each pond and sent to a contract laboratory for analysis of oil and grease. Samples were collected as deep as possible (to ensure the collection of the highest salinity water in the pond) without disturbing the bottom sediment.

The concentration of chloride ion in the samples was determined using a calibrated chloride ion selective electrode. TSS was analyzed according to Standard Method 2540D (American Public Health Association, American Water Works Association, and Water Environment Federation, 1995). The water sample was mixed well and was filtered through a pre-weighed standard glass-fiber filter. The residue retained on the filter was oven-dried at 105 °C. The filter containing the residue was weighed upon removal from the oven, with the increase in the weight of the filter representing the TSS.

Volume of Runoff

Measurements were taken to estimate the volumes of runoff that would be generated and the volumes of water that could be stored in the detention basins at each location sampled. The runoff area for each site was assumed to be equal to the area of the paved surface that drained into the detention pond. In some cases, this was significantly larger than the actual loading pad area at the sites. The surface areas and volumes of the ponds were estimated by measuring the length, width, and depth of each pond and estimating the slope of the sidewalls. The volume of salt water captured at each site was calculated by multiplying the measured surface areas and precipitation values and subtracting the volume lost to evaporation from the pond surface.

Calculations were made using total annual precipitation estimates and precipitation estimates for the months of November through March, as these five months covered the period when VDOT is most likely to apply salt. Historical precipitation data from 1965 through 2003 were obtained from the Southeast Regional Climate Center (2004). Three stations with historical climate data from 1965 through 2003 were located in each of the nine districts. An attempt was made to choose stations in different geographical locations in the district so that differences in precipitation across the district would be taken into account. Next, the annual precipitation recorded at each of the 27 stations was summed for each year in the 38-year period. The overall lowest amount of precipitation among the 27 stations occurred in 1965. The highest amount of precipitation occurred in 2003, and average precipitation occurred in 1973. Monthly evaporation averages were taken from 30 years of data collected at five regional stations throughout the state (Virginia State Climatology Office, 2001). The average treatment and storage volumes for the five sites in each of VDOT's nine districts was then multiplied by the total number of storage sites in each district to provide district volume and storage totals.

Evaluation of Treatment Alternatives

Current VDOT Practices

To determine the feasibility of any treatment technology, it must be compared with existing practices. To gain a better understanding of VDOT's method of handling salt-laden drainage water, the supervisors of each of VDOT's area headquarters sampled were asked to provide information regarding the handling and fate of the water captured in the stormwater collection basins. Specific items requested included approximate pond volume, fate of the collected water, frequency of removal, and costs associated with removal.

Selection of Alternatives

Three treatment options (RO, ion exchange, and electrodialysis) were selected for evaluation as a means of treating the runoff water collected at salt storage facilities. Manufacturers and users of these technologies were consulted to determine system capacities with respect to throughput volumes, removal efficiencies, equipment purchase costs, operational costs, maintenance issues, and brine-production percentage estimates. Management options that would reduce the volume of salt-contaminated water generated at the salt storage facilities were also considered.

RESULTS AND DISCUSSION

Literature Review

The review of the literature revealed relatively limited information on the management of contaminated stormwater runoff from salt storage facilities. The Transportation Association of Canada (2003) developed syntheses of best management practices for road salt management. In two of these documents (*4.0 Drainage and Stormwater Management* and *7.0 Design and Operation of Road Maintenance Yards*), significant information is provided on the environmental effects of chloride contamination on the roadside environment and on the design, layout, and operation of DOT maintenance yards. These documents recommend that runoff from loading pads be collected and then discharged to a sewage treatment facility or used for the production of brine. These appear to be the only two options recommended for DOTs that are properly capturing salt-laden water. No recommendations were found regarding the appropriate size and design of loading pads or ponds to help minimize runoff and maximize evaporation. Similarly, no mention of expected treatment concentrations, treatment volumes, or effluent concentration targets was found.

Survey of Transportation Entities

Very little information pertaining to the use of treatment technologies specifically for chloride removal was obtained from the e-mail survey. Although many states were interested in finding out more about the findings of the research effort, only a few responders were able to provide information relevant to the survey. The Indiana DOT, in conjunction with Purdue University, is beginning to use the rinse water (generated when washing down the salt spreaders) for the production of brine to be used as a pre-wetting agent. Salt is added to the rinse water after sediment, oil, and grease have been removed (Alleman, 2003). The Utah DOT also collects wash water and loading pad runoff in asphalt-lined retention basins. They use a portion of this collected water to make brine at approximately 25 stations. The retention basins are sized such that they are able to collect not only wash water, but also all runoff from each maintenance station site. Water that is not used for the production of brine evaporates, allowing for the removal of sediment once a year to a landfill (Bernhard, 2003). The Minnesota DOT experimented with the use of runoff from its salt storage facilities to make brine but found they were generating far more brine than they could use and subsequently halted the brine-generating process (Vasek, 2003). The City of Calgary reportedly uses solar powered pumps to pump water from collection ponds to the top of their maintenance yard, thereby increasing evaporation by allowing the water to flow across the asphalt surface (R. Hodgins, unpublished data). The Kentucky DOT has a National Pollutant Discharge Elimination System (NPDES) discharge permit that allows them to discharge water collected in their basins provided chloride concentrations are below 1200 mg/L (Jett, 2003).

The New York State DOT (Anderson, 2004), the Ontario Ministry of Transportation (Blackburn, 2004), and the Colorado DOT (Santangelo, 2004) are all using or developing systems to treat wash water resulting from the cleaning of vehicles used for the application of deicing chemicals;. Colorado's system cleans and recycles the water using a series of filters. Reportedly, all contaminants were lowered to drinking water standards with the exception of chlorides. Consequently, they are testing other materials that can be used to impregnate the filters to aid in the removal of chlorides (Santangelo, 2004). New York is in the process of constructing facilities using crushed glass as a filtering medium for the wash water prior to it going to an evaporation pond (Anderson, 2004). The Ontario Ministry of Transportation recycles their wash water for the production of brine (Blackburn, 2004).

Quality and Quantity of Salt-Contaminated Water

Water Quality Constituents

Table 1 presents average concentrations of chloride, TSS, and oil and grease for each VDOT district. The chemical composition of the detention pond water was quite varied, with chloride concentrations ranging from 140 to 3100 mg/L. Based on the standard deviation of the sample population, it can be predicted that 95% of VDOT's ponds will have chloride concentrations below 3200 mg/L. The statewide average chloride concentration was 1600 mg/L. In comparison, as stated previously, the Kentucky DOT has a NPDES permit to release water from its salt water basins provided the chloride concentration is below 1200 mg/L. Almost all of the chloride concentrations were significantly greater than state and federal regulatory guidelines for drinking water and surface water quality criteria, with individual values routinely exceeding 2000 mg/L. The Virginia anti-degradation limit for sodium is 270 mg/L (Virginia State Water Control Board, 2004), and the U.S. Environmental Protection Agency's National Secondary Drinking Water Regulation maximum contaminant level for chloride is 250 mg/L (U.S. Code, 2002). These secondary standards are non-enforceable guidelines for contaminants that could cause cosmetic or aesthetic (taste/odor) effects in water (U.S. Code, 2002). In addition, even though 45 chloride samples were analyzed, all the samples were collected during a year when the statewide precipitation was the highest it had been in 40 years. It is not unreasonable to assume that this resulted in a higher than normal dilution of the chlorides collected in the ponds. Therefore, sampling during drier years would likely result in higher measured chloride concentrations.

TSS values ranged from 3 to 270 mg/L, with a statewide average of 20 mg/L. Ninety-five percent of all of VDOT's ponds would be expected to have concentrations below 100 mg/L based on the standard deviation and average of the concentrations for the samples collected. The 270 mg/L concentration found at one of the sites appears to be an anomaly. These low concentrations are the result of the sediment settling after the water enters the ponds. Most of the pond bottoms did have significant accumulations of sediment. The low TSS concentrations are advantageous to all three of the treatment systems being considered.

Oil and grease concentrations ranged from less than 2 mg/L to 193 mg/L. With the exception of the highest reading, almost all of the sites had relatively low concentrations (<6 mg/L), as indicated by the statewide average oil and grease concentration of approximately 2 mg/L. Again, these low concentrations are beneficial with respect to the treatment systems VDOT could potentially use.

Table 1. Mean Concentrations of Chloride, Total Suspended Solids, and Oil and Grease in Samples Collected from Saltwater Storage Ponds in VDOT Districts

Sampling Site (District)	Chloride (ppm)	Total Suspended Solids (mg/L)	Oil and Grease (mg/L)
A	942	8.8	4.5
B	597	14.3	0.4
C	2118	10.2	1.2
D	1807	8.7	1.7
E	1322	5.3	1.8
F	1825	15.0	2.0
G	2604	23.0	1.0
H	1665	65.0	2.2
I	1578	33.0	39.0

Volume of Runoff

Measured pond areas ranged from 38 m^2 to 1350 m^2. Pond volumes were extremely varied, with measured values as low as 38 m^3 and as high as 568 m^3. Salt-loading-pad areas ranged from 66 m^2 to 2000 m^2. A typical layout for a storage site with an average-size pond and loading pad is shown in Figure 3. The average runoff areas, pond volumes, and salt water storage values calculated for each district are shown in Table 2.

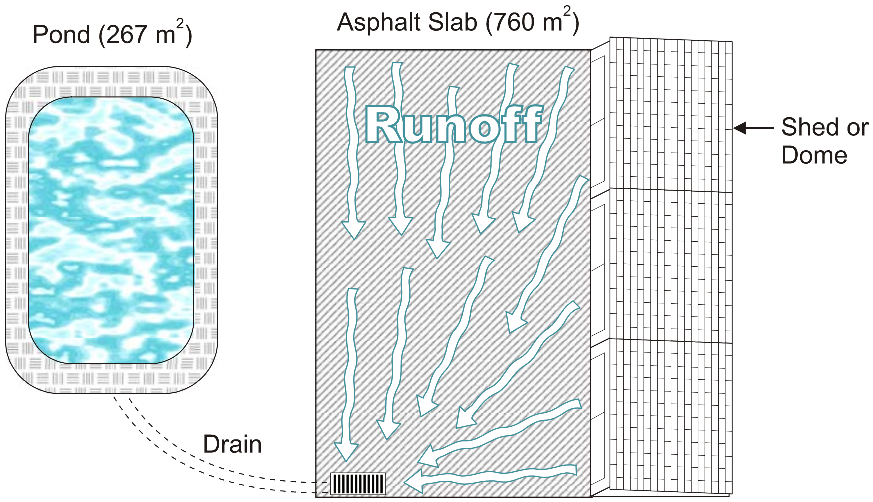

Figure 3. Diagram of Typical Layout of Salt Storage Facility with Average Size Pond and Loading Pad.

Table 2. Average Runoff Areas, Pond Areas, and Pond Volumes for VDOT Area Headquarters and Estimated Pond-Storage Volumes for VDOT Districts

Sampling Site (District)	Runoff Area (m^2)	Pond Area (m^2)	Pond Volume (m^3)	Pond Volume (gal)	No. Sites/ District	District Storage Volume (gal)
A	272	215	321	84,667	41	3,471,353
B	616	167	198	52,306	25	1,307,652
C	651	196	142	37,486	24	899,665
D	277	196	202	53,363	28	1,494,157
E	1,207	102	104	27,474	39	1,071,482
F	2,336	640	247	65,251	17	1,109,259
G	508	128	265	70,006	46	3,220,258
H	489	164	371	97,929	36	3,525,430
I	492	597	717	189,411	36	6,818,810
Total					292	22,918,066

Table 3 shows the treatment volumes calculated for each district. Minimum (1965 rainfall data), average (1973 rainfall data), and maximum (2003 rainfall data) volumes were calculated assuming precipitation was collected for the entire year and for the 5-month winter maintenance period. The evaporation data collected for Virginia did not have values for the months of November, December, January, February, or March, so no loss in treatment volume was assumed for the winter months.

Table 3. Treatment Volumes for VDOT Districts

District	Annual Treatment Volumes (gal)			Winter Treatment Volumes (gal)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
A	2,993,625	4,162,455	5,720,895	1,740,258	2,748,915	3,545,451
B	3,438,175	5,083,195	8,243,365	1,727,271	2,363,634	3,082,248
C	0*	4,433,237	6,078,257	219,913	2,341,989	2,948,049
D	900,167	2,129,603	2,869,862	701,298	1,558,440	1,588,743
E	10,571,211	14,164,281	17,194,581	4,030,299	6,363,630	6,493,500
F	7,264,381	10,641,001	18,606,361	3,796,533	5,151,510	6,926,400
G	3,721,483	6,665,203	11,297,233	1,783,548	3,562,767	3,735,927
H	2,818,428	5,619,291	8,433,141	1,891,773	3,229,434	3,246,750
I	3,652,935	5,730,855	9,150,765	2,662,335	3,679,650	4,320,342
Total	35,031,741	58,629,120	87,594,459	18,553,228	30,999,969	35,887,410

*Evaporation greater than precipitation.

The data in Tables 2 and 3 reveal the significant volume of salt-contaminated water generated and stored at facilities throughout Virginia. For an average rainfall year, approximately 60 MG of contaminated runoff water is generated from the 292 facilities. Even if only the runoff generated during the 5-month winter maintenance season is considered, the volume of salt-contaminated water is in excess of 30 MG.

It is also interesting to note the large variance in both pond volumes and runoff area from district to district (Table 2). This is likely caused by inconsistencies in either loading-pad design or pond sizing. Ponds and pads have been constructed based on current site characteristics as opposed to runoff expectations and evaporation rates. Figure 4 shows a comparison of loading pad sizes to pond storage volumes. It is evident from this figure that there is a very weak relationship between these two parameters.

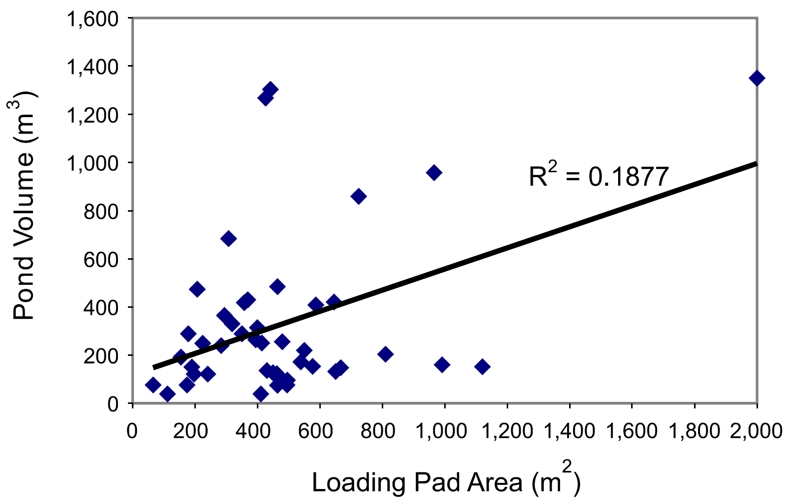

Figure 4. Loading Pad Area versus Pond Volumes for 45 Sample Locations.

Current VDOT Management Practices

In Virginia, supervisors of maintenance area headquarters provided information related to their disposal methods and the costs of stormwater management. Handling practices were quite varied. Some locations never have their ponds pumped. Others use VDOT employees to pump, haul, and spray the salt water captured in the ponds on gravel roads. Based on billing rate information provided by area headquarters for trucks, pumps, and drivers, the costs for this type of procedure are approximately $0.08/gallon. The majority of the area headquarters sampled hire a contractor to pump, haul, and dispose of captured salt water. The average per gallon cost for this disposal method is approximately $0.13. A limited number of others discharge the contaminated stormwater runoff to POTW systems. No cost estimates were obtained for this method of disposal. The frequency of pumping varied significantly from location to location, as did the total volume of disposed water. Some facilities are pumped up to 13 times a year, and others are reportedly never pumped. Some reported pumping even during the summer, and others only during the winter.

Evaluation of Other Management Alternatives

There are two possible alternative approaches VDOT can apply to manage stormwater runoff at salt storage facilities. First, additional management strategies can be employed to reduce the volume of salt-contaminated stormwater runoff generated at each facility. Second, the runoff that is captured can be treated to remove the salt and then released back to the environment. It is also possible that a combination of these two approaches can be employed.

Reduction of Runoff Volume

At present, stormwater runoff is directed to the storage ponds on-site. However, if salt deliveries and loading operations for a majority of facilities were limited to the five winter maintenance months (November through March), the diversion of runoff water during the remaining seven months from the ponds to a natural discharge point would not result in environmental salt contamination. This is consistent with current VDOT guidelines; however, it does not appear that these guidelines are being followed in all cases. Based on the storage volumes measured and the expected treatment volumes calculated, the number of times each pond in each district would need to be pumped or emptied is shown in Figure 5. This information highlights the benefit of diverting all water during the non-winter months. It also shows that for particular districts, storage ponds would have to be pumped more than once even if only runoff from the winter months was collected in the storage ponds. Multiplying the number of times pumping would be required for each district for an average precipitation year by the number of ponds per district results in a total of 628 pumping events required statewide, or an average of 70 events required for each district each year. It should be noted that this calculation assumes that all runoff water is collected and none of the water is sent to POTWs or used for roadway applications.

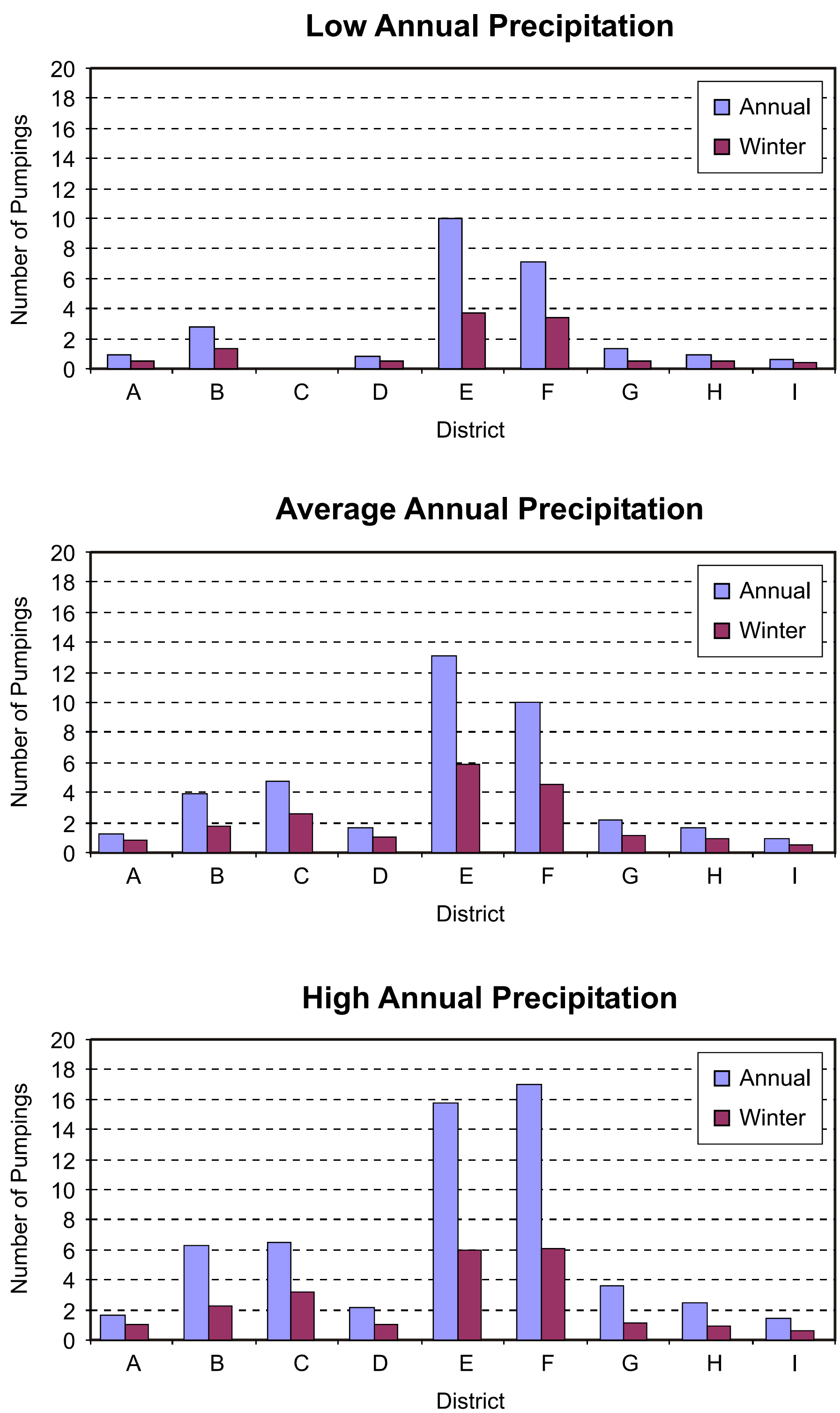

Figure 5. Average Number of Treatments Required for Each of VDOT's Salt Ponds Assuming Low, Average, and High Annual Precipitation.

Even with the evaporation losses that occur during the summer months, nearly twice the volume will require treatment if water is not diverted during the non-winter months. Diverting this water would in many cases require facility modifications, as many of the sites visited as part of this investigation do not have the valves or outlets that would be required to allow for this. Although retrofitting sites so that water diversion is possible would require substantial one-time capital costs, the potential savings from diversion are quite significant. If one assumed that VDOT was currently capturing 100% of the water that resulted from loading pad runoff year round but was then diverting all runoff collected from April through October, then VDOT could theoretically save approximately $4 million/year by retrofitting the sites. This scenario assumes average precipitation and that all water disposed of is done so at a cost of $0.13/gallon. In reality, VDOT is not paying this fee for all water that is captured, as previously explained.

Another method of reducing runoff entering the collection basins is simply reducing the size of the loading pads. Assuming average precipitation, each square foot of loading pad is collecting just over 26 gallons of water per year. Assuming VDOT pays $0.13 per gallon to dispose of this water and that 100% of the water is collected for the entire year, each square foot of loading pad results in $3.40 in water disposal costs per year. If runoff is collected during only the winter months, each square foot of loading pad results in disposal costs of $1.46 per year.

During site visits and discussions with VDOT staff, field personnel mentioned that the volume of salt-contaminated runoff water could also be greatly reduced by construction of steel-frame, open-sided roofs over each salt loading pad. The sizing and design of these structures would be very site specific, and although the initial capital costs of this approach would be substantial, operating and maintenance costs over the ensuing 10-year period would likely be small. Runoff collected at a site would be limited to precipitation that blows onto the pad from the sides and possibly rinse water from cleaning salt spreaders and the pad itself. Although it is difficult to predict this runoff volume, it is likely that the runoff produced would be less than the total evaporation for most sites. Therefore, it is reasonable to expect that no additional water treatment or management activities would be required for sites where loading pads were covered.

In addition to the significant capital costs required to construct open-sided coverings for loading pads, properly determining the size of the structures would be critical. As previously shown, the loading pads themselves are quite large. Because covering the entire loading pad would be impractical for most sites, the optimum length and width of the cover would need to be determined to ensure sufficient room to maneuver trucks and loaders. Diverting water from adjacent paved areas by way of berms would also be necessary to ensure that only water from the covered portion of the loading pad was directed to the storage pond. To accommodate dump type tractor-trailer unloading of salt at the larger storage facilities, the minimum height of the structure would need to be 35 feet. This height would make the structure itself more susceptible to wind uplift and the pad more susceptible to precipitation blowing in from the sides. It may be possible to cover pads where tractor-trailers do not have to be accommodated with lower structures, with the height being predicated on the height of the front loaders used. Based on construction costs for canopies constructed in conjunction with fuel pumps (Kinker, 2004), it is assumed that these type of structures could be built to serve VDOT's loading pads for approximately $50/square foot.

Runoff Treatment Alternatives

The three water treatment technologies reviewed to determine their feasibility in removing dissolved ions from water were ion exchange, electrodialysis, and RO. A brief description of each is provided here along with a general assessment of whether it would be technically feasible for VDOT to use based on the volumes of water to be treated, the starting TSS and chloride concentrations, and the assumed chloride target concentration of 250 mg/L. The approximate per gallon cost of treating salt water with each technology is also provided.

Ion Exchange

In an ion exchange treatment process, salt-contaminated water is pumped through a number of columns containing ion-exchange resins. The resins are characterized by ion-exchange sites that are initially saturated with H^+ or OH^- ions. When water containing ions such as Na^+ or Cl^- is pumped through the columns, the Na^+ ions exchange with H^+ ions, and the Cl^- ions exchange with OH^- ions. The H^+ and OH^- ions released into solution form H_2O, resulting in no net pH change of the treated water. After the exchange sites on the resins are depleted, flushing them with concentrated solutions of sulfuric acid and sodium hydroxide can regenerate the resins.

Generally, it was found that water with relatively high levels of total dissolved solids (e.g., greater than 400 mg/L) requires treatment beyond ion exchange alone. VDOT's average chloride concentrations are significantly higher than 400 mg/L, so this fact alone seems to preclude the use of this technology without pretreatment. In addition to this limiting factor, ion exchange also requires on-site storage of the caustic and acid regeneration solutions that would pose additional liability and risks for VDOT. The highly saline wastewater resulting from the regeneration process would also require a separate disposal mechanism (Benjamin Johnson, Marlo, Inc., unpublished data).

The cost of water treatment by ion exchange (including maintenance) ranges from $0.002 to $0.003 per gallon treated exclusive of disposal costs of the concentrated rinse solution produced during resin regeneration (Benjamin Johnson, Marlo, Inc., unpublished data).

Electrodialysis

Electrodialysis is an electrochemical separation process that uses two types of membranes: one permeable to cations, the other to anions. Direct current between two electrodes provides the driving force for the ions moving through the membranes. In real-world applications, hundreds of compartments are formed by the alternating membranes to produce a stream containing the concentrate and "clean" stream. Cargill, Inc., one of the world's largest distributors of deicing salt, provided most of the information related to this technology. Specifically, Cargill constructed and is operating an electrodialysis system to treat the runoff at their Lansing, New York, bulk salt storage facility. With this system, they are capable of treating very large volumes of water with significantly higher chloride concentrations than VDOT is currently capturing (50000 to 80000 mg/L versus 2500 mg/L). After lowering the chloride concentrations to approximately 40000 mg/L, Cargill is permitted to discharge the effluent to a nearby river (Mark Crandall, Cargill, Inc., unpublished data).

Due in part to this research effort, Cargill is in the process of designing and testing a smaller electrodialysis system based on VDOT's typical chloride concentrations. They have admittedly run into several problems that they have not experienced when aiming for higher effluent values with their larger system: increased water temperature and very low conductivity. Both of these problems stem from the relatively low chloride concentrations. Design and operation changes are being made to their test system in an attempt to overcome these two problems (Mark Crandall, Cargill, Inc., unpublished data). Cargill has been extremely helpful with this effort to identify a feasible technology and their testing of the system to meet VDOT's effluent goals continues.

No other electrodialysis applications that could be directly compared to VDOT's intended use were found. Although the final testing of Cargill's system is not complete, the very early cost estimates for treatment are in excess of $1/gallon. A Cargill representative emphasized that these estimates were admittedly high and will be revised as additional data become available following more complete testing (Anthony Hensley, Cargill, Inc., unpublished data).

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 applying an external pressure on the concentrated 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.

Unlike ion-exchange systems, RO systems do not require caustic or acid solutions for membrane regeneration, but they do require occasional membrane cleaning and eventual replacement. RO generally can achieve 90% to 98% removal of dissolved solids. This removal rate is satisfactory to treat the runoff water to a Cl^- concentration less than 250 mg/L, which is the U.S. Environmental Protection Agency's National Secondary Drinking Water Regulation maximum contaminant level (U.S. Code, 2002). However, the concentrated waste-stream discharge rate from the process can range between 20% and 50% of the inflow discharge. For treatment streams with only a few inorganic ions and low concentrations of TSS and organic constituents, concentrated waste-stream generation is likely to equal 20% to 30% of the inflow discharge.

The RO process is relatively sensitive to TSS concentrations greater than a few milligrams per liter. Based on the TSS values measured as a part of this study (Table 1), it may be necessary to pre-treat the pond water by ultrafiltration to remove TSS and prevent RO membrane fouling. Implementation of RO or ultrafiltration/RO systems would require consideration of several additional factors. For a mobile system, there must be treated-water discharge locations at each storage facility. Discharge sites might include sanitary/stormwater sewers, natural surface-water bodies (e.g., rivers or lakes), or spray irrigation on lots. Concentrated waste streams resulting from the RO treatment process would require storage prior to off-site disposal. It may be possible to have the existing ponds serve as storage for the waste stream. It is also possible that a portion of the concentrate could be used as the brine used for pre-wetting dry salt discharges to roadways. As discussed earlier, several states are doing this successfully.

The cost of water treatment by RO (including maintenance) is estimated to be about $0.00075 per gallon, not including the disposal costs of the concentrated waste stream generated by the process (Benjamin Johnson, Marlo, Inc., unpublished data). Another way of deriving anticipated costs with RO treatment are to use known capital costs (100 gallons per minute [gpm] RO unit = $62,000, replacement membranes = $14,400) and to assume a maximum lifetime throughput for the unit (120 MG). In this scenario, the cost per gallon is $0.00064, but this does not take into account actual operational costs or disposal costs of the waste stream. This scenario also assumes a very long membrane life.

The cost of water treatment by ultrafiltration is comparable to the cost of RO treatment. Therefore, combining ultrafiltration with RO (including maintenance) can be expected to cost about $0.0015 per gallon. The costs shown here for RO and ultrafiltration/RO do not include transportation costs, operator costs, or the cost to dispose/reuse the concentrated waste stream. For transportation, a portable, 100-gpm ultrafiltration/RO unit could potentially service each transportation district. The treatment system could, therefore, be driven to each VDOT storage location and used to treat the pond water on-site. The cost to purchase and maintain a truck for the water treatment system is approximately $12,000 per year. A full-time driver and operator for a 100-gpm treatment system (including salary, benefits, and overhead costs) is approximately $90,000 per year. Assuming that 25% of the treated water volume is converted to a concentrated waste stream that requires off-site disposal at a cost of $0.13 per gallon, the treatment cost of an ultrafiltration/RO system (assuming an average-precipitation year with treatment of year-round runoff water) is about $0.047 per gallon.

For an RO system not requiring ultrafiltration, the treatment cost would be about the same, as the savings from the capital costs of the ultrafiltration unit are small compared to the off-site disposal costs of the RO concentrated waste stream and the annual operator and transportation costs. The overall treatment cost of a mobile ultrafiltration/RO system ($0.047) is less than half the cost currently paid by VDOT for off-site wastewater disposal ($0.13). The cost is also 58% of the cost paid by VDOT to use the wastewater for dust control on gravel roads ($0.08). For a statewide annual treatment volume of 58.6 MG, this could potentially result in annual saving ranging from $1.9 million to $4.9 million, assuming all water was captured and treated or disposed of in some manner.

CONCLUSIONS

- There is great variability in the size of VDOT's loading pads and associated stormwater basins. This results in a wide variation in the amount of salt water collected and stored at the different facilities.

- VDOT's most commonly used disposal method (pump, haul, and dispose of at a POTW) costs approximately $0.13/gallon.

- Whatever treatment system VDOT decides to employ, significant cost savings could be realized by reducing the volume of water directed to the water collection ponds through a combination of loading pad size reduction, diversion valve installation, and consistent implementation of existing guidelines.

- Neither ion exchange nor electrodialysis appears to be a technically feasible treatment option that VDOT could implement immediately.

- RO and ultrafiltration/RO appear to be technically feasible water treatment options for reducing chlorides to a concentration of 250 mg/L or less. In addition, these treatment costs are as much as 170 times less expensive than the water disposal costs currently being spent by VDOT to remove the salt-contaminated pond water from salt storage facilities.

- By employing additional management strategies and alternative treatment technologies such as RO, VDOT could realize savings in excess of $2 million per year.

RECOMMENDATIONS

1. *VDOT's Environmental Division should further explore the possibility of using RO as a water treatment technology for water captured at salt storage facilities.* It is proposed that this be done by way of a pilot study with the assistance of RO vendors during the upcoming winter season. This pilot should provide more accurate data on the operational costs of RO systems, the frequency of filter replacements required, and the potential for using the waste stream generated as a result of the treatment.

2. *VDOT should strongly consider the feasibility of reducing the size of the bermed loading pads at sites where the pads are larger than necessary to accommodate loading.*

3. *VDOT should consider constructing an open-sided steel framed structure to cover a loading pad at one of its facilities.* This would provide more information on whether or not this type of covering would be feasible for additional sites throughout the state.

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