Salt Shed Design Template

Final Report

research for winter highway maintenance

Wilfrid Nixon and Associates

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16. Abstract
This project was undertaken to develop tools and guidelines for designing efficient, sustainable, and environmentally compliant salt storage facilities for winter maintenance operations. The project addressed critical issues such as environmental impacts of chloride runoff, optimization of facility design and location, and the development of tools to support agencies in managing these challenges effectively.
The research involved a comprehensive literature review, a national survey of current practices, and an analysis of the collected data. Key findings highlighted the importance of covered storage, impermeable surfaces, and efficient drainage systems in minimizing environmental contamination. Survey insights revealed diverse facility designs, with capacities ranging from 40 to 15,000 tons, and underscored the need for durable materials, protective coatings, and efficient loading systems.
The project resulted in two practical tools: a spreadsheet for estimating facility size based on storage needs and structure type, and a checklist to guide the design process, considering factors like site selection, environmental constraints, and structural requirements. These tools provide actionable solutions for addressing long-term operational needs, scalability, and sustainability.
This report concludes with recommendations for designing facilities that integrate environmental safeguards, operational efficiency, and adaptability to future demands. The outcomes of this project equip agencies with the resources to enhance winter maintenance operations while ensuring compliance with environmental standards. These tools and insights represent a significant step toward the strategic development of salt storage facilities nationwide.

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EXECUTIVE SUMMARY

Project Overview The "Salt Shed Design Template" project, under Project Number TPF-5(353), aimed to create effective tools and guidelines for designing salt storage facilities. These facilities are critical for winter maintenance operations, ensuring environmental compliance, operational efficiency, and adequate salt storage for varying needs. The project involved five key tasks: literature review, survey of current practices, data analysis, tool development, and final reporting.

Key Findings

1. **Environmental Considerations:**
   - Inadequate storage facilities lead to chloride contamination, harming ecosystems.
   - Proper drainage, impermeable pads, and covered storage mitigate environmental risks.
   - Reusing runoff for brine production can significantly reduce environmental impact.
2. **Optimizing Facility Design:**
   - Facility types include domes, sheds, and fabric-covered structures, each with trade-offs.
   - Efficient loading systems (e.g., conveyors) increase storage capacity and safety.
   - Structures must accommodate a five-year average of salt usage, with adjustments for growth and climate change.
3. **Survey Insights:**
   - Data from 16 agencies revealed varied practices, with storage capacities ranging from 40 to 15,000 tons.
   - Major concerns included durability, maintenance, and protection against salt corrosion.
   - Successful facilities featured robust designs, efficient loading/unloading systems, and environmental safeguards.
4. **Tool Development:**
   - Two tools were created:
     - A spreadsheet for estimating facility size based on storage needs and structure type.
     - A checklist for comprehensive design considerations, including site selection, environmental factors, and structure type.

Recommendations

1. **Design Practices:**
   - Incorporate modular designs tailored to specific operational and environmental contexts.
   - Use conveyor systems for efficient loading to maximize storage capacity.
2. **Site Selection:**
   - Prioritize central locations to minimize travel time for maintenance operations.
   - Evaluate soil quality, drainage, and proximity to environmentally sensitive areas.
3. **Sustainability:**
   - Integrate runoff capture and brine production systems to reduce environmental impact.
   - Use durable materials and protective coatings to extend facility lifespan and reduce maintenance.
4. **Planning for Growth and Change:**
   - Account for lane-mile growth and potential climate change impacts on salt demand.
   - Design flexible facilities with scalability options.

Conclusion This project provides a robust foundation for the design of salt storage facilities, addressing operational efficiency, environmental sustainability, and long-term durability. The tools and guidelines developed will enable agencies to optimize resources and enhance winter maintenance operations.

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This project was funded by Clear Roads and the Minnesota Department of Transportation. The time and support provided by the Clear Roads Project Subcommittee was invaluable and the project could not have been completed without their input and advice.

The participants in the survey (detailed in Chapter 3) provided significant insight into the processes involved in salt storage facility design and development. This insight helped to guide the project significantly. In addition, information provided by Chris Griessing of the Essential Minerals Association on storage of other granular materials was very helpful.

The research team is most grateful for all the assistance received in the completion of this project.

1: Introduction and Project Overview

The purpose of this project is to develop appropriate design tools that will allow for the more efficient and effective design of salt storage facilities as part of winter maintenance operations. To achieve this purpose, five tasks were identified.

Task 1 was a review of the pertinent literature, which fell, in general, into three parts: studies relating to minimizing negative environmental impacts due to salt run-off from sub-optimal storage facilities; studies examining the optimal placement of salt storage facilities within an area of operations that the facility will serve; and studies examining the design of salt storage facilities. This literature was examined to provide guidance on the development of design tools.

Task 2 was a national survey of current practice in salt storage facilities, including state and some local agencies. The intent of this task was to identify good or best practices in the design of such facilities.

Task 3 was the analysis of the information collected in tasks 1 and 2, with the goal of identifying overarching insights that could then be incorporated into the design tools that were to be developed as part of the project.

Task 4 was the creation of the design tools, along with testing of those tools to ensure that they were fully functional. Two tools were developed. One provides guidance on the appropriate sizing of a facility (of various structural types) to store certain quantities of salt. The second provides a detailed checklist of steps that must be taken as part of the facility design process.

Task 5 is the creation of the various final reports and end products/deliverables of the project.

2: Literature Review – Task 1

2.1 Introduction

The literature relating to salt storage for winter maintenance operations in general falls into three parts. Some reports address the issue of managing the site at which the salt is stored to minimize the run-off of chloride contaminated water from the site. Some deal with the placement of salt storage facilities on a highway network to optimize winter operations by minimizing the deadhead distance required for trucks to refill. And a third group of literature examines the issue of salt storage facilities design. Of these three groups of literature, the third is the most pertinent to this project (the creation of design templates for salt storage facilities). Nonetheless, the review will examine the first two groups of literature for completeness.

Minsk (1998) discusses the rationale behind the need for good salt storage facilities, noting that in particular rainfall will cause substantial losses from uncovered salt piles, citing Hogbin (1966) who estimated that for a total rainfall of 15 inches (spread over a summer season) a typical uncovered salt pile will lose 2% of its total mass, and that the runoff from such losses will be essentially saturated salt brine. Based on that result, the need for a covered stockpile is evident.

Other studies have examined the fate of chlorides that have been released into the environment from storage facilities (see e.g., Herb et al., 2017). These have included studies examining ways of reducing chloride impacts (Fay et al., 2013) and of collection runoff from salt storage and other facilities (Golub et al., 2008).

2.2 Minimizing Chloride Contamination

The drawbacks of chloride contamination on the environment are well known. In short, if streams and lakes get overly high levels of chlorides then wildlife is negatively impacted. Both chronic and short-term levels of chloride have been established by the Environmental Protection Agency, and some states have even more rigorous standards that they require for streams rivers and lakes, depending on the use of the water body. Numerous papers and reports have been published that address the issues of environmental impacts due to improper salt storage. For example, Hanneman (2008) provided an overview of the ways in which improper storage could negatively impact the environment.

There are primarily three ways in which chloride contamination can occur in relation to salt storage. First, if salt is not protected from rainfall, it will get wet, some of it will dissolve, and the salt brine thus formed will flow from the pile into the surrounding area. This brine will then either flow into adjacent water bodies (lakes, rivers, streams, etc.) or seep into the soil, thus potentially contaminating groundwater. This source of contamination is best addressed by storing the salt in a structure that provides protection against precipitation. This was detailed in the Salt Storage Handbook published by the Salt Institute (Salt Institute, 2015).

Second, if a salt pile is located such that water will flow into the pile, then the flowing water will create brine and then go on to cause contamination as above. This is an issue of topography and can be addressed by appropriate siting of the salt storage structure, and also by providing drainage around the salt pile that can both intercept inflowing water and capture any outflowing brine. The runoff captured by such surrounding drainage systems should be diverted to appropriate treatment facilities when necessary.

Third, when salt is either transferred into storage, or is taken from storage and loaded onto snow-plow trucks, the salt can be spilled, and this spillage, if not collected, can create a brine that may cause contamination as indicated above. This can be addressed in a number of ways. First, if the facility is suitable, then both unloading and loading can be done inside the structure which contains any spillage and allows for much easier cleanup of the same. If this first approach is not possible, then loading and unloading should be done on an impermeable pad with suitable drainage protection. Again, this will simplify cleanup. Note that a number of agencies use a pit-based conveyor system (see Figure 1) that allows the salt to be easily moved into storage.

Figure 1 A Pit Type of Conveyer System for Loading Salt into Storage

The issue of contamination from runoff was considered in some detail by Fitch et al. (2004) in a study conducted for the Virginia DOT (VDOT) examining how chloride contaminated runoff that was captured in stormwater basins at VDOT salt storage facilities might be treated more efficiently. They examined three possible treatment methods: reverse osmosis, electrodialysis, and ion-exchange resins. In addition, they considered costs associated with pumping of the water from their stormwater basins (at costs between $0.08 and $0.13 per gallon), savings possible by diverting run-off away from their stormwater basins during non-winter months (possibly as high as $4 million per year for the whole state), and the costs associated with placing open-sided coverings over the loading pads (from which the chloride contaminated run-off came) at an estimated cost of $50 per square foot of covered pad.

The final conclusions of the Fitch et al. (2004) study were that the only feasible solution of the three considered was reverse osmosis (possibly combined with ultra-filtration). They estimated that if this were implemented then VDOT could realize savings in excess of $2 million per year.

A follow-on study was conducted (Fitch et al., 2006) to test more thoroughly the possibility of using reverse osmosis (RO) to manage chloride contamination. They found that the RO method was very effective at reducing chloride contamination to levels below the U.S. Environmental Protection Agency's

National Secondary Drinking Water Regulation maximum contaminant level (250 mg/L for Chloride – U.S. Code, 2021). However, they did note that there were several challenges with using this method.

First, the water in the stormwater detention ponds typically had high levels of turbidity and removal of this turbidity prior to the RO process was challenging, primarily because the microfiltration units were prone to clogging. Secondly, the waste stream produced by the RO process would need to be handled in some way. The waste stream could be used as "feed stock" for salt brine production, but at the time of the study, VDOT was not using salt brine (for direct liquid application) in large quantities in all locations. Their final conclusion was that given the additional costs incurred by the frequent cleaning of the microfiltration units, the costs of the RO method did not provide sufficient cost savings to justify the expense of installing RO systems at all VDOT sites.

A third study (Fitch et al., 2008) examined in detail the possibility of using the runoff for brine production. They considered two end uses of the brine – one where the brine was only used for pre-wetting solid salt, and one where both pre-wetting and direct liquid application of salt brine was used. The latter situation will obviously use more brine than the former and will thus allow a greater percentage of the stormwater run-off to be recycled. They examined 72 scenarios in which types of application (pre-wet only or pre-wet and direct liquid application), accumulated stormwater run-off volumes (from a low of 19 million gallons to a high of 88 million gallons), and annual salt purchases (from a low of 139,000 tons to a high of 519,000 tons) were varied and determined the payback period for each scenario. Using a disposal cost of $0.13 per gallon for the run-off they found payback periods of between 3.6 and 0.6 years. Unsurprisingly, they recommended that a pilot program be undertaken to test this approach in more detail.

A study that compared indoor and outdoor loading of trucks with salt (Ostendorf et al., 2012) indicated that significant reduction in wasted salt could be achieved by loading trucks inside buildings rather than outside. Specifically, when loaded outside, approximately 0.3% of the salt that was loaded was wasted (due to spillage that could not be recovered). In contrast when trucks were loaded inside, only 0.06% of the salt was wasted.

Alleman et al. (2004) examined a process whereby truck wash water could be recycled to make salt brine, thus reducing run-off of chloride contaminated wash water from Indiana DOT facilities. While this project did not address storage per se, clearly if wash water is being recycled to help make brine, then less total salt is required, thus reducing (somewhat) storage needs. As part of this process, Indiana DOT has built some salt storage facilities that combine salt storage with brine making and with loading facilities. While this requires a larger structure footprint, the benefits justify the added costs.

2.3 Optimizing Salt Storage Locations

A suitably located salt storage shed can have a major beneficial impact on winter maintenance operations. It is thus not surprising that there have been a number of studies examining how to optimize the location of such facilities. The challenge with such studies is that often the facilities are already in existence and so discovering that they are sub-optimally located may not be particularly helpful. However, when dealing with situations where new facilities are to be located or where satellite facilities are to be placed, this approach has significant benefits.

A study by Yang et al. (2011) investigated placement of salt storage facilities using optimization methods to determine facility locations in South Korea, in response to a series of severe winter storms in early

2010. Their findings provided a series of recommended salt storage locations to transportation authorities in South Korea.

Dowds et al. (2015) conducted a study investigating the optimal location of satellite salt storage facilities for the Vermont Department of Transportation. The purpose of the study was first to develop a method to identify the optimal salt storage facility to add to a group of existing facilities. This method was then used to determine a listing of possible locations for siting such facilities in the State of Vermont. The metric they used to determine optimal locations was to maximize the number of lane miles that would be serviceable within a twenty-minute timeframe from the new set of salt-loading locations (which included existing locations). They considered interstate and non-interstate miles separately in their analysis and developed a listing of potential satellite salt storage locations that were rank ordered by the benefits that they gave.

2.4 Salt Storage Facilities Design

In general, there are three types of salt storage structure – domes, elongated domes, and sheds. Figures 2, 3, and 4 show each of these structures, respectively. In addition to these three types, the fourth option of a structure with a covering over it (see Figure 5) can be added. Each of these options will obviously have benefits and drawbacks.

The Salt Storage Handbook (Salt Institute, 2015) discussed these options and clarifies that the choice between them will be a function of the volume of salt that must be stored, the site layout, environmental issues on and around the site, and the availability of funds to construct the facility.

In addition to environmental concerns alluded to above, the Salt Storage Handbook includes much information on how to size storage buildings depending on how much salt is to be stored in them. The Handbook suggests that facility should be sized so that 100% of the five-year average salt usage can be stored in the structure. While the handbook does include some tables relating storage needs and building size, they do not have the degree of specificity identified as being important for this project.

Figure 2 Salt Storage Dome

Figure 3 Elongated Salt Storage Dome

Several States have examined the effectiveness of their salt storage facilities. Colorado DOT developed a method to estimate the environmental risks at each of their facilities (Johnson et al., 2004). The purpose of the program was to prioritize cleanup of contaminated locations as a function of the vulnerability of each location, thereby ensuring that the most vulnerable locations were identified and investigated first.

Ohio DOT conducted a study to address two issues – an inability to maximize salt storage in dome structures, and an inability to maintain accurate salt inventory (Walsh et al., 2015). Of note to this project, the study reported that the use of a conveyor system increased the possible salt storage in a given dome structure.

Figure 4 Salt Storage Shed (essentially rectangular)

Figure 5 Fabric Covered Salt Storage Facility

It was also noted in the Salt Storage Handbook that facility layout was an important factor to consider whenever a new salt storage facility is being designed. And that same handbook noted that not only did conveyer systems allow more salt to be stored in a given structure, but also the use of conveyers especially for placing salt inside structures was much safer than the use of front-end loaders to try and pile salt up as efficiently as possible.

2.5 Storage of Other Granular Materials

The literature review explored in some depth the possibility that there might be useful information to be found in studies on the storage of other granular materials. Unfortunately, after extensive discussions (Greissing, 2021; Bennett, 2021) it became clear that this was not the case. Other industrial minerals (see IMA-NA, 2021) are not, for the most part, soluble in water, and as such they do not need to be stored under cover to avoid material loss. In fact, some moisture in these outside stockpiles is desirable since it reduces the tendency of the material to blow away under the impact of wind.

Some information can be obtained from the storage of farm produce, in particular of grain. Grain is typically conveyed into a silo system, and from there is gravity loaded into trucks (from above). The trucks then discharge the grain from the bottom of the truck body when they reach the grain processing facility. While some European countries do use a similar system for salt storage (DeVries, 2019) it has not been adopted in the United States.

2.6 Conclusions

Based on the literature that was reviewed as part of the project, the following general points were incorporated into the design guidelines:

- Drainage around salt storage structures is a very important consideration that needs to be included in the design process from the beginning. Collection of any water that has been contaminated with dissolved salt should ideally be considered as a “feed stock” for a brine making system. While wash facilities are beyond the scope of this project, the use of recycled wash water in brine making systems should also be considered.

- When sizing salt storage structures, it is important to consider how the salt will be placed in the structure. The maximum storage of salt will be achieved most readily with some sort of conveyer system to load the salt into the structure. Use of a conveyer is also a safer approach to salt storage than using a front-end loader. Depending on the choice of loading system, the storage capacity of a given structure might be very different from the maximum desired capacity.
- A system that allows trucks to be loaded inside a building is less wasteful of salt than loading trucks outside. While loading trucks will almost certainly include some spillage, if that spillage is inside, then the salt can be much more effectively recovered than if the spillage is outside.
- There is no readily available tool to calculate the required size of a salt storage building based on the amount of salt to be stored in that facility. Accordingly, one will be developed in this project, as indicated in the initial proposal.

The information gathered in the literature review provided a useful starting point for the development of the modular designs. Together with survey results, sufficient information was available to create effective design templates.

3: Survey of the Practice – Task 2

3.1 Survey Design

The purpose of the survey was to elicit information from winter maintenance practitioners around the United States on the salt storage facilities which they maintain, design, or intend to design. The survey was conducted by providing participants with questions that they may either answer directly by email or through a personal interview (conducted by Zoom or the equivalent). Results from the survey have been collected for inclusion in the final report and will also inform the project in the development of design templates.

3.2 Survey Participants

The project research team used their personal connections with individuals who have vast experience in winter maintenance operations across the United States to facilitate survey participation and maximize the value derived from the survey. In addition to identifying potential survey participants from personal connections, the team worked closely with the Clear Roads project committee to expand and augment the list of survey recipients with the goal of receiving data from several agencies. Table 1 provides the survey recipient list.

Table 1 List of Contacts.

Name	Organization	Email	Telephone
Emil Juni	Wisconsin DOT	emil.juni@dot.wi.gov	(608) 266-3833
David Gray	New Hampshire DOT	david.gray@dot.nh.gov	(603) 419-9017
Clay Adams	Kansas DOT	clay@ksdot.org	(785) 296-3233
John Angel	Nevada DOT	jangel@dot.nv.gov	(775) 834-8303
Rhett Arnell	Utah DOT	rarnell@utah.gov	(435) 979-7083
John Oliva	Caltrans	john.oliva@dot.ca.gov	(916) 654-2490
Ty Barger	Nebraska DOT	ty.barger@nebraska.gov	(402) 479-4787
Craig Bargfrede	Iowa DOT	craig.bargfrede@dot.iowa.gov	(515) 239-1355
Mark Bloome	Illinois DOT	mark.bloome@illinois.gov	(217) 782-8419
Joseph Bucci	Rhode Island DOT	joseph.Bucci@dot.ri.gov	(401) 734-4800
Brian Burne	Maine DOT	Brian.Burne@maine.gov	(207) 624-3571
Patti Caswell	Oregon DOT	Patti.Caswell@odot.state.or.us	(503) 986-3008
John DeCastro	Connecticut DOT	John.decastro@ct.gov	(860) 594-2614
Jonathan Fleming	Pennsylvania DOT	jonfleming@pa.gov	(717) 772-1771
Larry Gangl	North Dakota DOT	lgangl@nd.gov	(701) 227-6510
Mark Goldstein	Massachusetts DOT	mark.a.goldstein@state.ma.us	(857) 368-9680
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Scott Lucas	Ohio DOT	Scott.Lucas@dot.state.oh.us	(614) 644-6603
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Todd Miller	Missouri DOT	Richard.T.Miller@modot.mo.gov	(573) 751-5415
Tom Peters	Minnesota DOT	tom.peters@state.mn.us	(651) 366-3578
Jeff Pifer	West Virginia DOT	Jeff.M.Pifer@wv.gov	(304) 677-9839
Alastair Probert	Delaware DOT	alastair.probert@state.de.us	(302) 853-1305
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Cliff Spoonemore	Wyoming DOT	cliff.spoonemore@wyo.gov	(307) 777-6377
Steve Spoor	Idaho DOT	steve.spoor@itd.idaho.gov	(208) 334-8413
James Stevenson	Texas DOT	james.stevenson@txdot.gov	(515) 416-3056
Joe Thompson	New York DOT	Joe.Thompson@dot.ny.gov	(518) 457-6916
Danny Varilek	South Dakota DOT	Daniel.Varilek@state.sd.us	(605) 773-2153
Anne M. White	Virginia DOT	annemargaret.white@vdot.virginia.gov	(804) 786-3387
Larry Schneider	City of Fort Collins	lschneider@fcgov.com	
Bret Hodne	City of West Des Moines	Bret.Hodne@wdm.iowa.gov	
Ron Knoche	City of Iowa City	Ron-Knoche@iowa-city.org	(319) 430-3625
James Morin	Washington State DOT	MorinJ@wsdot.wa.gov	509-899-0435

3.3 Survey Questionnaire

The survey as sent to all those on the recipient list is shown in Appendix A.

3.4 Survey Results

3.4.1 Number of Responses

The survey was sent to 37 different organizations. In total, 16 organizations responded, with information on 21 different shed designs. All of these responses referenced storage buildings that had been constructed during the past ten years. Not all agencies answered all questions, so in several instances there are fewer than 21 responses recorded.

3.4.2 Details of Responses

In terms of types of construction, two fundamental types of footprint were identified: shed – basically rectangular in footprint; and dome – basically circular in footprint. Two different types of roofing were identified (solid roofs, using wood trusses of one sort or another; and fabric roofs, typically stretched over some sort of hoop system).

The amount of salt stored in the facilities ranged from 40 tons to 15,000 tons in each facility. Only two agencies reported that they had not been able to store as much salt in their facility as they had planned to store in them. Facilities described as “small” had between 125 and 2,500 tons stored in them. “Medium” facilities had between 40 and 5,000 tons stored, and “large” facilities had more than 3,000 tons stored in them. These discrepancies do make sense, however, since a facility that is “large” for a small municipality would undoubtedly be “small” for a state agency in the midst of the snow-belt.

Four facilities were described as “package” designed – that is, the owners used a package provided by a vendor with little or no customization being possible. All others were described as “custom designed” except for the Iowa Department of Transportation buildings, which were noted as being designed to an IA DOT standard.

Given that all types of facilities included a section of vertical walling within them, the height of that walling was of significant interest. Wall height ranged from a low of 5 feet to a high of 15 feet. Of the 18 responses received to this question, 13 fell in the range of 8 to 10 feet. Design lifetimes of the facilities ranged between 20 and 50 years, as shown in Figure 6.

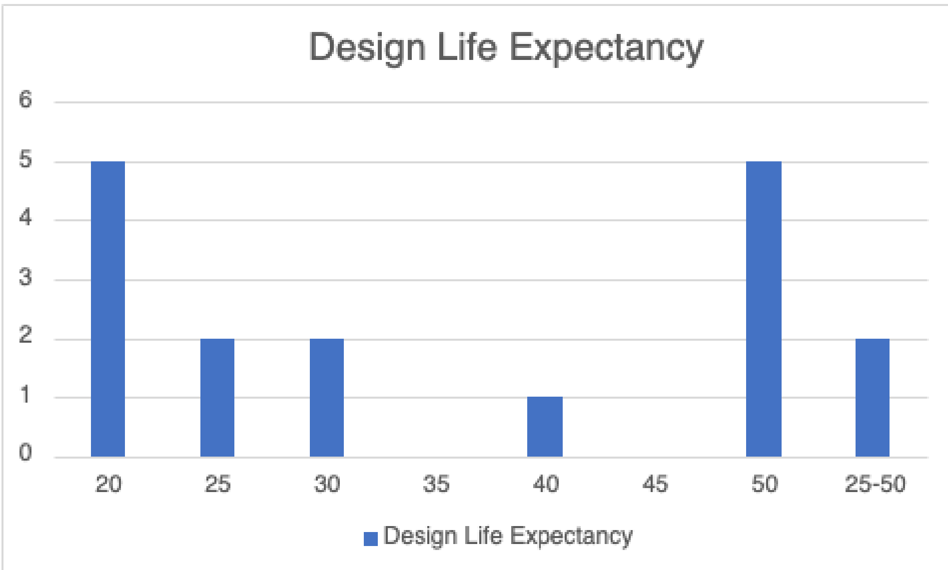

Figure 6 Frequency of Design Lifetimes

With regard to protecting the structures against degradation (both due to the salt, and due to what may be considered normal weathering) a number of written responses were received in addition to several yes/no responses (see table 2 below). Thirteen agencies responded that they had specified a coating or other protective system on the inside of their structure to protect against salt. Of these 13 agencies, only one indicated that the protective system had not worked as expected/desired. Three agencies had specified particular protection against chloride contamination (over and above protection against salt) and all three reported that this had worked. Of these three, one referenced Delaware DOT Class A concrete, and the other two noted “Xypex and other sealants, all work the same. Best if sealed yearly.” And “Xypex concrete additive.” Seven agencies noted that they had coated their rebar for protection, while eight noted that they had not done so.

Table 2 Written responses to "Did you specify a coating or other protective system on the inside of your structure to protect against salt? If yes, please supply details."

Epoxy Coated Truss Connectors.
Galvanized or stainless steel.
Silane treatment, no deterioration so far.
Silane treatment.
Specified lower connections be treated and they are performing as expected. The galvanized tubing, cables, and connections are not performing as expected.
Top of concrete walls we placed angled 4' plywood sheeting to eliminate salt getting to the metal.
All walls coated in salt inhibitor. Not permanent, has to be reapplied.
Only 2 yrs. old, in bid documents.
Only 2 years old, unsure.
Crystal x working well, but not 20 years.
Xypex Concrete additive.
Hot dip galvanized.
Annual coat of linseed oil on concrete floor.

On the topic of impermeable pads for the storage structures, 13 responses were affirmative, with only one response being negative. That agency reported having asphalt pads with a geomembrane in place for all their storage structures. Six agencies reported being able to fill their trucks under cover in their storage buildings, while eight indicated they did not have such capability. In regard to brine making and storage, eight agencies reported that their brine facility was separate from their salt storage facility, while four indicated they stored their brine along with their solid salt, but brine making was done separately. Six agencies reported that they only stored salt in their facilities, with one other saying that they stored a small amount of treated salt as well as straight road salt. Others indicated that storing one or multiple material types varied from location to location within their agency.

On the issue of how salt was placed into the storage building, ten agencies reported using front end loaders, two used conveyors, and three used both conveyors and front end loaders. The conveyor types used were both pit and above ground conveyors.

In terms of managing runoff from the structure and/or the site, Table 3 shows the comments received on this issue.

Table 3 Written responses to "How do you manage any runoff from your structure?"

Goes to Wastewater Plant.
This is a weakness of our structures we get bleed through at the ecology block intersections. Grade is flat inside the shed. Sloping away in the front outside the main doors.
Site drains to grass swale detention area.
No roof gutters, site grading.
New fabric buildings have containment system that captures all of the runoff from the structures and trucks under cover.
Grade is sloped to wet/dry bioremediation pond.
Mechanically sweep salt residue into domes. Lower volumes or empty trucks can dump right into domes.
Nothing formal.
All runoff is contained.
Asphalt is sloped into the salt pile to contain water. Sweeper cleans loading area.
There is no runoff.

Twelve agencies have a well-defined process in place for dealing with spills of salt and to handle general housekeeping around the storage site. One agency has such processes "in select locations," while another does not have any such formal processes. Seven agencies have had environmental issues with their salt storage in the past, while six had not. Those issues were primarily at the State level rather than the National level. Eight agencies reported that their salt storage was part of their MS4 permitting process, while three reported that this was not the case. Only two agencies reported that their salt storage was subject to a direct permitting process. Three comments were received on the permitting issue. "New barns cannot be within 300' of a body of water (2022-2023)."; "HazMat Tier II annual reporting, and state administrative code 277 annual inspection."; "Plan review and building permit required for all."

Table 4 shows the written comments received in response to the question "What factors did you consider in placing your facility footprint?"

Table 4 Written responses to "What factors did you consider in placing your facility footprint?"

Unloading delivery trucks.
Don't Know, Site master plan.
Layout for trucks to fuel up, fill with salt, and be emptied. Entry should not face prevailing winds.
Primarily the quantity of material, but also aquatic resources on site.
Size of existing facility, truck radius for deliveries, portable conveyor setup, maximize building size for shared State/County storage.
Movement around the site, loading/unloading needs with ramps.
Ease of delivery (enter, dump, exit). Ease of access for fully dressed tandem axle plow trucks with wing plows. Ensure all plow trucks are loaded from driver side. Adequate area for truck maneuvers to operate.
Circle road access, building height to accommodate trailer delivery and dumping.
Ease of loading and unloading.
Grade matters, direction of door opening, traffic flow, proximity to brine making facilities.
Room for dumps and triaxle to turn in and out.
Placing open end to south or east. Turning radius for trucks and plows.
Loading trucks, unloading trucks, yard layout, drainage.
Entrance covering distance.

The survey concluded with a series of questions about what agencies liked or disliked about their facilities, whether they considered their facilities to be successful, and if so, why were they successful. Table 5 shows responses to "What do you like most about your facility?" (with a maximum of three factors), while Table 6 shows responses to "What do you like least about your facility?" (again, with a maximum of three factors). All respondents considered their facilities to be successful, and Table 7 shows written responses as to why they believe they are successful.

Table 5 Responses to "What do you like most about your facility?"

We were able to dial back a bay in the truck barn where we used to store salt totes.
It is right out the door to get trucks filled up.
Metal Roofing 50-year life.
Keeps the salt dry.
Fits with community buildings in the area.
Very well-lit inside.
Taller concrete walls and shorter metal structure (avoid damage).
Ability to take deliveries under cover. Trailers can dump inside.
max flexibility for delivery includes 6 dumping at one time.
We have generally good luck with past dome and standard woodsheds.
Low cost, quick construction.
Loading and offloading under cover.
Interior height to try to limit building hits.
Cost.
Keeps our salt neat and contained to one area, out of the way.
Salt Brine is right by our stockpile.
LED Lighting.
Relatively inexpensive.
New building with little to no maintenance.
High storage capacity.
Bollards at structure entries.
Ability to load inside.
Increased height with no driver obstructions.
The size and ability to store large volumes in the domes.
Hoops provide better building and more flexibility than domes – especially for loading/unloading.
Brine system and 60,000 Gallons inside building.
Functionality.
It serves a great purpose.
No metal structures to rust out.
Ecology blocks can take a beating.
Barn door design is low maintenance but heavy to maneuver and often left open by staff.
Low risk of damage.
Fabric buildings are low maintenance.
Ease of loading with portable conveyor.
Prewash pit for trucks prior to final wash.
Ease of repairs.

Table 6 Responses to "What do you like least about your facility?"

Due to lack of room, the location isn't the best.
We need a conveyor.
Very expensive compared to coverall building.
Leaching of salt through cracks between ecology blocks.
Cleaning fabric.
Fabric susceptible to wind damage if not properly maintained.
Low quality vinyl siding, blows off.
Geodesic dome roof seems higher maintenance than others.
Fabric roofs weak in winds.
Cost.
Moisture driven into building in summer, salt there all year.
It would be good if the roof was heated to eliminate snow shed off the back.
Can't rotate salt around, salt in the back is older.
Open barns on sides provides ventilation, but exposure to atmosphere. Birds.
Not large enough to load inside.
Tears in the fabric.
Large birds' nest and roost in the buildings. Difficult to manage.
Steel roll-up door has had some maintenance issues and is beginning to rust.
Limited vendors, limited service.
Loading/Unloading door could be wider.
Wood can rot.
Low rafters sometimes impacted by loaders.
Overhead door failures.
Once loaded, nearly impossible to treat walls with sealant.
Issues with loaders pushing against back wall, installed berm behind.

Table 7 Responses to "Why do you believe your facility is effective?"

It gives a contained and clean storage are for our salt. Out of the way of daily activities.
It does what it needs to. It holds salt.
Long life, durable.
Retains salt and keeps it from the weather.
Workforce is happy with improvement over previous timber structures.
Keeps salt dry. Meets requirements of RI Department of Environmental Management. Relatively cost effective.
Excellent team effort by state, county, contractors.
Ease of loading and unloading. More than enough capacity.
It does the job.
It is an industry leading facility that is multi-featured.
Keeps product available for winter events and protects environment during storage.
It enables NDOT to maintain an effective salt storage program that allows us to meet demand. With the cost, and administration's willingness to fund salt storage, we now have enough inventory to get through most winters, and this allows us to order salt in summer at reduced cost.
MS4 compliance.

3.4 Implications of Survey Responses

The survey responses provided invaluable information pertaining to salt storage structure design. Two factors stood out as being of particular importance.

First, it is clear that different agencies use their salt storage facilities in different ways. In some cases, the facility is solely for the storage of salt, while others use it as a loading facility for their trucks during and prior to storms, for pre-washing of trucks, for brine making and storage, and no doubt in other ways as well. In creating the design templates, this difference or variation in end use will need to be considered and respected.

Second, given that design lives of between 20 and 50 years are the norm for such structures, it will be important to consider structural maintenance during that lifetime, and design templates will need to include features that make such maintenance as straightforward as possible.

4: Design Analysis – Task 3

4.1 Introduction

Based on the information collected in the literature review and the surveys, a reasonably complete picture of the types of buildings, their benefits and drawbacks, and the constraints that impact each of them has been formed. Task 3 (Design Analysis) presents those findings and recommendations on the final design process.

It is clear that the design of a salt storage structure is more than just a series of drawings, but is rather a process that must consider several different factors. Without considering all these factors the final design will be incomplete and will, ultimately, fail to provide the needed facility for the agency. Given this, the approach the project team is taking is to create a checklist, along with an explanatory document for the checklist which is considered in the next Chapter, and formed task 4 of the project.

The checklist is broken down into five areas (Sizing of facility, site selection, environmental factors, type of structure, and general/administrative). In each of these areas there are several topics that an agency's design team would need to consider. These are discussed in the explanatory document and are elaborated upon further in this memo.

Each of the items identified in the checklist will be presented in the final design guide to allow users of the guide to consider the available options and assist them in deciding between those options. Thus at this point the topics are being introduced and will be significantly expanded upon in the final design guide. Appendix B shows an addendum to the original memo on Task 3 which summarizes the checklist topics.

4.2 Checklist Topics

Five broad areas or topics were included in the checklist approach: sizing and footprint of facility, site selection, environmental factors, type of structure, and general/other. The checklist topics are shown graphically in figure 7. While the graphic suggests that the various checklist items be considered in some sort of linear process (for example, five decisions are shown in the "sizing of facility" sub-list) the reality of the design process is that it is iterative (at times, highly so) and an initial completion of any item in the list does not mean that item is finalized until all other items, and their potential impact on the given item, have also been completed. Nonetheless, the ability to designate that any given item has been considered ensures that no potential issues will be ignored.

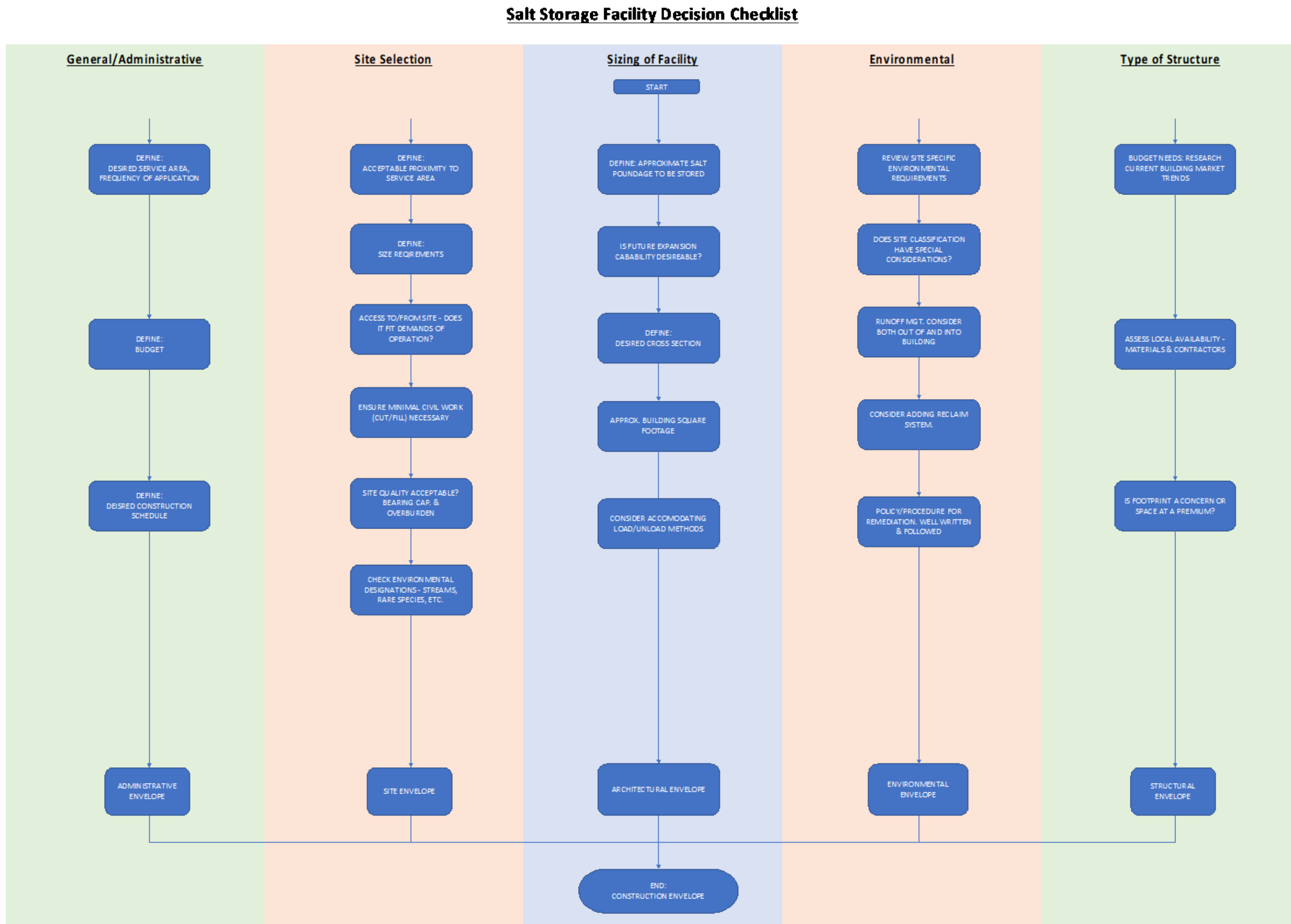

Figure 7 Salt Storage Facility Design Checklist

The following presents the five broad areas in the approach.

1. Sizing and footprint of Facility

In deciding what size of facility an agency needs, long-standing advice suggests that an agency should have sufficient storage for their annual average (over a five-year period) salt usage. However, for an agency with a growing transportation system, this five-year average will need to be increased to take into account the expected growth in lane miles. This can be accounted for with the following formula:

$$future\ storage\ needs = \frac{current\ five - year\ average\ usage}{current\ lane\ miles} \times future\ lane\ miles$$

The ratio of future lane miles to current lane miles indicates the expected growth in lane miles over the expected lifetime of the storage building. The current five-year average usage is the average of the past five years of salt tonnage used at the facility which will be served by the new storage building. Thus, if the five-year average for a given location is 9,000 tons, and the ratio of future lane miles to current lane miles is 1.20 (i.e. lane miles are expected to grow by 20% over the lifetime of the new storage facility) then the future storage needs would be 10,800 tons (9,000 multiplied by 1.20). This is an ideal storage quantity, and it may not be possible to accommodate this much salt storage due to site constraints. However, it does represent a suitable starting point for design.

To determine the facility footprint, the shape of the planned structure must be known in general terms. There are two basic shapes – a conical facility, and a rectangular facility. It is also possible to have an elongated conical facility. These three options are shown in figures 8, 9, and 10 respectively. The amount of salt that can be stored in such structures is a function of geometry and the angle of repose of salt in a pile (32 degrees). A fourth option is a rectangular building with a fabric roof as shown in figure 11.

Figure 8 Conical Storage Facility

Figure 9 Elongated Conical Storage Facility

Figure 10 Rectangular Storage Facility

Figure 11 Fabric Covered Salt Storage Facility (courtesy of WYDOT)

Another factor that must be considered in developing the footprint of the facility is how salt will be loaded into the structure. The most efficient way of loading salt is by use of a conveyor system, which can be fixed (I.e., only usable at that storage facility) or mobile (capable of being used in several facilities). If a facility has such a system, then it is reasonable to assume that up to 90% of the theoretical maximum salt storage capacity can be used. However, if the structure is to be loaded using front end loaders or the equivalent, then it must be assumed that only 60% of the theoretical maximum salt storage capacity is available.

A third item for consideration is the impact of climate change on future salt needs. This is rather problematic, since there are no clear numerical indications as to how winter severity will change as a result of climate change. However, this is a factor that should be considered. To address this, the design guide includes an appendix (included here as Appendix C), discussing how a winter severity index could be used to indicate possible trends in future salt usage for a facility.

Spreadsheet tools have been developed under task 4 to calculate the footprint for the various structure shapes identified in figures 8, 9, 10, and 11. However, these tools calculate the theoretical maximum, so the quantity of salt needed to be stored must be adjusted to account for the method of loading. So, if, for example, a storage facility with a capacity of 10,000 tons is required, then the tools must be adjusted to calculate for a quantity of 10,000/0.90 if a conveyor system is available or will be used, and for a quantity of 10,000/0.60 if no such system is available.

2. Site Selection

Site selection will often be constrained by what land is available for an agency, but in ideal terms the first consideration in terms of siting a storage facility is that it should be optimally placed to serve all roads that must be maintained from that location. This generally requires that it be centrally located within an area of responsibility.

Four situations may be experienced in terms of site selection:

A. The site may be located essentially anywhere within the area of operation of an agency.
B. The site may be located within a few (perhaps two or three) locations within the area of operation of the agency.
C. The site is fixed, but the storage facility may be located within the site with some degree of freedom.
D. The location of the storage facility within the site is generally constrained such that there is only one location where it can be placed, and the only variable in site location is the available footprint.

Case A involves many considerations, but from the point of view of salt storage, the primary one will be optimal placement so that all routes going from the facility will be essentially equal in time to serve. Alternately, if the various routes have different priorities and thus different desired times to completion, then routes should be chosen to achieve those timing goals. This is a complex optimization problem and given that case A is the least likely of the four cases, it is recommended that if an agency finds itself dealing with case A, it acquires expert advice on the optimization of routes from potential locations. Other factors such as land availability and costs will also be involved in this sort of decision.

Case B is simpler than case A in that it is more constrained. Again, the approach will be to develop routes for each of the possible locations and see how well they can be balanced in terms of timing and priority. Because the locations are limited in number, the challenge of case B is much less than that of case A, and agencies should be able to develop potential route maps for evaluation without great difficulty.

In case C, the issue of route times and priorities no longer plays a role, since the general location of the site is fixed. However, in this circumstance (and after the general location of the site in cases A and B), the flow of traffic around the site must be a major factor of consideration. There are two aspects to this – first, it must be easy for trucks delivering salt to safely make those deliveries. And secondly, it must be easy for plow trucks to reload with salt both before and during storms.

Additional considerations regarding siting the storage facility include minimizing civil work (e.g., little to no cut or fill required), good soil conditions to support the building loads, and no (or as few as possible) environmental concerns (this is discussed in greater detail below).

In case D, the location is essentially fixed by other constraints on the site, and in fact it may not be possible to place as large a facility as needed (as determined from step 1 above). In this case, the agency will need to revisit step 1 to determine how much of their future salt storage needs can be met, and in particular, this limitation might increase the need and value of a conveyor-based loading system.

3. Environmental Factors

One of the major purposes of good salt storage is to minimize the likelihood of any environmental impact from the salt being stored. Thus, consideration of environmental factors is a critical part of the design process. Primary concerns in this regard are well known – the need to prevent water running into the salt storage area, the need for an impermeable surface on which to store the salt, the need to collect and/or contain any runoff from the stored salt have all been well documented and discussed elsewhere (most notably in the Salt Institute Sustainable Salt Storage handbook).

In addition to these factors, the need to keep the storage facility as far away as possible from any environmentally sensitive areas (streams, wetlands, etc.) is an obvious constraint. Additionally, orientation of the facility so that loading entrances do not face the prevailing wind (thus minimizing the potential for precipitation to enter the building) is a major benefit, although this must be considered along with concerns about ease of loading salt into the building and loading trucks from the building discussed in item 2 above.

Some facilities may be multi-purpose, in that in addition to storing salt, they are also used for salt brine making and salt brine storage. In such cases, the appropriate containment requirements for salt brine manufacturing and storage must be incorporated into the design. Other multi-purpose designs have included truck loading facilities, and truck washing facilities. Both of these have obvious advantages but will also significantly increase the required building footprint.

Since lifetimes for these facilities are typically in the 25-to-50-year timeframe, it is important to include maintenance and preservation requirements as part of the design process. If the structure requires special coatings, the design should be such that those coatings can be re-applied as needed. If certain parts of the structure are designed to be replaced on a cycle less than the total structure lifetime, then that replacement should be considered in the design so that it can be done without undue effort and expense.

One primary purpose of a salt storage facility is to minimize the likelihood of environmental contamination. Accordingly it is appropriate in this part of the design process to consider how to avoid any such contamination, and further, should such contamination, how to manage the contaminant material. Ideally, any spilled material should be reclaimed although using it after spillage is not always possible due to regulations. Historically a number of facilities have captured runoff, for example, in storage ponds, and consideration has been given to using this captured runoff material in the brine making process. For any given location this may not be either suitable or feasible, but consideration can be given to such approaches.

4. Type of Structure

There are three general types of salt storage structure. The conical or beehive structure typically has concrete vertical walls, and then a roof in place over a wooden frame. The rectangular structures come in two types. In the first, the building is a regular frame type of building, with combinations of wood and concrete as needed. The roof on such structures is solid. The second type of rectangular structure uses a fabric covering over metal hoops for a roof system. This may be anchored into regular concrete walls, or into large ecology type blocks.

Cost will clearly be a major factor in the selection of structure type. In general, using a fabric roof rather than a solid roof will provide a lower initial cost, but may require more maintenance over time. A life cycle cost approach will be considered in this regard. Cost will also likely be impacted by the availability of both contractors and materials for the desired structure. Table 8 shows comparative costs (on a per square foot basis) of the general structure types. There is significant variation in these comparative costs, reflecting the likely variability of material and construction costs in different parts of the country. Nonetheless, Table 8 represents an overview of the comparative costs of the different structure types.

Table 8: Comparative Costs of Structures

Structure Type	Comparative Cost per Square Foot
Fabric Covered	1.0
Rectangular Solid-Roofed Structure	1.20 – 1.50
Dome Style Structure	1.60 – 2.40

It is likely that different structures will have different construction timelines and this will need to be factored into the final decision on structure type. Under circumstances where timing is a critical path in the design and construction process, the timing might be the deciding factor between different types of structures.

In terms of efficiency of storage, the beehive/conical shape is more efficient than the rectangular shape or the elongated conical storage facility. However, other factors may either limit the available footprint or constrain the shape of the footprint in other ways. If the available space is rectangular, for example, then it is likely that a rectangular shape will be able to store more material than a conical shape. Also, the conical storage solution requires special tools to be filled efficiently, which implies additional costs that may make that solution prohibitive.

Loading the structure with material is another factor to consider and may create additional constraints on the structure type, given the available footprint. Further loading concerns are discussed above under section 1.

5. General/Other

This section is meant to consider the back of house criteria that will ultimately describe what a successful storage facility will look like. Standards defined in this section will consist of items such as available budget, operational requirements, service area, and desired construction timeline. Essentially, this part of the checklist considers the broader constraints upon the storage facility. This would include but not limited to how the construction of the facility fits into other concurrent or planned site developments relating to winter maintenance or other operations.

4.3 Conclusions

A checklist process for the design of salt storage facilities has been developed and presented herein. The checklist identifies five general areas (sizing of facility, site selection, environmental factors, type of structure, and general administrative issues) that must be considered during the design process. In each of the five areas sub-topics have been identified and expanded upon. Full details will be provided in the final design guide.

5: Design Templates and Checklist – Task 4

5.1 Introduction

Task 4 required the creation of appropriate design tools to guide the process of designing a salt storage facility. Two specific tools were developed to fulfill this task. First, a spreadsheet tool was developed to estimate the required facility size. Second, a checklist tool was developed to ensure that all potential design considerations had been addressed in the design process.

5.2 Facility Sizing Tool

The purpose of the tool is to provide a first order estimate of how much salt can be stored in a structure of a particular type (the various building types being given above) and a given size. It can also be used iteratively to determine how large a particular type of structure needs to be to store a given quantity of salt. The guide to using the spreadsheet is included herein as Appendix D. The spreadsheet itself is available as a separate file on the Clear Roads site (www.clearroads.org).

5.3 Checklist Tool

The checklist tool takes the user through the various steps needed to create a completed design of a salt storage facility. The purpose of this tool is to ensure that all pertinent issues that require consideration when designing a salt storage facility have been identified and considered. The checklist document is presented in Appendix E of this report. Some broad based "envelope" drawings are provided as a separate document, but detail drawings cannot be provided because so many different factors (e.g., structure type, roofing system, soil at structure location, etc.) impact the detail design components that providing examples might be counter-productive.

5.4 Conclusions

Using the materials developed in tasks 1, 2, and 3 two specific design tools for the design of salt storage facilities have been developed and are presented as separate, stand-alone documents or products of this research. Some of the information in these tools is presented in appendices to this document as appropriate.

6: Conclusions

This project has enabled the creation of tools that provide significant assistance in the design of salt storage facilities. The tools are based upon information collected by way of an extensive literature review and a detailed survey of the current practice in winter maintenance operations nationwide. These tools will allow agencies to manage the process of salt storage facility design more efficiently and effectively, going forward.

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APPENDIX A

The survey as sent to respondents.

Survey of Practice

For Clear Roads Project Salt Shed Design Template

Project Number TPF 5(353)

April 2022

Purpose:

The purpose of the survey is to elicit information from winter maintenance practitioners around the United States on the salt storage facilities which they maintain, design, or intend to design. Results from the survey will be collected for inclusion in the final report of this project and will also inform the project in the development of design templates. The survey comprises four sections: Basic Shed Structure; Flooring, Site Plan, and Environmental Issues; General Topics; and Contact Information.

1: Basic Shed Structure

Question	Response (circle or complete)	
Has your agency built a salt shed within the last ten years?	Yes	No
Note: if your agency has built more than one shed in this time, and if the sheds are significantly different in size and/or design, please use the additional answer sheets at the end of the survey to provide information on the other shed designs. We have provided space for up to three additional designs.		
If Yes, please answer the following questions. If No, please go to the next section of the survey (part 2).		
If Yes, may we get copies of your drawings?	Yes	No

Question	Response (circle or complete)			
What type of structure did your agency construct (circle all applicable for this structure)?	Dome	Shed	Solid roof	Fabric roof
How much salt (in tons) did you intend to store in your shed?				
Have you been able to store that much salt in it?	Yes		No	
Do you consider your shed to be small, medium or large?	Small	Medium	Large	
Was your structure custom designed, or did you get a "package" from a vendor?	Custom		Package	
How high were the concrete walls in your structure?	__________ feet			
What lifetime (in years) was your structure designed for?	__________ years			
What maintenance do you need to achieve that lifetime?				

Did you specify a coating or other protective system on the inside of your structure to protect against the salt?	Yes	No
If Yes, did it work as you expected?	Yes	No
If Yes, please supply details:		
Do you specify a particular concrete mix for chloride protection?	Yes	No
If Yes, did it work as you expected?	Yes	No
If Yes, what is that mix?		
Do you coat your rebar in the structure to protect it?	Yes	No

2: Flooring, Site Plan, and Environmental Issues

Question	Response (circle or complete)			
Is your structure on an impermeable pad?	Yes		No	
If Yes, what is the pad made of?				
Does your structure have an area inside (or under cover) to use for loading your plow trucks with salt?	Yes		No	
Does your structure include a brine making and loading facility, or is that in a separate structure?	Small	Medium	Large	
Do you only store one material in your structure (e.g., straight road salt) or do you store several (e.g., straight road salt and a premium, coated salt product)	Custom		Package	

For loading your structure do you have a conveyer system? Or do you load it with front end loaders pushing the pile of salt into the structure?	Conveyer	Front End Loader
If you have a conveyer system, is it a pit system (for loading) or an above ground system?	Pit	Above Ground
How do you manage any run-off from your structure?		
Do you have a process in place to deal with spills and handle general housekeeping?	Yes	No
Has your agency had environmental issues in the past?	Yes	No
If yes, were these state level or national level?	State	National
Is your salt storage part of your MS4 permit process?	Yes	No
Is your salt storage subject to any direct permitting of any sort?	Yes	No
If yes, please provide details?		

3: General Topics

Question	Response (circle or complete)
What factors did you consider (e.g., loading your salt trucks, unloading delivery trucks, other) in placing your salt shed on your facility footprint?	
What (maximum three things) do you like most about your facility? #1	
#2	

#3		
What (maximum three things) do you like least about your facility? #1		
#2		
#3		
Do you consider your salt storage facility to be a “successful” facility?	Yes	No
If yes, what makes it successful?		

Contact Information: Please provide the following information:

Contact Name	
Agency	
Position	
Email	
Phone number	

Thank you very much for contributing to this research by completing this survey. If in section 1 you identified that you had more than one salt storage structure type for inclusion in the survey, there is space on the following pages for information about two more structure types.

If you need to contact the researchers for this project, please feel free to do so. The primary contact is:

Wilfrid Nixon

wilf@psassoc.org

319-594-4447

Information for Structure # 2

Question	Response (circle or complete)			
What type of structure did your agency construct (circle all applicable for this structure)?	Dome	Shed	Solid roof	Fabric roof
How much salt (in tons) did you intend to store in your shed?				
Have you been able to store that much salt in it?	Yes		No	
Do you consider your shed to be small, medium or large?	Small	Medium	Large	
Was your structure custom designed, or did you get a "package" from a vendor?	Custom		Package	
How high were the concrete walls in your structure?	__________ feet			
What lifetime (in years) was your structure designed for?	__________ years			
What maintenance do you need to achieve that lifetime?				
Did you specify a coating or other protective system on the inside of your structure to protect against the salt?	Yes		No	
If Yes, please supply details:				
Do you specify a particular concrete mix for chloride protection?	Yes		No	
If yes, what is that mix?				

Do you coat your rebar in the structure to protect it?	Yes	No

Information for Structure # 3

Question	Response (circle or complete)			
What type of structure did your agency construct (circle all applicable for this structure)?	Dome	Shed	Solid roof	Fabric roof
How much salt (in tons) did you intend to store in your shed?				
Have you been able to store that much salt in it?	Yes		No	
Do you consider your shed to be small, medium or large?	Small	Medium	Large	
Was your structure custom designed, or did you get a "package" from a vendor?	Custom		Package	
How high were the concrete walls in your structure?	__________ feet			
What lifetime (in years) was your structure designed for?	__________ years			
What maintenance do you need to achieve that lifetime?				
Did you specify a coating or other protective system on the inside of your structure to protect against the salt?	Yes		No	
If Yes, please supply details:				
Do you specify a particular concrete mix for chloride protection?	Yes		No	
If yes, what is that mix?				

Do you coat your rebar in the structure to protect it?	Yes	No

APPENDIX B

Checklist and Description of Checklist

Designing a salt storage facility is a complex task, filled with decision criteria that are often overlapping and are unique to each individual site, agency, and geographical area. Included in this phase of the report is a flowchart called the "Salt Storage Facility Decision Checklist." While it's not intended to be comprehensive, it should provide a general idea of the individual decision swimlanes that must be accounted for in a successful project. The chart is divided into five individual sections, each of which will yield a succinct envelope of boundaries for that section. They are further described below:

1. **General/Administrative:** This section is meant to take into account the back of house criteria that will ultimately describe what a successful storage facility will look like. Standards defined in this section will consist of items such as available budget, operational requirements, service area, and desired construction timeline.

2. **Site Selection:** Once the boundary conditions are defined, it's time to begin the process of selecting a site. The main concepts considered here are items such as size requirements, location, and geotechnical quality of the site. When considering size, be sure to capture space requirements for not only the storage building, but also things like ancillary buildings, parking for employees and equipment, and operational room. This requirement will often be iterated with the following section and can be fluid based on further decisions in the process. When considering location be sure to think about proximity to the service area, access for employees and deliveries, security requirements, etc. Geotechnical quality analysis consists of items such as whether there will be any cut/fill requirements, if soil quality meets the overburden demands of a structure, and if there are any special environmental requirements. This step is a good time to bring in a Geotechnical, Civil, and Structural Engineer to help define these requirements and ensure your site will accommodate your agencies needs.

3. **Sizing of Facility:** This step will overlap some with the previous section, as well as the "Type of Structure" section later. In this section, consider first how much salt will need to be in the storage facility at any one time. Once that number is defined, consult with the Administrative swimlane on whether there should be expansion capability or not. Each general shape of structure provides a different storage capacity of salt per square foot, consider each of these options and choose the one that best meets agency needs, both for operational space and footprint on the site. Consider how the salt will be loaded or unloaded into the storage facility and consider if adding extra space under roof to accommodate this operation would be desirable for the project.

4. **Environmental:** This section is the most unique, in terms of different jurisdictions and locations. Items to consider in this section are requirements specific to the site (defined in the Site Selection phase), how runoff is managed and what the parameters are for a specific area, and how your agency will define environmental policy and procedures to define what is within and what is outside of normal operating conditions. This is a good time to consider whether adding a reclaim system to a project would be beneficial.

5. **<u>Type of Structure:</u>** Defined elsewhere in this report, there are several different configurations of salt storage facilities. Items to consider in selecting which of the shapes to use include budget needs, what is available to a locality, and footprint requirements. Often different construction methods will vary in pricing in different localities and with market conditions. Research and consider the implications of what is the most economical method in your agency's area. This step should include both the general type of structure (shed, dome, etc.), materials, as well as contractors with relevant experience. This section can overlap some with the Site Selection envelope as well, such as when land is unavailable or comes at a high premium. Locations with little accessible land or expensive land may be better suited to choose a structure that is higher, rather than one with a larger footprint.

APPENDIX C

Climate Change Considerations when Determining Salt Storage Requirements

(from the Design Checklist Guideline document)

There is no question that a changing climate will change the sorts of storms to which agencies must respond. Indeed, many agencies have already reported examples of such changes. Unfortunately, it is not at this time clear how much these changes in winter storms will impact the salt used by an agency on an annual basis, and thus how much more or less salt storage will be required by an agency over time. Other factors can also impact the required amount of salt storage, such as improved technologies (which may tend to reduce salt usage), increasing lane miles (which may tend to increase salt usage) and no doubt other factors too (for example, changes in acceptable levels of services required by the traveling public).

Nonetheless, it may be important for an agency to demonstrate that it has considered the potential impacts of climate change in determining its future salt storage needs. There is therefore a need for, at the least, a factor by which the current salt storage needs can be multiplied to determine a future value of salt storage needs. This can be termed the salt storage climate change adjustment factor, or F_{sscca} for short. Thus, we can express the adjusted salt storage needs as:

$$Climate\ adjusted\ salt\ storage\ needs = current\ salt\ storage\ needs\ \times\ F_{sscca} \qquad \text{(A.1)}$$

How do we calculate this factor? The methodology is not fully developed at this time, but an estimate can be determined by using a winter severity index (see https://www.clearroads.org/planning-weather/ for extensive information about winter severity indices). These index values (WI) can be calculated in several different ways, as detailed in the reports available at the link. To calculate the salt storage climate change adjustment factor (F_{sscca}) an agency will need a record of their winter index (WI) over several winter seasons (ideally at least 20 such seasons, if we truly wish to incorporate a measure of climate change impacts).

If an appropriate dataset of winter indices exists for a location, then that dataset can be used to create a model indicating how the winter index will change over time. The exact way in which the winter index will change over time is currently unknown, therefore the simplest approach is likely the best to use absent better insight. This approach is to model the variation of the winter index as a linear function of time (t, expressed in years). This provides a model of the form:

$$WI = mt + WI_0 \qquad \text{(A.2)}$$

Where WI_0 is the value of the winter index at time t = 0 and m is the slope of the linear relationship found by linear regression of the winter index values and the time in years. The slope of the model, m, may be thought of as the amount the WI increases (or decreases) each year due to climate change. This model will have uncertainty in it, which can be measured by use of the Pearson correlation coefficient, termed r (see: https://en.wikipedia.org/wiki/Pearson_correlation_coefficient for a review of this). The closer the value of r is to 1 (indicating WI increases over time) or -1 (indicating a decrease over time) the stronger the model may be considered. In general, if the value of r lies between +0.5 and -0.5 then the linear relationship may be considered sufficiently weak that WI may be considered not to be changing over time.

If the value of r is more than +0.5 or less than -0.5 then variation of WI with time may be considered. In such cases, it is important to note two assumptions that are being made to attempt to incorporate climate change into the salt storage facility design. These two assumptions are:

1. That salt demand is well modeled by the winter index.
2. That the relationship between WI and time is linear.

Neither of these two assumptions have been validated at this time.

If the model shows that WI increases over time, then it may be necessary to increase the salt storage capacity of the facility to reflect the potentially greater need for salt usage. The amount of increase is represented by the salt storage climate change adjustment factor (F_{sscca}). If the lifetime of the facility is designed to be t_{lt} years and the current value of the winter index is WI_{now} then:

$$F_{sscca} = \frac{mt_{lt}}{WI_{now}} + 1 \qquad \text{(A.3)}$$

Using this, the climate adjusted salt storage needs are simply calculated using equation A.1 above.

If the model shows that WI decreases over time (i.e., the value of m in equation A.2 is negative) then the needed salt storage capacity may decrease over time. However, given the uncertainty indicated in the two assumptions that have been made above, it would not be prudent to reduce the required salt storage capacity, given the uncertainty in how salt usage may change due to climate change.

APPENDIX D

Guide for Stockpile Sizing Spreadsheet

As part of Task 4 of the project Salt Shed Design Template an Excel spreadsheet has been created to provide insights to users on how large various buildings would need to be to store a given quantity of salt. This document is intended as a guide in the use of the spreadsheet.

The spreadsheet does not provide precise sizing information, but it does provide an indication of how much salt can be stored in a given type of structure, of a given size. How much salt can actually be stored in a structure will depend on how the salt is loaded into the structure. If the salt is loaded from the top of the structure using a conveyer system, then it is a conservative assumption that the building will hold about 90% of its calculated maximum storage. If the salt is loaded by a front-end loader or equivalent (essentially being pushed or shoveled into the storage building), then it is a conservative assumption that the building will hold about 60% of its calculated maximum storage. These assumptions are used in the spreadsheet.

The spreadsheet has three tabs. The first provides a calculation of how much salt is stored in a conical pile of salt. This provides an initial "ballpark" estimate of the size of the building that might be required to store given amounts of salt. Two calculations are shown. The first calculates how many tons of salt can be stored in a conical pile of a given diameter. It also gives the height of the pile. The second calculates what size of cone is needed to store a given weight of salt. These calculations depend on two given assumptions about how salt sits in a pile.

ASSUMPTION 1: The angle of repose of a conical pile of salt is 32°. This means that the angle between the sloping face of the salt pile and the horizontal is 32° as shown in figure 1.

ASSUMPTION 2: The density of salt granules is approximately 80 lbs. per cubic foot.

Tab 1: "Conical Piles No Walls"

In calculating the values in the first tab, the height of the pile (designated as h) is given as a function of the width or diameter of the pile (designated as w) by this equation:

$$h = \left(\frac{w}{2}\right) \tan 32 \qquad (1)$$

The equation for the volume of a cone (V) is given by (using r for radius, which is half of the diameter, w):

$$V = \frac{1}{3}\pi r^2 h \qquad (2)$$

If we substitute in for r and h in terms of w, we get:

$$V = \frac{1}{3}\pi \left(\frac{w}{2}\right)^3 \tan 32 \qquad (3)$$

Which simplifies to:

$$V = \frac{1}{24}\pi w^3 \tan 32 \qquad (4)$$

This can then be converted into tons of salt (denoted as W), using the density of salt given above (80 lbs per cubic foot) and taking 2,000 lbs per ton:

$$W = \frac{80}{(24 \times 2000)}\pi w^3 \tan 32 \qquad (5)$$

Equation 5 is used in option 1 of tab 1 (“Conical Piles No Walls”) to calculate the weight of stored salt in tons. The user supplies the width of the pile (w) in cell C7 in feet and the weight is returned in cell C12. The height of the salt pile (h) is given in terms of the width of the pile (w) in equation 1, and this is used to calculate the height of the pile in feet given in cell C13.

Option 2 in tab 1 takes a given weight of salt (in tons) supplied by the user in cell H7 and inverts equation 5 (shown in equation 6) to find the width or diameter of the pile (w) in feet, which is given in cell H12. The height of the pile is calculated using equation 1 as before and is given in cell H13.

$$w = \sqrt[3]{\frac{(24 \times 2000)W}{80\pi \tan 32}} \qquad (6)$$

Figure 1 shows the conical pile.

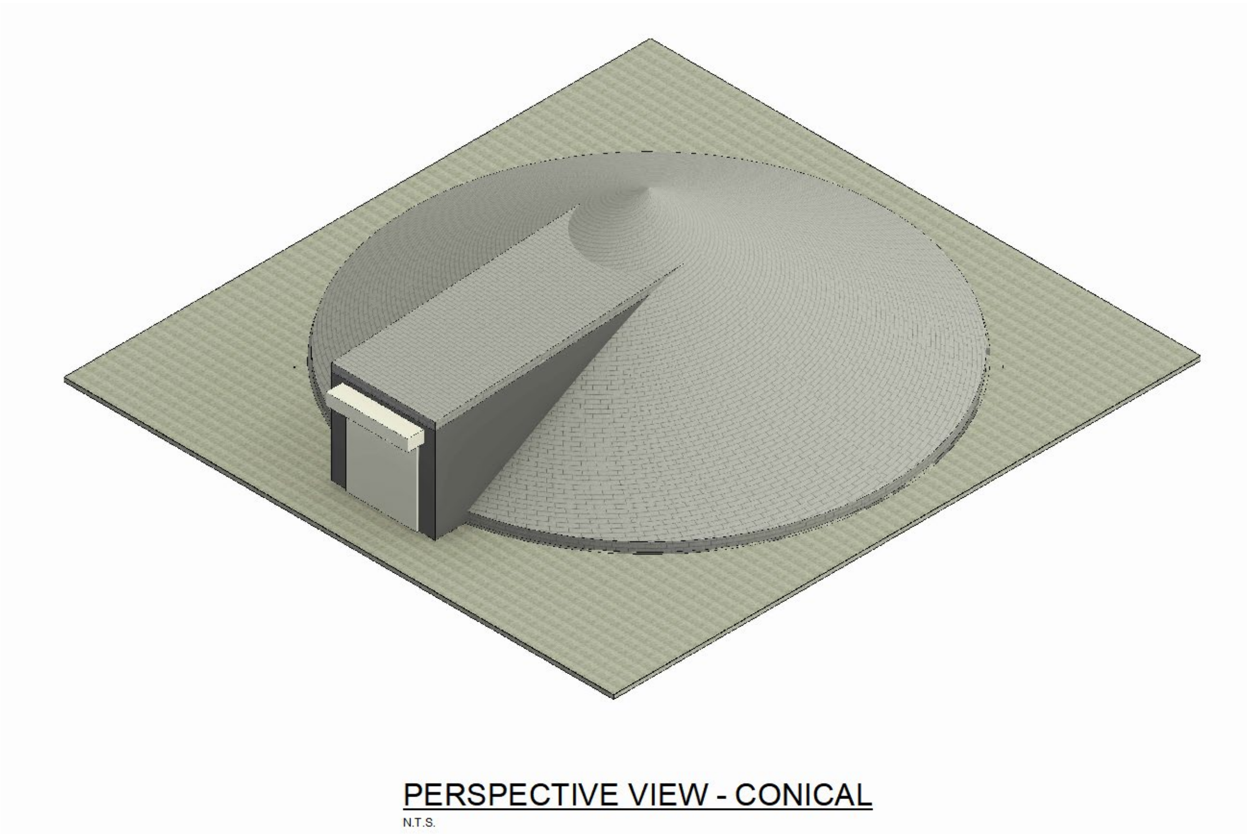

Figure 1: Perspective view of the conical pile.

Tab 2: "Storage in Conical Building"

This set of values is derived from the amount of salt that can be stored in a conical building with vertical side walls as depicted in figure 2. Prior to any calculations, a suitable value must be entered into cell F4 for the height of the walls (entered in units of feet and designated as h_w in the equations below).

From this point, the user has two sets of calculations available. Option 1 is for a building loaded with a conveyer system which assumes (see above) that 90% of the total available storage can be utilized. Option 2 is for a building loaded with a front-end loader or equivalent which assumes that 60% of the total available storage can be utilized.

To calculate the salt stored in a conical building of a given diameter (w in feet – this value is provided by the user in cell C11 for option 1 and cell H11 for option 2) the volume of a cylinder of diameter w and height h_w is found and then added to the volume of the cone of diameter w and with angle of repose 32° as given in equation 4. This volume (in cubic feet) is then converted into tons of salt by multiplying by the density of granular salt (80 lbs per cubic foot) and dividing by the number of pounds in a ton. This gives the following equation for the weight of salt stored in a conical building of diameter w feet and with wall height h_w feet:

$$W = \frac{80}{2000}\left[\frac{\pi w^2}{4} h_w + \frac{1}{24}\pi w^3 \tan 32\right] \qquad (7)$$

The solutions in the two options are then obtained by multiplying the value obtained in equation 7 by 0.9 and 0.6 respectively, giving the salt stored in a conical structure with a conveyer system in cell C15 and in a structure without a conveyer system in cell H15. The height of the salt pile is simply the sum of the height of the wall (provided by the user in cell F4) plus the height of the cone on top of the pile (calculated using equation 1 as before) and is provided in cells C16 and H16 respectively.

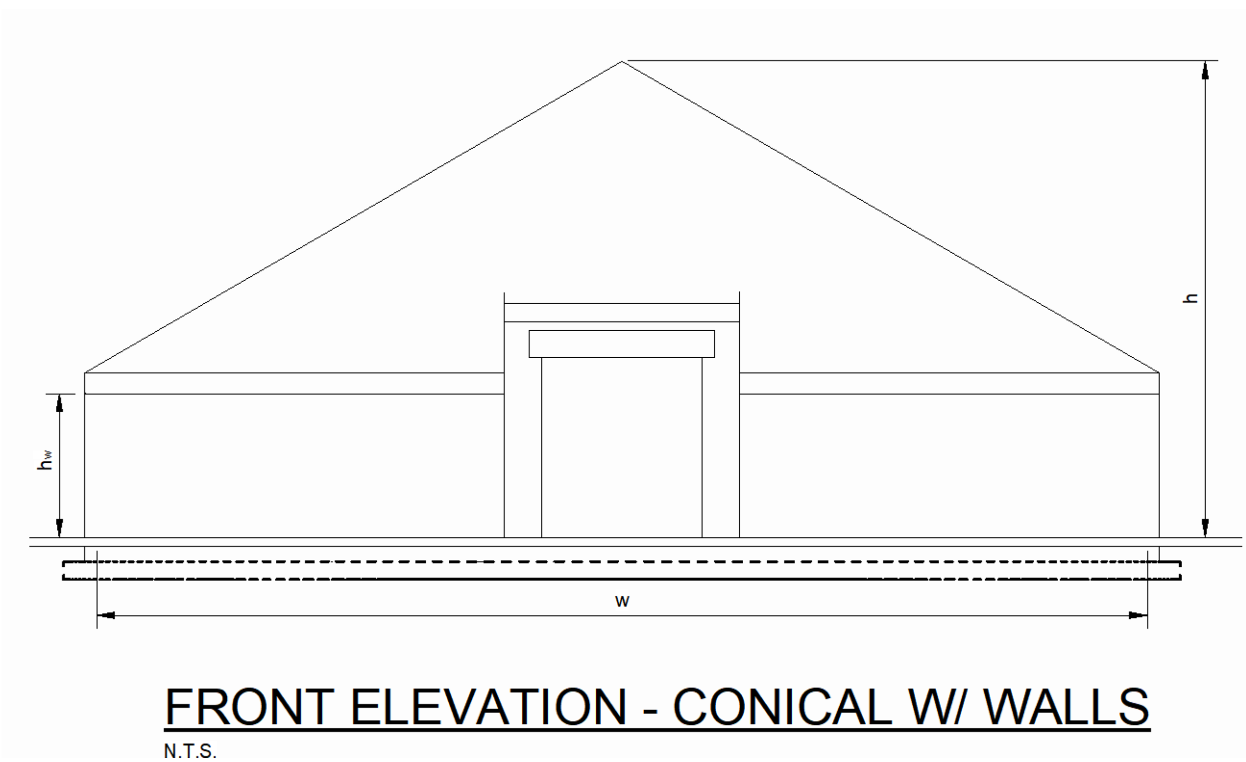

Figure 2: Conical Building with Vertical Walls

Tab 3: "Storage in Rectangular Building"

This set of values is derived from the amount of salt that can be stored in a rectangular building with vertical sidewalls as depicted in figure 3 (a and b). It is assumed that the salt will form a shape with rounded ends and a prismatic central section as shown in figure 3. Key input variables for the calculations are the height of the building walls (h_w) entered in feet in cell E4, and the aspect ratio of the building (the ratio of the building length to its width – designated as A_r) entered in cell E6. The aspect ratio should be at least 2.0 (that is, the length should be twice the width as a minimum). The total length of the building (L) is given as:

$$L = wA_r \qquad (8)$$

As in tab 2, the user has two sets of calculations available. Option 1 is for a building loaded with a conveyer system which assumes (see above) that 90% of the total available storage can be utilized. Option 2 is for a building loaded with a front-end loader or equivalent which assumes that 60% of the total available storage can be utilized.

The building width, w, (in feet) is entered by the user in cell C11 for option 1 and H11 for option 2. Different widths can be assigned for each option as needed by the user, since this allows the user to compare the size of building needed to store a given salt amount with a conveyer system, with the size of building needed to store that same salt amount without a conveyer system.

The volume of salt stored in the building is calculated by "breaking" the salt stored into two parts – the ends of the pile are assumed to be approximately semi-conical (so the two ends together will make a cone), while the center of the pile is a prismatic shape, with a triangular cross section placed upon a rectangular base (again, as shown in figure 3). Using this representation, the weight of salt stored in the ends of the pile is the same as in a conical building of diameter w feet as given in equation 7. To this is added the weight of the salt stored in the prismatic part of the pile. To calculate this, we first estimate the length of the prismatic section (*l*) as shown here:

$$l = w(A_r - 1.0) \qquad (9)$$

Using this, and the height of the walls (h_w) previously entered, as well as the height of the triangular cross-section pile of salt on top of the rectangular base as calculated using equation 1 (h) we can calculate the volume of the prismatic section of the pile (V_p) as:

$$V_p = wl\left(h_w + \frac{h}{2}\right) \qquad (10)$$

As discussed above, equation 7 provides the weight of the salt stored in the semi-conical ends of the pile, and we can add this to the weight of salt stored in the prismatic central section of the pile to obtain the total weight stored in the pile (W), as shown here:

$$W = \frac{80}{2000}\left[wl\left(h_w + \frac{w \tan 32}{4}\right) + \pi\left\{\frac{h_w w^2}{4} + \frac{0.3125w^3}{24}\right\}\right] \qquad (11)$$

The solutions in the two options are then obtained by multiplying the value obtained in equation 11 by 0.9 and 0.6 respectively, giving the salt stored in a conical structure with a conveyer system in cell C16 and in a structure without a conveyer system in cell H16. The height of the salt pile is simply the sum of the height of the wall (provided by the user in cell F4) plus the height of the cone on top of the pile (calculated using equation 1 as before) and is provided in cells C17 and H17 respectively.

Figure 3a: Perspective View of Elongated Conical Building

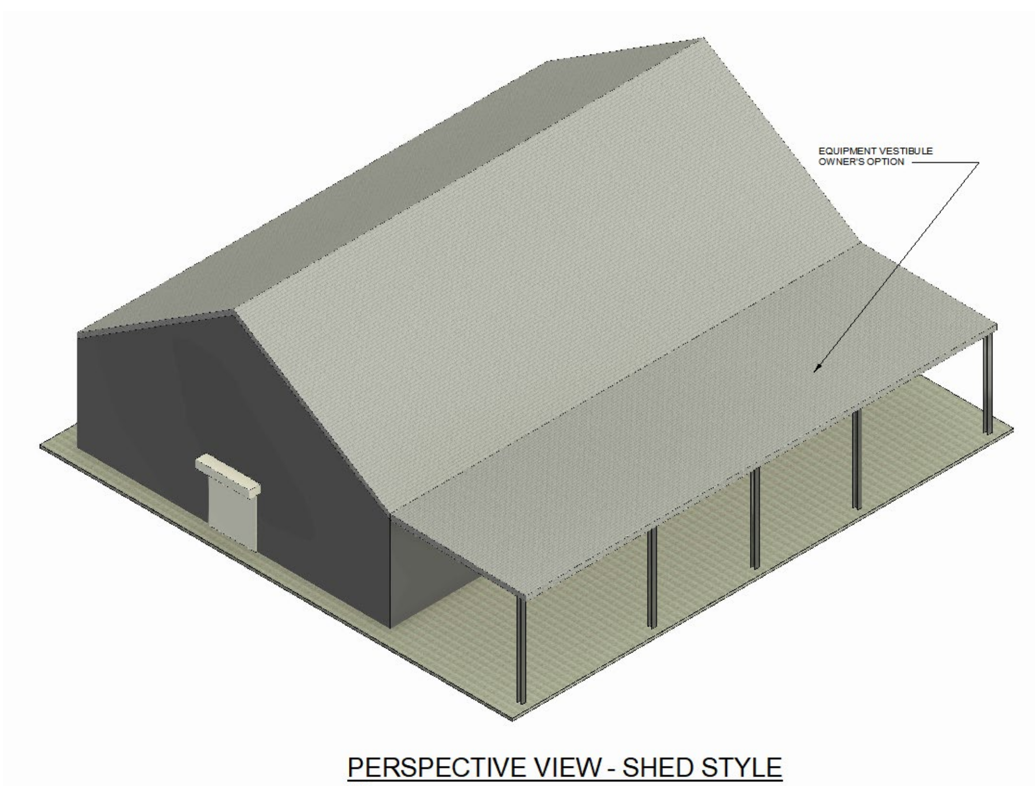

Figure 3b: Perspective View of Rectangular Shed Style Building

Using the Spreadsheet Tool

The purpose of the tool is to provide an estimate of how much salt can be stored in a given size of structure. Users may choose to employ the tool as they wish, but the following is offered as a general guide to how the tool might be used by an agency interested in sizing a salt storage facility.

Step 1: Starting Estimates

Let's suppose that an agency needs a facility that can store 12,000 tons of salt (which is based upon their five year average of salt use at the location where the new facility will be placed). With this number in mind, the user might go to the first tab (Conical Piles No Walls) and input the desired storage (12,000 tons in this example) into cell H7 (this is under option 2). The output for this is shown in Figure 4.

Option 2: What diameter to store a given weight of salt	
Input Section	
Weight of Salt Stored (in tons)	12000
Output Section	
Diameter of Conical Pile (in feet)	**154.2**
Height of Pile (in feet)	**48.2**

Figure 4: Output of the First Step

The cone to store this much material is about 155 feet in diameter. Of course, there is no wall around this pile, which will likely reduce the parameter somewhat. So the next step is to investigate whether a conical structure would allow the desired amount of salt to be stored within a reasonable footprint.

Step2: Conical Footprint

The user now proceeds to the second tab (Storage in Conical Building). Two initial choices must be made. First, what height of wall would be suitable in your conical building. Ten feet is a reasonable number to begin with, but this can be adjusted as needed. If the required wall height to store the needed salt exceeds 20 feet then it is likely not feasible. The wall height is entered into cell F4.

The second initial choice is whether salt will be stored with or without a conveyer system. A conveyer system allows much more efficient usage of the available storage space but the initial capital costs for such a system may not be feasible.

For the purpose of this example, we will assume a conveyer system is available, then we will run a parallel computation to see how large a building would be needed if no conveyer system was used. In other words, we will do our initial calculations in the Option 1 box, then a comparative calculation in the Option 2 box.

In the Option 1 box, we enter our initial estimate of the building diameter into cell C11. In step 1 we found that a conical pile needed to be about 155 feet in diameter to store 12,000 tons of salt, so that is a good starting point. As figure 5 shows, this gives us a salt storage of about 17,700 tons – rather more than we need.

Option 1: How Much Weight Stored for a Given Diameter Pile (assuming conveyer used so 90% efficient storage)	
Input Section	
Diameter of Pile (in feet)	155
Output Section	
Weight of Salt Stored (in tons)	17761
Height of Building (in feet)	58.4375

Figure 5: Salt stored in a conical structure.

Clearly, we do not need such a large structure. We can enter in different values of pile diameter in cell C11 until we get close to 12,000 tons stored. Doing this (see figure 6) we find that a diameter of 134 feet is sufficient to store 12,000 tons, in a facility with a conveyer system.

Option 1: How Much Weight Stored for a Given Diameter Pile (assuming conveyer used so 90% efficient storage)	
Input Section	
Diameter of Pile (in feet)	134
Output Section	
Weight of Salt Stored (in tons)	12164
Height of Building (in feet)	51.875

Figure 6: Diameter of conical structure to store 12,000 tons.

As discussed above, we can conduct a parallel calculation for a structure without a conveyer system, using option 2, and entering the pile diameter into cell H11. As can be seen in figure 7, we would need a conical building 156 feet in diameter (and with a 10 foot vertical wall) to store 12,000 tons of salt if we did not have a conveyer system.

Option 2: How Much Weight Stored for a Given Diameter Pile (Assuming no conveyer so 60% efficient storage)	
Input Section	
Diamter of Pile (in feet)	156
Output Section	
Weight of Salt Stored (in tons)	12041
Height of Building (in feet)	58.75

Figure 7: Size of Conical Building with no Conveyer System

Step 3: Rectangular Footprint

When considering a building with a rectangular footprint, the aspect ratio (the length of the building divided by its width) must be specified as well as the wall height. The spreadsheet requires that the aspect ratio (entered in cell E6 under the third tab “Storage in Rectangular Building”) have a value of at least 2.

Continuing our example of storing 12,000 tons of salt, we may consider both the conveyer equipped option (option 1) and the building without a conveyer (option 2). As figure 8 shows, using a wall height of 10 feet and an aspect ration of 4, the conveyer equipped building would be 68 feet wide and 272 feet long.

Option 1: How Much Weight Stored for a Given Width of Building (assuming conveyer so 90% efficient storage)	
Input Section	
Width of Building (ft)	68
Output Section	
Length of Building (in feet)	272
Weight of Salt Stored (in tons)	12075
Height of Salt Pile (in feet)	31.3

Figure 8: Rectangular Building Footprint with Conveyer.

In contrast, if no conveyer system is available, then option 2 shows us (see figure 9) that the building would be 80 feet wide and 320 feet long.

Option 2: How Much Weight Stored for a Given Width of Building (Assuming no conveyer so 60% efficient storage)	
Input Section	
Width of Building (ft)	80
Output Section	
Length of Building (in feet)	320
Weight of Salt Stored (in tons)	12082
Height of Salt Pile (in feet)	35.0

Figure 9: Rectangular Building Footprint without Conveyer.

In any specific situation, the details of the available facility footprint will drive the selection of building shape, aspect ratio, wall height, and so forth. However, the spreadsheet tool provides a useful initial analysis tool to investigate the options in a broad sense.

APPENDIX E

Salt Storage Facility Design Checklist

INTRODUCTION

Design is an iterative process, and as such it is not feasible to provide a linear roadmap through the whole design process. Instead of this, a checklist has been developed and is presented here. The purpose of this is to allow users to be confident that all areas of design of a salt storage facility have been considered.

The checklist is presented in five topic areas (sizing of facility, site selection, environmental factors, type of structure, and general/other). In each of these areas, a section goal is given to provide context for the topic. Then, those decisions that are required for a successful design have been identified and information pertinent to making those decisions is provided. At the end of each topic area, the outcome of these decisions is presented. However, because of the iterative nature of design, it may be necessary for a topic area to be revisited depending upon findings and decisions made in other topic areas. For example, the constraints on site selection may be such that the desired size of the facility cannot be accommodated, in which case the sizing decisions will need to be revisited with the additional constraints included.

This document also includes a tabular version of the checklist decisions that may be helpful for any design teams using this approach. There is also an appendix that provides an approach for estimating how climate change might impact future salt storage needs.

CHECKLIST TOPICS

1. Sizing and footprint of Facility

Section Goal: Determine how much salt the facility must store and what size of facility will be needed to store that.

As a first consideration, facilities may be designed as the primary facility for a specific area, or as a satellite facility within an area that is used to minimize dead-head time for trucks. When an area of responsibility is particularly large, satellite facilities may be useful ways of minimizing the time when trucks are returning to a facility with no salt on board. Regardless of whether the facility being considered is a primary facility or a satellite location, the driving factor regarding how much storage is needed is how many lane miles the facility must serve.

Decision # 1-1

- Primary storage facility, or
- Satellite storage facility

In deciding what size of facility an agency needs, long-standing advice suggests that an agency should have **sufficient storage for their annual average (over a five-year period) salt usage**. However, for an agency with a growing transportation system, this five-year average will need to be increased to take into account the expected growth in lane miles. This can be accounted for with the following formula:

$$future\ storage\ needs = \frac{current\ five - year\ average\ usage}{current\ lane\ miles} \times future\ lane\ miles$$

The ratio of future lane miles to current lane miles indicates the expected growth in lane miles over the expected lifetime of the storage building. The current five-year average usage is the average of the past five years of salt tonnage used at the facility which will be served by the new storage building. Thus, if the five-year average for a given location is 9,000 tons, and the ratio of future lane miles to current lane miles is 1.20 (i.e. lane miles are expected to grow by 20% over the lifetime of the new storage facility) then the future storage needs would be 10,800 tons (9,000 multiplied by 1.20). This is an ideal storage quantity, and it may not be possible to accommodate this much salt storage due to site constraints. However, it does represent a suitable starting point for design.

Decision # 1-2

- Calculate future salt storage needs incorporating expected growth in lane miles.

To determine the facility footprint, the shape of the planned structure must be known in general terms. There are two basic shapes – a conical facility, and a rectangular facility. It is also possible to have an elongated conical facility. These three options are shown in figures 1, 2, and 3, respectively. The amount of salt that can be stored in such structures is a function of geometry and **the angle of repose of salt in a pile (32 degrees)**. The fourth option is a rectangular building with a fabric roof as shown in figure 4.

Figure 1: Conical Storage Facility

Figure 2: Elongated Conical Storage Facility

Figure 3: Rectangular Storage Facility

Figure 4: Fabric Covered Salt Storage Facility (courtesy of WYDOT)

Another factor that must be considered in developing the footprint of the facility is **how salt will be loaded into the structure**. The most efficient way of loading salt is by use of a conveyor system, which can be fixed (I.e., only usable at that storage facility) or mobile (capable of being used in several facilities). If a facility has such a system, then it is reasonable to assume that up to 90% of the theoretical maximum salt storage capacity can be used. However, if the structure is to be loaded using front end loaders or the equivalent, then it must be assumed that only 60% of the theoretical maximum salt storage capacity is available.

A third item for consideration is the impact of climate change on future salt needs. This is problematic since there are no clear numerical indications as to how winter severity will change because of climate change. However, this is a factor that should be considered. This design guide addresses how this can be handled in Appendix A, discussing how a winter severity index could be used to indicate possible trends in future salt usage for a facility.

Spreadsheet tools have been developed that calculate the footprint for the various structure shapes identified in figures 1, 2, and 3. The tools incorporate calculations based on the method of loading (with or without a conveyer system).

Decision # 1-3

- Calculate size of storage facility, using spreadsheet tool, for various structural shapes.

Outcome of step 1

When step 1 is complete, the designer will have sizes for different storage structures based upon the salt storage needed. Note that in step 2, site selection of the various structures will be considered, and the calculated size may be too large for the available space. If that occurs, then the storage facility will either have less storage than ideal or will require additional surface area to be acquired.

2. Site Selection

Section Goal: Locate the facility so that it best serves the winter operations needs of the agency, within the constraints that limit possible facility locations.

Site selection will often be constrained by what land is available for an agency. The first consideration in terms of setting up a storage facility is that it should be optimally placed to serve all roads that must be maintained from that location. This generally requires that it be centrally located within an area of responsibility. However, other constraints may limit the site selection as listed here:

1. The site may be located essentially anywhere within the area of operation of an agency.
2. The site may be located within a few (perhaps two or three) locations within the area of operation of the agency.
3. The site is fixed, but the storage facility may be located within the site with some degree of freedom.
4. The location of the storage facility within the site is generally constrained such that there is only one location where it can be placed, and the only variable in site location is the available footprint.

Decision # 2-1

- Which of the four situations (A, B, C, D) applies in your case?

Case A involves many considerations, but from the point of view of salt storage, the primary one will be optimal placement so that all routes going from the facility will be essentially equal in time to serve. Alternately, if the various routes have different priorities and thus different desired times to completion, then routes should be chosen to achieve those timing goals. This is a complex optimization problem and given that case A is the least likely of the four cases, it is recommended that if an agency finds itself dealing with case A, it acquires expert advice on the optimization of routes from potential locations. Other factors such as land availability and costs will also be involved in this sort of decision.

Decision # 2-2-A

- Determine who can provide expert advice on route optimization for the various possible locations, and using their input, select the optimal site location.

Case B is simpler than case A in that it is more constrained. Again, the approach will be to develop routes for each of the possible locations and see how well they can be balanced in terms of timing and priority. Because the locations are limited in number, the challenge of case B is much less than that of case A, and agencies should be able to develop potential route maps for evaluation without great difficulty.

Decision # 2-2-B

- Create route maps for each of the potential locations and use these to determine which location is optimal.
- Include in the evaluation other factors (e.g., location cost, access to utilities, etc.) that will impact on both the cost and the functionality of each potential location.

In case C, the issue of route times and priorities no longer plays a role since the general location of the site is fixed. However, in this circumstance (and after the general location of the site in cases A and B), the flow of traffic around the site must be a major factor of consideration. There are two aspects to this – first, it must be easy for trucks delivering salt to safely make those deliveries. And secondly, it must be easy for plow trucks to reload with salt both before and during storms. Figure 5 shows a layout (from the city of Fort Collins, CO) where trucks have an easy path for both unloading (via the conveyer system on the right) and loading (note that on the bottom left of the picture are stations where trucks can load liquid via special pumps).

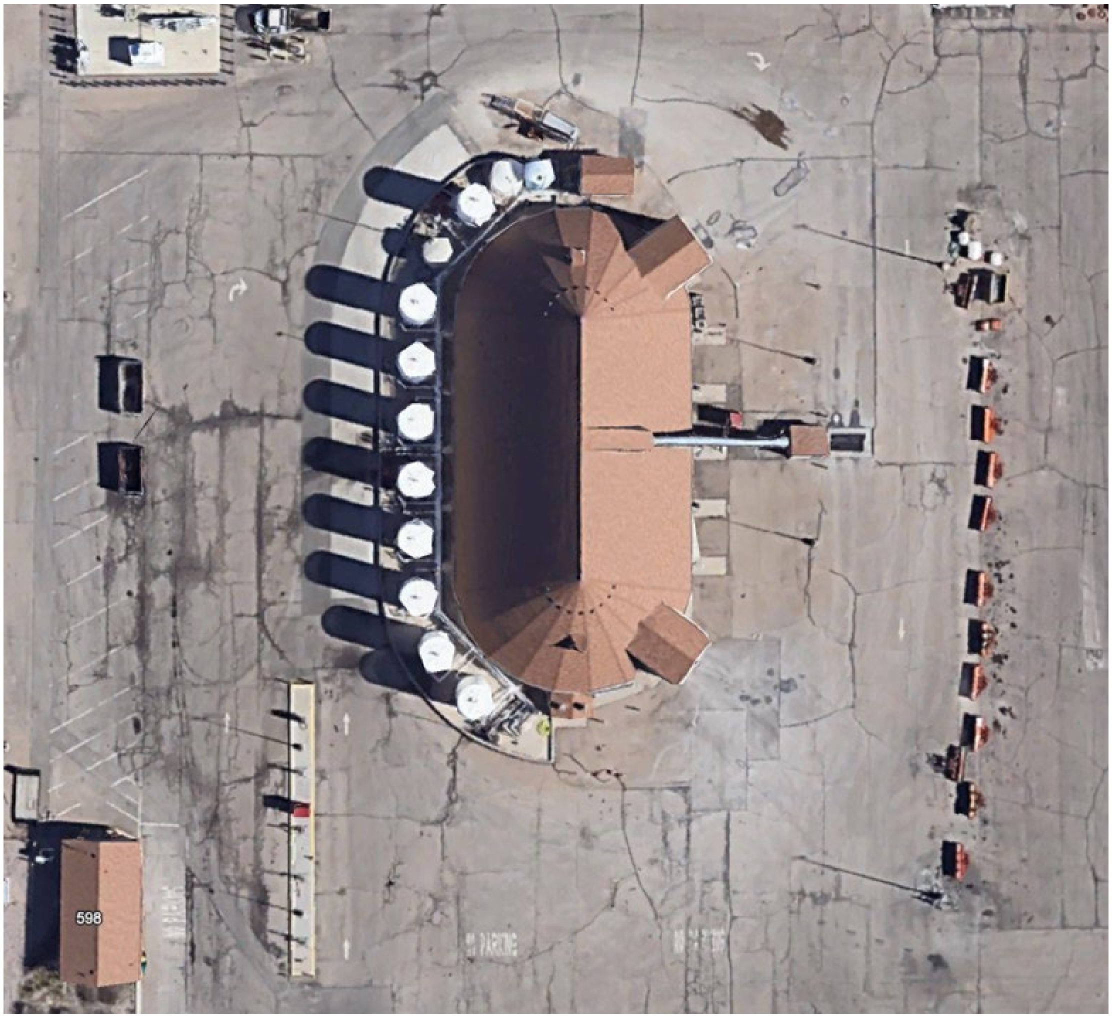

Figure 5: Salt Storage Facility showing Good Site Layout for Loading and Unloading.

Additional considerations regarding location of the storage facility include minimizing civil work (e.g., little to no cut or fill required), good soil conditions to support the building loads, and no (or as few as possible) environmental concerns (this is discussed in greater detail below).

Decision # 2-2-C

- Select site location so that salt loading and unloading is simplified.
- Consider locations that minimize cut and fill, have good soil conditions to support building loads, and minimal environmental concerns.

In case D, the location is fixed by other constraints on the site, and in fact it may not be possible to place as large a facility as needed (as determined from step 1 above). In this case, the agency will need to revisit step 1 to determine how much of their future salt storage needs can be met, and in particular, this limitation might increase the need and value of a conveyor-based loading system.

Decision # 2-2-D

- Given the size constraints imposed by the site, determine (via step 1) how much salt can be stored in the size-constrained facility.
- Further consideration of a conveyer system for loading salt into the structure may provide additional storage in spite of the constrained facility footprint.

Outcome of step 2

When step 2 is complete, the site for the salt storage facility will have been selected, and the location of the facility within that site will have been specified.

3. Environmental Factors

Section Goal: Ensure that the structure is designed to minimize any potential environmental impacts that may derive from the salt being stored within the structure.

One of the major purposes of good salt storage is to minimize the likelihood of any environmental impact from the salt being stored. Thus, consideration of environmental factors is a critical part of the design process. Primary concerns in this regard are well known – the need to prevent water running into the salt storage area, the need for an impermeable surface on which to store the salt, the need to collect and/or contain any runoff from the stored salt have all been well documented and discussed elsewhere (most notably in the Salt Institute Sustainable Salt Storage handbook).

Decision # 3-1

- Select site location so that rainwater does not drain into the salt storage facility, but rather flows away from it.
- Specify a suitable impervious flooring system for the structure and the surrounding area, to prevent soil contamination due to salt infiltration.
- Ensure that any runoff from the stored salt is either collected or contained in such a way that it cannot cause contamination.

In addition to these factors, the need to keep the storage facility as far away as possible from any environmentally sensitive areas (streams, wetlands, etc.) is an obvious constraint. Additionally, orientation of the facility so that loading entrances do not face the prevailing wind (thus minimizing the potential for precipitation to enter the building) is a major benefit, although this must be considered along with concerns about ease of loading salt into the building and loading trucks from the building discussed in item 2 above.

Decision # 3-2

- Ensure that there is sufficient distance between the location of the storage structure and any environmentally sensitive areas to minimize the possibility of contamination of those areas due to salt runoff.
- Consider orienting the structure so that loading entrances do not face the prevailing with, with the proviso that orientation must not make loading the structure with salt overly complex.
- The design should be reviewed to ensure that it complies with all appropriate and applicable code requirements.

Some facilities may be multi-purpose, in that in addition to storing salt, they are also used for salt brine making and salt brine storage. In such cases, the appropriate containment requirements for salt brine manufacturing and storage must be incorporated into the design. Other multi-purpose designs have included truck loading facilities, and truck washing facilities. Both have obvious advantages but will also significantly increase the required building footprint.

Since lifetimes for these facilities are typically in the 25-to-50-year timeframe, it is important to include maintenance and preservation requirements as part of the design process. If the structure requires special coatings, the design should be such that those coatings can be re-applied as needed. If certain parts of the structure are designed to be replaced on a cycle less than the total structure lifetime, then that replacement should be considered in the design so that it can be done without undue effort and expense.

Multi-Purpose and Multi-Owner Facilities

Many agencies share salt storage facilities and find this to be a very useful way of ensuring adequate supply without needing large on-site storage. Others build facilities that not only store salt, but also are used for loading trucks, making brine, storing brine, and loading brine into trucks as needed. Such multiple use facilities may be worth considering.

Decision # 3-3

- When designing the storage facility, it is important to consider how the facility will be maintained throughout its planned lifetime.
- Any part or coating replacement that is needed as part of the maintenance plan should be designed into the original structure, so that maintenance can be done with minimal effort and expense.

Outcome of step 3

When step 3 is complete, the facility should be such that there is minimal potential for negative environmental impacts because of the materials stored within the structure.

4. Type of Structure

Section Goal: Determine which type of structure works best within the constraints of the salt storage project.

There are three general types of salt storage structure. The conical or beehive structure typically has concrete vertical walls, and then a roof in place over a wooden frame. The rectangular structures come in two types. In the first, the building is a regular frame type of building, with combinations of wood and concrete as needed. The roof on such structures is solid. The second type of rectangular structure uses a fabric covering over metal hoops for a roof system. This may be anchored into regular concrete walls, or into large ecology type blocks.

Cost will clearly be a major factor in the selection of structure type. In general, using a fabric roof rather than a solid roof will provide a lower initial cost, but may require more maintenance over time. A life cycle cost approach will be considered in this regard. Cost will also likely be impacted by the availability of both contractors and materials for the desired structure.

Decision # 4-1

- In terms of relative cost of structures, the cheapest structure for a given storage volume (in initial construction cost) will be the fabric covered rectangular building. The beehive type of structure is typically the most expensive. The regular frame rectangular structure offers greater flexibility in terms of additional uses in the building other than simply storing salt.
- While construction costs are relatively clear, lifetime costs are more complex. Fabric covered buildings will need the fabric covering replaced at some point, and any building used to house salt will need to be carefully maintained to minimize deterioration over time.
- Cost is unlikely to be a simple calculation since each of the building type options offer additional factors above cost. Thus, a beehive is often considered more aesthetic, and if such factors are important, they may override simple cost concerns.

It is likely that different structures will have different construction timelines, and this will need to be factored into the final decision on structure type. Under circumstances where timing is a critical path in the design and construction process, the timing might be the deciding factor between different types of structures.

Decision # 4-2

- Because construction time may be a constraint, when selecting a building type it may be necessary to consider how long each type will take to construct. The simpler the building, in general the less time it will require for construction. Accordingly, if the desired building type cannot be completed in the available time, another building type will be required.

In terms of efficiency of storage, the beehive/conical shape is more efficient than the rectangular shape or the elongated conical storage facility. However, other factors may either limit the available footprint or constrain the shape of the footprint in other ways. If the available space is rectangular, for example, then it is likely that a rectangular shape will be able to store more material than a conical shape. Also, the conical storage solution requires special tools to be filled efficiently, which implies additional costs that may make that solution prohibitive.

Decision # 4-3

- Rank the building types according to maximum storage within the available space footprint at the construction site. Having done this, apply cost and other factors to determine the optimal building type.

Once a selection of building type has been made, decisions are required on the detailed design components. These include foundation and wall designs (wall height and thickness) including wall to foundation connections and drainage around the foundations. In addition, details of roof design (considering wind and snow loads) and the connections between the roof and the walls, as well as details of the structure door system need to be finalized.

Decision # 4-4

- Complete the various design details for the final building selection for the salt storage facility.

Outcome of step 4

When step 4 is complete, the optimal building type subject to various constraints (cost, space, time of construction, etc.) will have been selected. Further, design details for the final building will have been completed.

5. General/Other

Section Goal: Ensure that all "back of house" criteria and issues have been addressed appropriately.

This section is meant to consider the "back of house" criteria that will ultimately describe what a successful storage facility will look like. Standards defined in this section will consist of items such as available budget, operational requirements, service area, and desired construction timeline. This part of the checklist considers the broader constraints upon the storage facility. This would include but not limited to how the construction of the facility fits into other concurrent or planned site developments relating to winter maintenance or other operations.

Decision # 5-1

- Determine the amount of funding available for the construction of the new storage facility.

Decision # 5-2

- Determine the timeframe within which the facility must be constructed.

Decision # 5-3

- Ensure that the operational requirements for the new facility are well defined and documented.

Outcome of step 5

When step 5 is complete, all "back of house" criteria for the project will have been addressed.

Checklist for Salt Storage Facility Project

	Preliminary	Final
Topic 1: Sizing and Footprint of Facility		
Decision 1-1: Type of Facility (main or satellite)		
Decision 1-2: Future Storage Needs		
Decision 1-3: Size of Facility (using spreadsheet)		
Topic 2: Site Selection		
Decision 2-1: Determine Type of Site Constraint		
Decision 2-2-A: Select route optimization expert for guidance on location		
Decision 2-2-B: Select optimal location based on route maps generated for each option		
Decision 2-2-C: Select specific location within current site		
Decision 2-2-D: For constrained site redetermine salt storage capacity		
Topic 3: Environmental Factors		
Decision 3-1: Design flooring system		
Decision 3-2: Diminish local environmental impacts		
Decision 3-3: Consider facility maintenance and lifetime factors		
Topic 4: Structure Type		
Decision 4-1: Preliminary type selection		
Decision 4-2: Consider construction timeframe		
Decision 4-3: Select optimal structure type		
Decision 4-4: Complete detailed design		
Topic 5: General/Other		
Decision 5-1: Determine funding in detail		
Decision 5-2: Establish a desirable timeframe for project		
Decision 5-3: Define and document operational requirements		

research for winter highway maintenance

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