Mine Closure 2023 - Behrooz Abbasi, Jeff Parshley, Andy Fourie & Mark Tibbett (eds)

doi:10.36487/ACG_repo/2315_030

Design and regulatory approval of a novel in-situ salt cap for final closure of contaminated wastewater ponds at a brine mining operation

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Abstract

A novel closure technology was developed and approved by regulators for the final closure of a series of large (over 4 sq km) earthen evaporation ponds at a brine mining operation adjacent to the Great Salt Lake in Utah, USA. The cap design included in-situ precipitation of a salt cap (primarily sodium chloride) to prevent contact between humans and wildlife with contaminated sediments and mine wastes contained in the facility's wastewater evaporation ponds. The salt cap is a nature- based solution that is designed to mimic naturally-occurring salt beds present regionally in the Great Basin and is preferable over traditional closure approaches (soil cap, consolidate and cap, or off-site disposal) for the following reasons: 1) saturated wastes and sediments in the ponds are not suitable for traditional earthwork equipment operation; 2) long haul distances for waste disposal or importing cap materials; and 3) the size of the wastewater evaporation ponds and large volume of wastes / sediments. Salt cap design parameters including annual salt deposition rates (in centimetres), brine requirements, and salt weathering rates were estimated through a multi-year field-scale pilot test at a salt accumulation test cell constructed within the footprint of one of the wastewater evaporation ponds. Pilot testing also evaluated effects of brine source on salt deposition rates, where brine was obtained either from Great Salt Lake or from solar evaporation ponds brine feedstock for the mining operations. Key technical challenges that were addressed during salt cap design included: construction of interior partitions, irregular/sloping beds and groundwater discharge areas within the wastewater evaporation ponds, expected timeframe for construction, and potential for contaminant leaching upward into the salt cap. The salt cap closure was approved by the USEPA as the approach for final closure of the wastewater evaporation ponds under both Superfund and RCRA programs. This technology also uses sustainability best management practices to limit the use of natural resources and energy, reduce negative impacts on the environment, and minimize or eliminate greenhouse gases to the greatest extent possible.

Keywords: *innovative technology, capping, nature-based solution, contaminated site, sustainability*

1 Introduction

A brine mining operation located adjacent to Great Salt Lake (GSL) in Utah, USA, includes a series of large (over 4 sq km) earthen evaporation ponds for process wastewater. These waste ponds historically received wastewater contaminated with biproducts from electrolytic refining operations at the site. Due to their size, geotechnical characteristics, and location, traditional remediation and closure approaches such as removal (with on-site off-site disposal) or placement of a vegetated soil cover are impracticable and/or cost prohibitive to implement.

A salt cap closure for the waste ponds is an innovative, site-specific closure approach that has been evaluated and approved by the facility operator, U.S. Environmental Protection Agency (USEPA), and Utah Department of Environmental Quality (UDEQ) through a series of investigations completed as part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Remedial Investigation/Feasibility Study (RI/FS) conducted at the site. The salt cap closure has been approved by USEPA as the default closure approach for the waste ponds (ERM 2021).

The salt cap barrier remedy will create a cap over sediments in the waste ponds through the deposition of salts, primarily sodium chloride (NaCl), precipitated in place by evaporation of a brine feedstock obtained from the operation's network of solar evaporation ponds. Construction of a salt cap barrier will include the following steps:

1. Evaporation ponds within the waste ponds will be constructed by utilizing existing berms and the installation of internal partition containment structures. The evaporation ponds will be designed, constructed, and operated as zero-discharge facilities.
2. The waste ponds will be flooded with brine obtained from a solar evaporation pond containing evapoconcentrated brine sourced from GSL.
3. Brine evaporation will precipitate salts, primarily NaCl; brine will be added to the waste ponds intermittently throughout the evaporation season, which extends from approximately May to October.
4. Brine evaporation will continue until the design cap thicknesses are achieved, marking the end of the salt cap construction phase.
5. After completion of salt cap construction, the salt caps and containment berms will be monitored and maintained by performing additional brine evaporation, berm maintenance, or other actions, as necessary.

The salt cap is preferable over traditional closure approaches (soil cap, consolidate and cap, or off-site disposal) for several reasons:

- The salt cap is a nature- based solution that would mimic naturally-occurring salt beds present regionally in the Great Basin.
- Saturated wastes and sediments in the ponds are not suitable for traditional earthwork equipment operation.
- Due to the sites remote location, long haul distances would be required for waste disposal or importing cap materials.
- The size of the wastewater evaporation ponds and large volume of wastes / sediments contained therein would result in an enormous volume of materials requiring treatment or disposal if removed.

The proposed salt cap uses an available nearby resource that does not require truck traffic to import cover materials. Consequently, safety risks, road repair, and greenhouse gases associated with an alternative soil cover (requiring an estimated 3.2 million cubic meters of capping material) are eliminated. Thus, the proposed salt cap is sustainable in accordance with the USEPA's strategic plan for compliance and environmental stewardship.

1.1 Site conditions

The waste ponds were developed in the 1970s and 1980s on the bed of the GSL and adjacent mudflat areas. The 324-hectare NE waste pond was constructed first and is located on the bed of the GSL. The 204-hectare SW waste pond design utilized existing low-lying mudflats separated from the GSL lakebed (and NE waste pond) by beach ridges composed primarily of oolitic sands. The ponds are unlined and surrounded by earthen berms. The waste pond configuration is shown in Figure 1.

The floor or subgrade of the waste ponds is comprised of soft, wet, low-strength sediment with waste that ranges in thickness from centimetres to over 1 meter. Subsurface stratigraphy in the vicinity of the waste ponds includes Holocene mudflats and playas consisting of laterally continuous layers of silty clay, silty sand, oolitic sand, and gravel, with the stratigraphic units within the area generally sloping to the East/Northeast. The generalized stratigraphy beneath the waste pond area consists of the following:

- Ground Surface to less than 1.5 m below ground surface (bgs): Fine-grained sand, silt/sandy silt/clayey silt with areas of oolitic sands and imported fill material in most boring locations.
- Approximately 1.5 to 3.0 m bgs: Low to Medium plasticity clay/silty clay varying in thickness from 0.6 to 2.4 m.
- Approximately 3.0 to 10.7 m bgs: Silty/fine-grained sand, oolitic in part, interbedded with silt and clay, oolitic in part; gravel and cemented gravel present in top 1.5 m.
- Approximately 10.7 to 16.8 m bgs: Low to medium plasticity clay/silty clay layer. This Deeper Silty Clay unit ranges in thickness between 3.4 to 5.5 m in the waste pond area, and generally is encountered at greater depths and thickens towards the east. This silty clay layer acts as an aquitard between the upper shallow aquifer zone and the lower shallow aquifer zone.
- Greater than approximately 16.8 m bgs: Silty sand/fine-grained sand interbedded with lenses and layers of low to medium plasticity clay/silty clay.

Groundwater in the vicinity of the waste ponds area occurs in three primary hydro-stratigraphic units: the upper aquifer zone (0 to 10.2 m bgs), the deeper silty clay (10.2 to 15.1 m bgs) aquitard, and lower aquifer zone (15.1 m bgs and deeper). The deeper silty clay unit acts as a confining layer between the two aquifer zones. Groundwater levels within the upper aquifer zone range from approximately 1284.7 m amsl to 1280.8 m amsl, with an average gradient of 0.001 across the site.

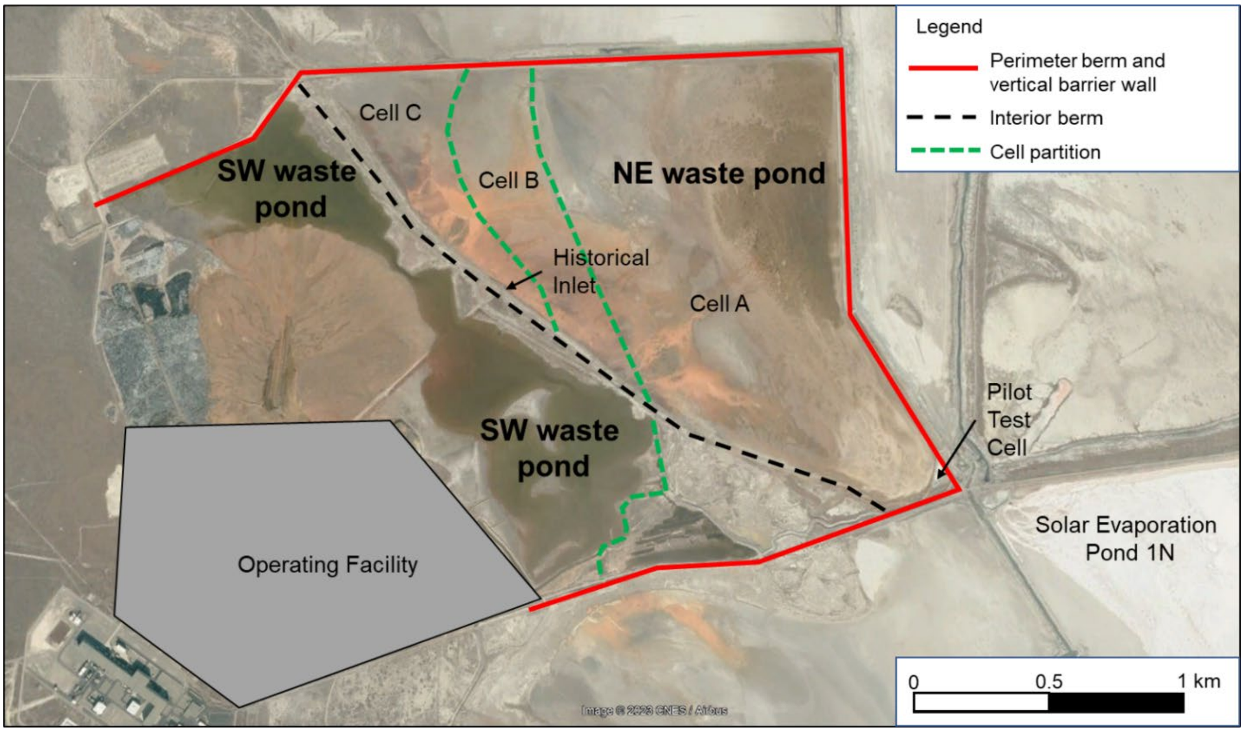

Figure 1 Site layout

Groundwater in the vicinity of GSL has naturally high levels of dissolved salts and minerals; as a result, it is not usable as a potable water supply. Measured total dissolved solids concentrations near the waste ponds range from 29,000 milligrams per liter (mg/L) to 300,000 mg/L in the upper aquifer zone and 56,000 mg/L to 160,000 mg/L in the lower aquifer zone. Because of the upward hydraulic gradient observed at the site, shallow ground water may rise to the surface where it supports the ecosystem of the salt flats area, and potentially the GSL.

1.2 Closure performance standards

The performance standard for the cover system and overall closure of the waste pond is protection of human health and the environment. Based on the environmental data collected and analysed during the RI and risk assessment conducted as part of the CERCLA RI/FS project, the following performance standards were established for closure of the waste pond:

- Protect human health and the environment by preventing direct contact with the underlying impacted materials;
- Prevent direct contact to areas of highest concentrations during the initial stages of closure;
- Be durable and permanent;
- Maintain compliance with State Class 1C Groundwater Protection Levels for ecologically important groundwater as established by the operation's Groundwater Discharge Permit;
- Use sustainability Best Management Practices to limit the use of natural resources and energy, reduce negative impacts on the environment, and minimize or eliminate greenhouse gases to the greatest extent possible in accordance with the USEPA's strategic plan for compliance and environmental stewardship; and
- Minimize maintenance requirements during the post-closure period.

1.3 Waste pond closure approach

To prevent direct human and ecological contact with impacted sediment along the bottom of the waste pond, the waste pond will be covered with a salt cap. The salt cap is the primary element that comprises closure of the waste pond. A salt cap closure was selected due to its effectiveness, constructability, limited on- and off-site disturbance, limited need for imported materials, availability and proximity of salt, site climate, compatibility with surrounding areas, and cost.

A salt cap is a uniquely site-specific, innovative remedial technology that was evaluated during a salt cap treatability study conducted from 2015 through 2018 (ERM 2019). The salt cap will cover all impacted sediments in the waste pond by the deposition of salts, primarily NaCl, precipitated from the evaporation of a brine feedstock processed by the operation's solar evaporation pond system.

2 Methods

Site hydrology and the chemistry of waste, sediments, surface water, and groundwater in the waste ponds were evaluated as part of a RI/FS. The results of these investigations were used to characterize the nature and extent of contamination and to conduct human health and ecological risk assessment. Several studies specific to evaluating implementability and design aspects for the salt cap remedy were also conducted. These include a multi-year salt accumulation pilot test and a reconnaissance of existing salt deposits in the general vicinity of GSL. These salt cap-associated studies are described below and the results from these studies are summarized in Section 3.

2.1 Accumulation pilot test

A salt cap accumulation pilot test was conducted over four years to evaluate:

- The site-specific annual rate of salt deposition.
- The uniformity of areal distribution of accumulated salt as a function of water depth and bottom topography.
- The weathering of deposited salt under Site conditions.

- Site-specific impacts on physical implementability and integrity of a salt cap.
- The structural stability of the waste material under the load of a salt cap.

The pilot test was conducted at the site using a test cell that weas constructed in a corner of the NE waste pond (see Figure 1). The triangular test cell had an area of 0.4 hectare and was constructed using an existing berm, an enhanced existing berm, and a new berm. The new and enhanced existing berms were both approximately 1 m high, 6 m wide at the top, and 12 m wide at the base (Figure 2).

Figure 2 Salt accumulation test cell during post-evaporation season sampling

After test cell construction, pilot testing operations involved pumping of brine into the test cell during evaporation seasons (approximately May to October). A portable diesel-powered pump was used to transfer brine from an adjacent solar evaporation pond during the first two years' evaporation seasons and from the GSL during the next two years' evaporation seasons. The pilot test cell was essentially a batch reactor with periodic additions of brine to maintain a pool of brine in the test cell, maximizing evaporation and salt deposition. The volume of brine pumped into the test cell was calculated based on pumping rates and durations. Brine pumping was stopped near the end of each evaporation season (typically in August) to allow evaporation of the remaining brine.

Monitoring was performed during evaporation and non-evaporation seasons and included the following activities:

- Monthly sampling of brine pumped into the test cell during the evaporative seasons.
- Brine volumes pumped to the test cell based on pumping data.
- Test cell inspections conducted on a monthly basis during non-evaporation seasons and on a weekly basis during the evaporation seasons.
- Pre- and post-evaporation season monitoring events that involved collection and descriptions of salt cores at five locations within the test cell and inspections of the salt cap to document conditions across the cell.
- Continuous monitoring of temperature and precipitation at the test cell site.

The pilot test cell and sampling equipment are shown in Figure 2.

2.2 Existing salt deposit reconnaissance

Numerous natural and man-made salt deposit sites are present in the general vicinity of the GSL. These include the Bonneville Salt Flats, evaporation ponds associated with commercial salt operations (Cargill Salt, Morton Salt), evaporation ponds associated with mineral operations (US Magnesium, Compass Minerals, Intrepid Potash), former evaporation ponds at Knolls, UT, and the West Desert Pumping Project residual salts within Newfoundland Basin or "West Pond." These existing salt caps (salt deposits) were evaluated for their potential to provide qualitative information on the short-term and/or long-term performance of salt deposits as a barrier to underlying soil and sediment. Specifically, the questions to be answered by an evaluation of existing salt deposits study were:

- How do salt caps weather?
- What are the short-term and long-term behaviours of salt caps?

These questions were answered by performing an existing salt deposit study comprising a desktop review of salt deposit sites in the general vicinity of the GSL and a qualitative field reconnaissance of three selected salt deposit sites. Site 1 included the former Knolls evaporation ponds located at the southeast corner of Newfoundland Basin. The Knolls evaporation ponds were operated briefly during the late 1980s. Site 2 included two evaporation ponds at a commercial salt operation. These ponds had been fallow for approximately 8 years at the time of the reconnaissance. Site 3 was a solar evaporation pond associated with one of the mineral production operations at GSL. These existing salt deposits were selected based similarity to the proposed salt cap remedy, and ease of access.

The salt deposit reconnaissance provided observations of the selected salt deposit. During the field reconnaissance, the following features of the existing salt deposits were described:

- Evaporite types.
- Salt crust surface conditions (smooth, pocked, rilled, etc.).
- Desiccation cracks and their characteristics (width, depth, degree of healing).
- Presence of ponded or flowing surface water or groundwater discharges.
- Gullies, rills, or other indications of erosion by surface water.
- Potholes, subsidence, or other indications of salt dissolution by groundwater.
- Thickness and stratification (at locations where hand auger borings were successful).
- Substrate conditions (at locations where hand auger borings were successful).
- Photographs with accompanying photograph log for salt deposit areas visited and features observed.
- Global Positioning System coordinates for salt deposit areas visited and features observed.

3 Results

3.1 Salt cap accumulation pilot test

The salt cap accumulation pilot test was performed from June 2015 to October 2018 to provide information to support the evaluation of the feasibility of a salt cap and to support the salt cap design. The results from the pilot test are summarized below for salt cap implementability and integrity, annual rate of salt deposition, areal distribution of salt deposits, and weathering of salt deposits.

3.1.1 Implementability and integrity

Construction of the test cell and successful operation for four evaporation seasons indicated that a salt cap barrier is implementable at the site. Salt deposition was observed throughout the test during all four years of operation and was independent of the nature and heterogeneity of test cell pond floor waste/sediments. As such, the nature and extent of waste/sediments within the floor of the test cell did not appear to affect the physical implementability and integrity of the salt cap.

3.1.2 Annual rate of salt deposition

The annual rate of salt deposition in the test cell was assessed based on salt cap thickness measurements collected during 2015-2018 pre- and post-evaporation season monitoring. A summary of the salt deposition rates observed during the pilot test is provided in Table 1.

Several key observations of salt deposition were identified based on the pilot test operations and monitoring. First, measured salt cap thicknesses indicated salt deposition during evaporation seasons and salt dissolution and redistribution during non-evaporation seasons, with evaporation season deposition being greater than non-evaporation season dissolution. Salt thickness measurements from the core sample locations were averaged for each monitoring event to assess the average rate of salt deposition across the test cell.

Table 1 Results from the salt accumulation pilot test

Year	Brine Source	Average Brine Specific Gravity	Liters Brine Evaporated	Centimeters Salt Deposited
Year 1 (2015)	Solar evaporation pond 1N	1.219	3,339,000	10.2
Year 2 (2016)	Solar evaporation pond 1N	1.222	4,111,000	20.1
Year 3 (2017)	GSL	1.154	2,294,000	5.1
Year 4 (2018)	GSL	1.126	2,146,000	3.3

Salt accumulation was influenced by brine volume and average specific gravity (Table 1). Solar evaporation Pond 1N brine was used during the 2015 and 2016 evaporation seasons when the average salt thickness increased 10.2 and 20.1 cm, respectively. GSL brine was used during the 2017 and 2018 evaporation seasons when the average salt thickness increased 5.1 and 3.3 cm, respectively. Pond 1N brine had a higher average specific gravity than GSL brine, and larger volumes of brine were pumped into the test cell during the seasons that pond 1N brine was used. Based on these data, the rate of salt deposition appears to be higher when brine with higher specific gravity is introduced at higher volumes.

The annual rate of salt deposition is a factor of salt accumulation during the evaporation season and salt dissolution during the non-evaporation season. During three non-evaporation seasons, average salt thickness decreased 1.5 cm during 2015-2016, 9.1 cm during 2016-2017, and 1.5 cm during 2017-2018. Staff gauge/piezometer water levels and precipitation data were analyzed to assess the potential for precipitation to influence non-evaporation salt dissolution and to assess possible reasons for larger decrease in average salt thickness during the 2016-2017 non-evaporation season than during the 2015-2016 and 2017-2018 non-evaporation seasons. Total precipitation during the 2016-2017 non-evaporation season was higher than during the same period of 2015-2016 and 2017-2018, and groundwater levels at piezometers installed at the test cell perimeter were correspondingly higher during the 2016-2017 non-evaporation season. This correlation suggests that precipitation may contribute to salt loss during non-evaporation seasons.

On the other hand, precipitation may not entirely account for the observed salt thickness changes during the non-evaporation seasons. Importantly, non-evaporation season water level data from a staff gauge in the NE wastewater pond adjacent to the test cell and a piezometer located in the berm between test cell and the wastewater pond showed water levels in the wastewater pond and test cell to be closely correlated, indicating the water levels in the (much larger) wastewater pond influence groundwater levels in. Salt loss during the non-evaporation season due to precipitation on the test cell could not be entirely separated from the influence of elevated wastewater pond water levels adjacent to the test cell.

3.1.3 Aerial distribution of salt deposits

Aerial distribution of salt deposits within the test cell was apparently influenced by the pond floor topography, which has a natural depression in the center and slopes upward toward the berms. Total change in elevation across the test cell pond floor was approximately 0.5 m. Accumulated salt thicknesses were highest in the center of the test cell and lower in relatively higher elevation portions of the cell. Salt deposited in the center of the test cell was generally more competent and had lower amounts of windblown dust and berm material displaced during rain events than was observed in the corners of the test cell. Salt dissolution was generally greater in the higher elevation areas of the pond than in the pond center.

3.1.4 Weathering of salt deposits

Monitoring during the pilot test included routine inspections to observe formation and weathering of the salt deposits within the pond. Inspections were conducted monthly during non-evaporation seasons and weekly during evaporation season operations. Pre- and post-evaporation season inspection events included collection of salt cores and measurements of salt cap thickness at specified monitoring locations. Based on the inspections, the following salt cap observations were made:

- The salt cap surface in the central portion of the test cell was generally smooth, white, and very hard, while the salt surface in higher elevation areas of the pond (e.g., adjacent to the berms and in the pond corners) was less competent and is rough/pocked, likely the result of periodic high intensity rain events.
- Depressions in the test cell floor preferentially accumulated salt, which eliminated topographic relief of the test cell pond bottom.
- Salt spires and mounds were present in the east and south portions of the pond following the initial evaporation season. During subsequent years of the pilot test, the salt spires and mounds appeared to dissolve over time, leaving a flat salt surface. Based on these observations, the salt surface appears to flatten and harden over time.
- Similar to observations from the existing salt deposits study, salt self-healing appears to be an important process in allowing a salt deposit to retain hardness and competence over time. Self-healing of erosional features (cracks) were observed within the test cell and appears to be a function of redistribution and re-precipitation of salts within the pond.

3.2 Existing salt deposit reconnaissance

As part of the overall engineering evaluation for the salt cap, a study was performed of existing salt deposits at three sites within the GSL region to assess long-term weathering of the salt deposits. These salt deposits are composed of similar evaporite types to that proposed for the slat cap. Key conclusions from the existing salt deposit reconnaissance were:

- The observed salt deposits are composed of similar evaporite types to those proposed for the design of the salt cap barrier remedy.
- The observed salt deposits are compatible with and structurally stable on natural substrate types similar to those found at the wastewater ponds.

- Control of surface water runoff is a key factor in the weathering and erosion of salt deposits. Where surface water runoff is prevented, the surfaces of the observed salt deposits retain hardness and competence over time, and salt deposition may occur over large areas (well over 4,000 hectares). Where surface water runoff is allowed or encouraged, salt deposits were moderately or significantly eroded/dissolved.
- Salt self-healing appears to be an important process in allowing a salt deposit to retain hardness and competence over time. Self-healing of erosional features (cracks, rills, and channels) was observed where precipitation runoff is entirely or partially retained on the salt deposit, which allows for dissolution, redistribution, and re-precipitation of salts as the surface water accumulates in low areas and evaporates. This suggests that containment of surface water on the salt cap enables redistribution of salts and results in a flat, smooth, and hard salt surface.
- Topography has a significant influence on salt accumulation and erosion. The observed salt deposits at Site 1 were thickest in low-lying areas, and higher elevation areas have limited salt accumulation and/or are more likely to be subject to salt erosion/dissolution. The salt ponds at Site 2 were designed with a very flat topography, which enables an even accumulation of salt across the ponds. Salt deposits at Site 3 (shown in Figure 3) initially formed in the low-lying central portion of the pond and have thickened and expanded across the pond during several decades of salt deposition. These observations suggest that pond bottom topography is a consideration for the proposed salt cap barrier remedial alternative (i.e., berm configuration is likely an important design element for salt cap construction).
- Dissolution by groundwater may compromise salt deposit integrity in localized groundwater discharge areas, although salt deposits dissolved by groundwater were observed to self-heal if conditions at the discharge area allow for evaporation of pooled surface water (i.e., there is no overland flow of water away from the discharge area).
- Wind erosion does not appear to have significant effects on salt deposits, and the introduction of windblown debris and dust appears to have little effect on the observed salt deposits.
- After formation, salt deposits have competent, hard, and uniform surfaces that form effective physical barriers over underlying soils/sediments. The hard and cemented crystalline salt layers that comprise these deposits are effective to prevent direct contact with underlying soils/sediments and are unsuitable for burrowing or digging.

The observations described above from other salt deposits were further considered and incorporated into the design and engineering evaluation.

4 Waste pond closure design

In order to provide sufficient thickness for preventing dermal contact to the waste pond sediments, the salt cap will consist of a minimum 0.6-m thick salt deposit over the floor of the waste pond. The minimum 0.6-m thickness of salt cap will provide a sufficient thickness contingency to maintain protection throughout potential short-term losses from dissolution and redistribution, erosion, and maintenance activities. Since the cap's source brine is a liquid and will maintain a consistent elevation when placed in the waste pond, the final salt cap gradient will be relatively flat and, therefore, significantly thicker (up to 2.4 m thick) in the lower lying area of NE waste pond to obtain the minimum 0.6-m thickness in the higher elevation areas. The cap constructed in the SW waste pond will have a relatively uniform thickness because there is minimal topographic relief across the pond bottom. The brine will be sourced from a solar evaporation pond (pond 1N) that will be operated until plant closure. During cap construction, brine will be periodically pumped from the GSL to the solar evaporation pond as necessary to supplement the brine depletion.

The salt cap will be installed in 15-cm lifts, via numerous repetitive increments of accumulated salt over several years. This slow, incremental increase in salt thickness and corresponding pressure is synonymous to the traditional geotechnical approach for improving soft soils by pre-loading or pre-consolidating subsurface materials by placing a soil pile over an area prior to construction of a structure.

Figure 3 Exposed salt deposit at a mineral facility's evaporation pond

The thin incremental lifts of salt will gradually increase the pressure on the subbase by a nominal uniform load of 2.9 to 3.4 kilopascals (estimated for 15 cm of salt). The gradual increase allows time for dissipation of any water, establishment of equilibrium, and formation of hard crystalline salt structure prior to adding the subsequent lift. Consequently, the subbase will be adequate to support the low, incremental, and uniformly applied load from salt cap placement. Additionally, after placement and formation, the salt provides a competent, hard, and uniform surface. The hard and cemented crystalline salt layers will provide additional support for subsequent lifts. The low, incremental, and uniform load coupled with the crystalline structure also mitigates potential for mud wave formation during cap installation or sediment migration into the salt, which are typical challenges with non-uniform loading over soft, low strength materials.

Consequently, the salt cap application process allows for consolidation of the subgrade and mitigates the potential for settling of the salt cap into the subgrade materials. During the non-evaporation-season, rain may dissolve the surface layers of salt and temporarily reduce the thickness of the salt cap. However, due to the flat salt cap surface, significant sheet-flow is not likely to occur and the solubilized salt will precipitate within, or near, the same area that it was dissolved, thereby replacing the dissolved salt layers. This cycle will result in a limited-to-no net loss of cap thickness due to weathering, such that salt is expected to accumulate a net of 10 to 15 cm per year. The final surface of the salt cap will be flat, the final thickness of the salt cap will range from 0.6 m thick to 2.4 m thick.

4.1 Site preparation

Salt cap construction will rely on berms and partitions to provide lateral containment of brine during evaporation season while the salt cap is deposited in the ponds. The alignments for these berms and partitions are shown in Figure 1. The site preparation work required for construction of the salt cap includes improvements to the interior berm between the NE and SW waste ponds and construction or placement of cell partitions within the waste ponds. Neither wholesale excavation nor significant regrading of the pond floor is necessary, as the salt cap will be applied over the existing pond floor grades.

4.1.1 Perimeter and interior berms

Areas where the integrity of the interior berm between the NE and SW waste ponds has been impacted will be repaired. Furthermore, the interior berm will also be extended prior to salt cap installation to achieve a minimum crown elevation of 1286.3 m amsl to provide sufficient freeboard above the maximum brine and salt cap elevations while considering the 100-year, 24-hour storm event of 5.61 cm. Currently, the elevation of the interior berm varies between 1283.2 and 1286.3 m. Repair and raising the interior berm between NE and SW ponds will be performed with soil borrowed from the site. The extended berm between the SW and NE ponds will have a minimum top width of 6.1 m for accessibility purposes.

The existing perimeter earthen embankment was enhanced as a separate project for wastewater management and operations; therefore, no perimeter berm enhancement will be required before closure and salt cap construction. The perimeter berm enhancements completed during plant operations include a) extending the height of the perimeter berm to 1286.3 m amsl, b) installing a vertical barrier wall around the ponds, and c) stabilization and armoring of the outer berm slope for flood and scour protection. The planned elevation of waste pond berm of 1286.3 m amsl exceeds the GSL catastrophic flood elevation of 1285.3 m (DFFSL 2013), and therefore, the perimeter waster pond berm will provide sufficient engineering protection of the salt cap from flooding by the GSL.

4.1.2 Cell partitions

The area of highest constituent concentrations in the SW pond are located in the lowest elevations; consequently, the initial lift of salt cap will provide cover over this area. A series of two partitioning berms will be constructed to facilitate cap installation in areas with existing elevated and irregular terrain within the eastern portion of the SW pond (Figure 1). The existing pond floor within the partitioning berm area is at approximately 1285.0 m amsl. These partition berms will facilitate the brine filling operation within the elevated areas of the SW pond to be concurrent with remaining area of the SW pond. The SW pond partitioning berms will achieve a final top elevation of 1286.3 m, and will have a minimum top width of 1.5 m.

Conversely, the highest concentrations within the NE pond are located within the former inlet area at elevations between 1282.6 to 1283.2 m amsl, which is about a meter above the lowest elevation. The bed of the NE pond is characterized by a gradual topographic relief ranging from 1282.0 to 1284.4 m amsl along the pond bottom, with an approximate gradient of 0.15%. Therefore, it will be difficult to maintain brine coverage over the entire NE pond bottom, including the former inlet area without interim partitions. To provide an interim cover consisting of a thin layer of salt over the area of highest concentrations during the initial stages of closure, the NE pond will be divided into three cells, Cell A, B, and C as shown in Figure 1. These cells will be created by placing a partition or barrier along elevation 1282.6 m and 1282.9 m. Prior to cap installation, the partitions will be installed and the three cells established.

The NE pond partitions should be capable of being installed on the soft pond soils and retaining a combined minimum of 61 cm of brine and salt. The specific construction material or product will be selected during the final design but could consider a low-permeability, 76-cm high aqua tube that is filled with brine or water, or standard erosion control products, such as fiber logs or silt fence, that will provide a surface upon which salt crystals will form and retard flow. The partitions may be removed upon sufficient accumulation of salt, such that the salt elevation is nearly equivalent across all cells. However, based on the specific product's durability, including UV resistance and long-term salt compatibility, the final design could consider leaving the partitions in place provided that the partition remains 61 cm high to comply with the minimum cap thickness.

4.2 Salt cap construction

The mechanics for installing the salt cap are characterized by natural processes and consist of the following three primary activities:

1. Addition of brine to the waste pond
2. Evaporation of water
3. Accumulation of the salt from repetitive brine evaporation cycles

The source of brine for the salt cap will be a solar evaporation pond 1N that is part of the brine mining operation's solar evaporation ponding complex. The specific gravity of pond 1N brine is approximately 1.2 with a salinity of 20 to 23%. Brine from the GSL is pumped from an intake canal into pond 1N. Pond 1N covers approximately 7900 hectares and can contain 47.7 billion liters of brine under normal operation at an averaged depth of 61 cm. The operator currently pumps on average 37.9 to 45.4 billion liters of brine from GSL to pond 1N each year; however, only approximately 9.8 billion liters of GSL brine is required to produce the annual volume of concentrated solar evaporation pond brine for cap construction. During cap construction, GSL-sourced brine will continue to be periodically pumped each year from the GSL, as necessary to supplement the brine depletion in pond 1N. The brine will remain in pond 1N until it achieves a specific gravity of approximately 1.2. If water levels of GSL decrease as a result of climate change or upstream water diversions, the salinity of GSL brine would increase, and therefore, the volume of GSL-sourced brine required to supplement pond 1N would decrease. In the event that GSL-sourced brine is no longer available, alternative approaches can be explored, such as application of solid salts available in the site vicinity and/or generating brine from salts that have historically deposited and accumulated in the facility's solar evaporation pond network.

Brine for salt cap construction will be pumped from pond 1N and conveyed through a network of pipes to distribute the brine to designated discharge outlet locations located within each pond area. The brine discharge outlets will be spaced throughout the waste pond to decrease the erosive flow at each location and to uniformly distribute the brine throughout the waste pond, to the extent practical. Each discharge location will consist of an outlet protection structure to mitigate pond sediment disturbance and erosive flow onto the cap. It is estimated that the SW pond and NE pond will require approximately 1900 and 3000 million liters of brine, respectively, from pond 1N per evaporative season. A maximum of 91 cm of brine will be applied during the evaporative season (May through October).

At an accumulation rate of 15 cm per year, it is estimated to require approximately 16 years to achieve a 2.4-m thick cap in the lowest elevation of NE waste pond in Cell A. The 2.4-m thick cap in the lowest elevation of NE waste pond corresponds to the salt cap design final elevation of 1284.4 m in the NE waste pond. If the salt accumulation rate is assumed to be 13 cm per year (average), the construction period of salt cap will be extended by three additional years (i.e., 19 years). For the SW pond, with a salt deposition rate of 15 cm per year, it is estimated that salt cap accumulation will require approximately 10 years of construction. if the salt accumulation rate is assumed to be 13 cm per year (average), the construction period of salt cap will be extended by 2 additional years (i.e., 12 years).

Contrary to the requirements of a prescriptive engineered barrier layer cap, which is to promote controlled surface water run-off, it is important to limit sheet-flow of surface water over a salt cap, such that the accumulation or ponding of surface water is contained where it is deposited. Therefore, the waste pond salt cap will be uniformly installed over flat surfaces and will maintain as flat of a cap surface as possible. Dissolution of a portion of salt from the surface will likely occur during the off-season from rainfall events. This phenomenon is likely to cause the loss of salt and temporary reduction in salt cap thickness due to the solubility of salt in water. The flat surface design of the salt cap, however, allows for the precipitation of dissolved salt to occur within proximity of the area it was dissolved, thereby yielding a no net loss of salt thickness. Additionally, if there are voids or localized depressions, the precipitation of salt will favor low-lying areas, which will naturally repair these imperfections resulting in surface equilibration (i.e., self-repairing). Self-repairing has been observed in other salt deposits and was documented in the treatability study

4.3 Post closure

There is currently no intent for public re-use of the site following post-closure activities. In addition, no construction or reuse for industrial propose is planned following closure. The area will be secured, maintained, and monitored for the entire post-closure care period. Post-closure care will consist of monitoring the effectiveness and integrity of the closure system (including the salt cover, interior berm, perimeter berm, and groundwater monitoring system), and site security. Site inspections and routine maintenance will also be performed as throughout the post-closure period.

5 Conclusion

A salt cap closure for waste ponds at a brine mining operation was evaluated and designed as an innovative, site-specific nature positive closure approach. The salt cap barrier remedy will create a durable permanent cap over sediments in the waste ponds through the deposition of salts, primarily sodium chloride (NaCl), precipitated in place by evaporation of a brine feedstock obtained from solar evaporation ponds adjacent to GSL.

The salt cap closure plan developed for the waste ponds has been approved by USEPA as the default closure approach and complies with the performance standards presented in Section 1.2. A compliance summary is provided for each of the standards below:

- Prevent direct contact: The primary exposure pathway is physical contact with the impacted materials. The proposed minimum 0.6 m of salt cap protects human health and the environment by covering the impacted materials to prevent physical contact with the underlying sediments. The final salt cap will range in thickness from 0.6 to 2.4 m thick.
- Provide an interim cover of salt over the areas of highest concentrations within the initial stage of closure: Although the salt cap will take many years to achieve the 0.6-m minimum thickness (i.e., between 4 and 16 years are projected for particular areas), the design approach herein incorporates cells to obtain a minimum 5 cm of salt cover in the areas of concern for the NE waste pond within the first year. Due to the flatter terrain in the SW waste pond, it is anticipated that the areas of higher constituent concentrations will be covered with 10 to 15 cm after the first year.
- Be durable and permanent: The cemented crystalline salt layers will provide a competent, hard, and uniform surface that will be durable. Erosion, voids, or dissolution that may occur will be naturally repaired through precipitation, resolution, redistribution to low areas and re-precipitation of the salt.
- Be compatible with other remedial actions and compliant with groundwater standards: An enhanced perimeter berm related to the vertical barrier wall will further protect the salt cap. The salt cap utilizes available resources and mitigates conflicts with other activities. Consequently, the salt cap is compatible with other future remediation. Additionally, the groundwater impacts are limited within the waste pond area and will be contained by the vertical barrier wall, therefore, the salt cap remedy will be compliant with the groundwater protection levels as required by the State Groundwater Discharge Permit.
- Incorporate sustainability: The proposed salt cap uses an available nearby resource that does not require truck traffic to import cover materials. Consequently, safety risks, road repair, and greenhouse gases associated with an alternative soil are eliminated. Thus, the proposed salt cap is sustainable in accordance with the USEPA’s strategic plan for compliance and environmental stewardship.

- Minimize maintenance: Due to the perimeter controls and flat topographic design of the salt cap, erosion and other conditions that could compromise the integrity of the cap are limited. Additionally, the salt precipitation process promotes natural repairs of any holes, rills, or voids. Consequently, maintenance is anticipated to be minimal.

References

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