LONQUIST
FIELD SERVICE

December 27, 2023

Stephen H. Lee, Director
Louisiana Department of Natural Resources
Injection and Mining Division
617 N. 3rd Street
Baton Rouge, Louisiana 70802

Re: Third Response to 3rd Supplement to Compliance Order No. IMD 2022-027
Westlake US 2, LLC – Well 6X (SN 57788) & Well 7B (SN 67270)

Dear Mr. Lee,

This response letter is submitted on behalf of Westlake US 2, LLC ("Westlake") who received the 3rd Supplement to Compliance Order No. IMD 2022-027 on October 25, 2023. The order listed certain findings of fact, and orders requiring responses at various due dates.

- The First Response was submitted on November 27, 2023.
- The Second Response was submitted on December 1, 2023.
- This is the Third Response to satisfy certain Orders as presented below.
- Additional Reponses will be submitted at later dates.

Orders & Responses:

3. Westlake must as soon as possible, but in no event later than thirty (30) days after receipt of this Supplement, submit all of the following to IMD:
    a. An identification of the potential path(s) of migration for liquids from within Cavern 6 and 7 to the outside of the salt stock;

Westlake Response:

Westlake submitted an official response to this Order on December 1, 2023.

e. A plan to install tiltmeters on all accessible Westlake cavern wellheads by the end of the calendar year 2023, including specifications of the tiltmeters used and a data reporting schedule;

Westlake Response:

See Attachment A.

5. Westlake must as soon as possible, but in no event later than sixty (60) days after receipt of this Supplement, submit all of the following to IMD:
    a. An assessment for the use of an alternate source of freshwater, such as surface water, in lieu of withdrawing from the Chicot

Aquifer for Westlake's operations at its Sulphur Mines Salt Dome cavern facility -

Westlake Response:

See Attachment B.

b. A plan for back-filling for cavern stability.

Westlake Response:

See Attachment C.

6. Westlake must as soon as possible, but in no event later than ninety (90) days after receipt of this Supplement:
   a. Install artificial reflectors in areas of poor satellite point coverage within the boundary of the InSAR survey area; and

Westlake Response:

See Attachment D.

Note that the anticipated timeline for procuring and installing the corner reflectors has a completion date of January 25, 2024. Westlake has already committed to the long lead materials order to meet the proposed quantity. If Westlake receives IMD approval for the planned reflector locations (Attachment D) by January 3, 2024 then the estimated install completion date of January 25, 2024 can be met. If the IMD Orders and provides justification for a quantity of corner reflectors in addition to what is proposed in the plan, then Westlake will need to provide an updated estimate for the install completion date of the additional reflectors.

TRE Altamira provided guidance on the requirements for selecting CR locations and has reviewed and verified their agreement with the proposed plan. Reflectors were also positioned to support monitoring of the monument locations that were utilized in past annual level surveys. The frequency of data collection and reporting currently employed for the SNT and TSX/PAZ satellite sources will be used for monitoring of the reflector array. Note that the first report for these new InSAR datasets will not be available until mid-May 2024 due to the time and image count required for initial amplitude analysis and development of a suitable image stack for processing. This timing estimate applies to the higher frequency TSX/PAZ data collection. A longer timeline may be required for initial delivery of SNT reflector data.

If there are any questions, please contact Josh Bradley (Westlake US 2, LLC), Coleman Hale (Lonquist Field Service, LLC), Ben Bergman P.E. (Lonquist Field Service, LLC) and Troy Charpentier (Kean Miller LLP).

Sincerely,

Coleman Hale

R. Coleman Hale
Vice President
Lonquist & Co., LLC

BEN H. BERGMAN
License No. 40184
12/27/2023

Certified By:
Lonquist Field Service, LLC
Louisiana Registration No. EF-5853

Ben H. Bergman P.E. 12/27/2023

Ben H. Bergman, P.E.
Senior Engineer
Louisiana License No. 40184

Date Signed: December 27th, 2023
Houston, Texas

<u>Attachment List</u>

A. Tiltmeter & Differential GPS Plan
B. Alternate Source of Water Plan
C. Backfilling Feasibility Report
D. Proposed New InSAR Reflectors Map

ATTACHMENT A

Tiltmeter & Differential GPS Plan

Plan to monitor ground deformation at Sulphur Mines Salt Dome: Precision Tiltmeter and Differential GPS Arrays

(LDNR Compliance Order No. IMD 2022-027)

NATHANIEL L. BYARS
License No. 40697

Nathaniel Byars

Date Signed: December 22, 2023
Austin, Texas

Nathaniel L. Byars, P.E.
Principal Engineer
Louisiana License No. 40697

Dr. Sergey Samsonov, InSAR Corporation
Julie Shemeta, MEQ Geo Inc.

December 22, 2023

Introduction

An integrated surface deformation monitoring plan has been designed for Sulphur Mines salt dome. The plan combines InSAR monitoring, precision tiltmeter, and Differential GPS arrays. The design of the tiltmeter and Differential GPS arrays was based on a theoretical model of deformation at Sulphur Mines.

Modeling Deformation at Sulphur Mines. The Mogi point source model was used to create a forward deformation model for the Sulphur Mines dome (*Mogi, 1958; Tiampo et al., 2000; Lisowski and Dzurisin, 2006*). This model measures the immediate response of an elastic medium to a change in pressure or volume of a cavity. Elastic models were successfully used to describe ground deformation prior to sinkhole formation (*Atzori et al., 2015*). This type of model provides the largest possible extent of the area that can be affected by the processes in a deep cavity and predicts where the greatest horizontal deformation is likely to occur.

The modeling results are shown in Figure 1-4, which display the expected surface deformation caused by pressure or volume change in the source. The point source of the deformation was modeled at a depth of 3000 ft (h), a depth near the thinnest edge of salt for Cavern 7 to the flank, and a volume change (ΔV) of 630,000 BBL was used as a starting point for the model. The volume change was chosen to provide a measurable displacement of at least 10 mm. A key point of this model is the shape of the ground deformation does not depend on the amount of volume change but only on the source depth. The magnitude of the surface deformation at the surface changes with volume. The deformation surface pattern depends on the depth of the source.

The equations used for the model are:

$$\mathrm{U_x = 3\Delta Vx/(4\pi R^3)}$$

$$\mathrm{U_y = 3\Delta Vy/(4\pi R^3)}$$

$$\mathrm{U_z = 3\Delta Vh/(4\pi R^3)}$$

where Ux,y,z are the displacements in the x, y, or z directions, x and y are the distance in the x (east-west) and y (north-south) directions from the center of the sphere along the surface of the earth, h is the depth of the source from the surface, R=sqrt(x2+y2+h2), V is the amount of volume change.

The modeling results are shown below, the vertical deformation in Figure 1 and the horizontal (*Uh=sqrt(Ux*^{2}+*Uy*^{2})) in Figure 2. The maximum deformation is a downward vertical motion with ~28 mm deformation centered on Cavern 7 (Figure 1). The deformation pattern extends outward in a radius greater than 6500 ft from Cavern 7. The modeled maximum horizontal deformation of about 10 mm is at *0.7h*=2100 ft distance from Cavern 7. The east-west and north-south modeled horizontal deformation are shown in Figures 3 and 4. The magnitude of the deformation will vary with the volume of the cavern that might be affected. The deformation pattern spatially depends on the depth of the deformation. If the deformation occurs at a shallower depth, the deformation pattern will retract towards the cavern.

These Mogi model results form the basis for the tiltmeter and Differential GPS array designs. The sensors are placed in positions to optimally capture the expected deformation patterns due to processes in Cavern

7. GPS sensors measure horizontal deformation with higher precision than vertical deformation. Therefore, we propose one GPS sensor right above Cavern 7, where vertical deformation is expected to be the largest, and four other GPS sensors in the northwest, northeast, southeast, and southwest corners at *0.7h* distance from Cavern 7*,* where the model has predicted horizontal deformation to be the largest. The model is designed to estimate the largest possible areal extent of surface deformation. Therefore, tiltmeter sensors are also proposed in a greater density throughout this region to facilitate monitoring and definition of less extensive ground deformation patterns.

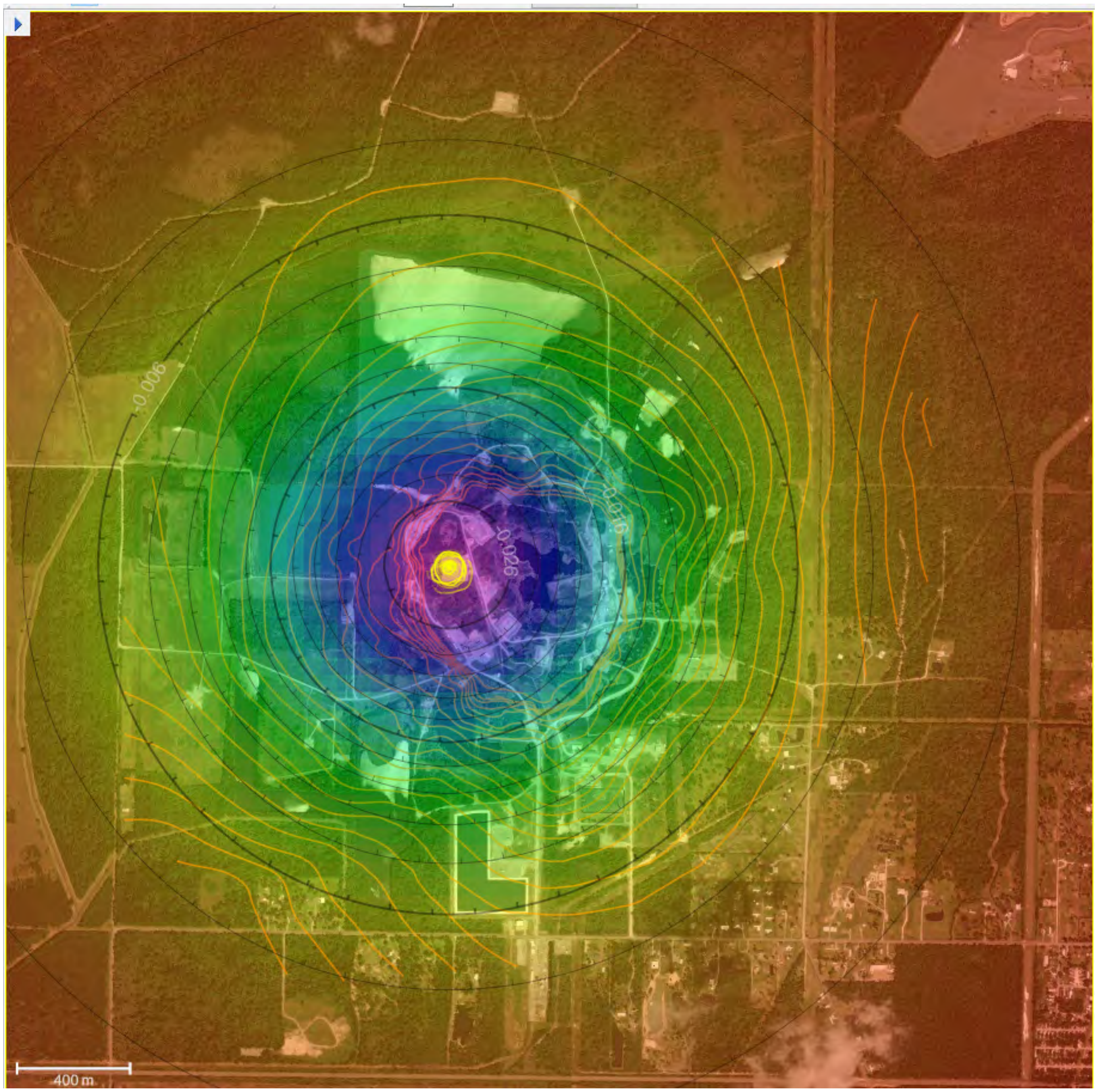

Figure 1. Colored and contoured map of the modeled vertical deformation pattern resulting from a point source at 3000 ft depth at Cavern 7 as described in text. The deformation contours are 2 mm, the contours are labeled in meters. The salt geometry at Sulphur Mines Dome is shown by orange solid lines, the sonar of Cavern 7 is shown in yellow. A satellite photo is shown for reference.

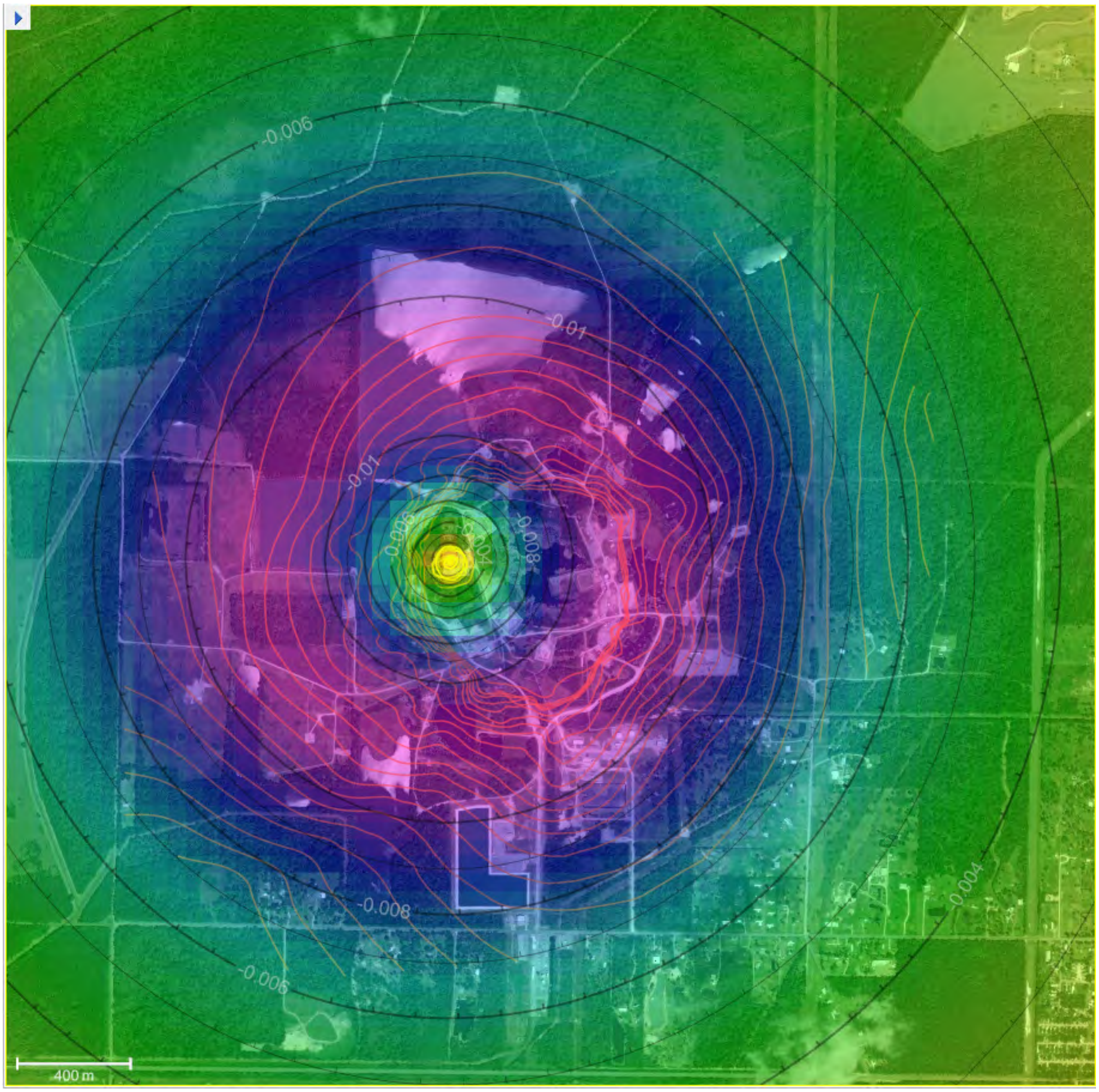

Figure 2. Colored and contoured map of the modeled horizontal deformation pattern resulting from a point source at 3000 ft depth at Cavern 7 as described in text. The deformation contours are 1 mm, the contours are labeled in meters. The salt geometry at Sulphur Mines Dome is shown by orange solid lines, the sonar of Cavern 7 is shown in yellow. A satellite photo is shown for reference.

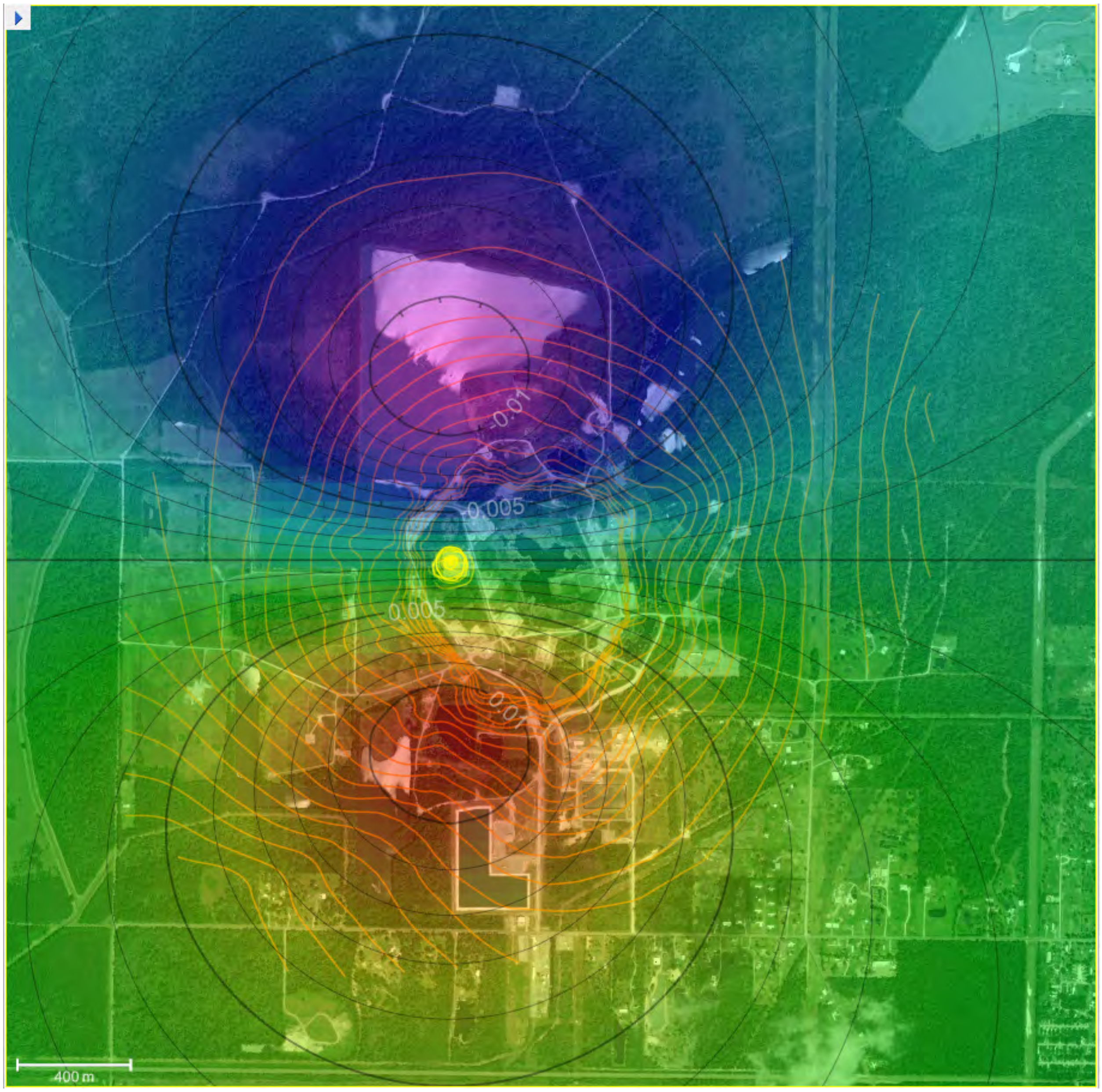

Figure 3. Colored and contoured map of the modeled north-south deformation pattern resulting from a point source at 3000 ft depth at Cavern 7 as described in text. The deformation contours are 1 mm, the contours are labeled in meters. The salt geometry at Sulphur Mines Dome is shown by orange solid lines, the sonar of Cavern 7 is shown in yellow. A satellite photo is shown for reference.

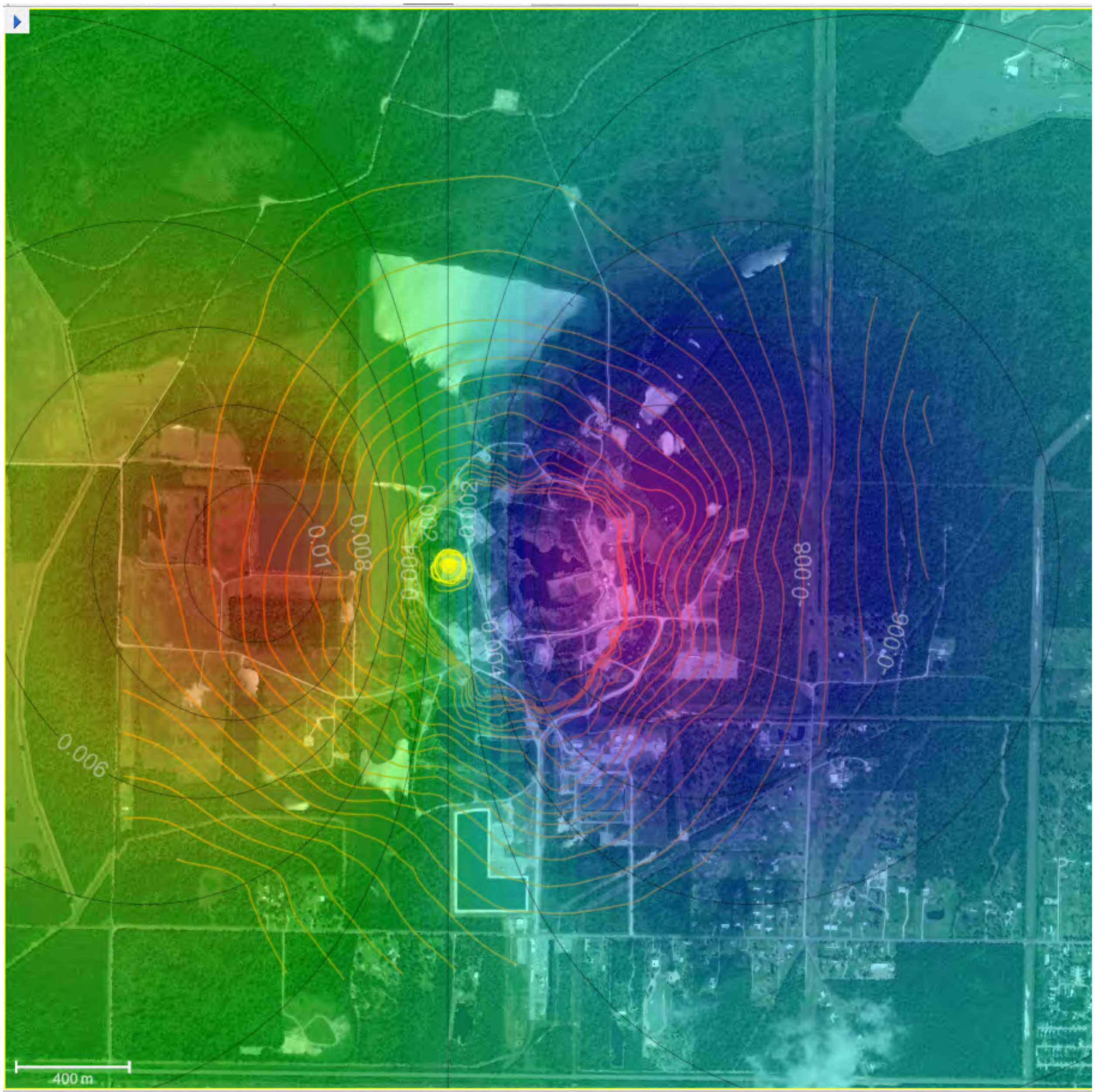

Figure 4. Colored and contoured map of the modeled east-west deformation pattern resulting from a point source at 3000 ft depth at Cavern 7 as described in text. The deformation contours are 2 mm, the contours are labeled in meters. The salt geometry at Sulphur Mines Dome is shown by orange solid lines, the sonar of Cavern 7 is shown in yellow. A satellite photo is shown for reference.

Tiltmeter and Differential GPS Array Geometry. Halliburton's Pinnacle group has proposed 20 Tiltmeter sites and 6 Differential GPS locations to monitor the micro-deformation at Sulphur Mines (see Appendix 1 for full proposal by Pinnacle). The GPS system is "anticipated to provide millimeter level 3D displacement sensitivity" (excerpt from Pinnacle's proposal), while the tiltmeters, which measure the displacement gradient, an angular measurement, have a precision of one billionth of a radian and results are often reported in the microradians (see Appendix A). InSAR monitoring data will be integrated with the tiltmeter and GPS measurements.

The location of the Tiltmeters and GPS sites are shown in Figure 6 with the vertical deformation modeling results. Tiltmeters will be located near the well pads for the Cavern Gallery well 4, Caverns 6, 7, 21 and 16 (Figure 7). The tiltmeter array was placed to best measure the potential deformation pattern modeled for a failure at Cavern 7 location and depth (Figure 6).

The GPS stations are placed in a cross-pattern relative to Cavern 7 to capture the deformation pattern (Figures 6 and 7). A GPS control point is located about 7000 ft south of Cavern 7 to provide a baseline location with no expected deformation related to activity near the salt dome (Figure 7 inset). The details of the GPS and Tiltmeter arrays are described in the Pinnacle proposal (Appendix A).

Note, the proposed tiltmeter and GPS locations may shift in position during installation, depending on local field conditions, permitting, etc. The GPS stations require a good line of site and may be adjusted to provide the highest quality data. The locations shown in this proposal should be considered as tentative.

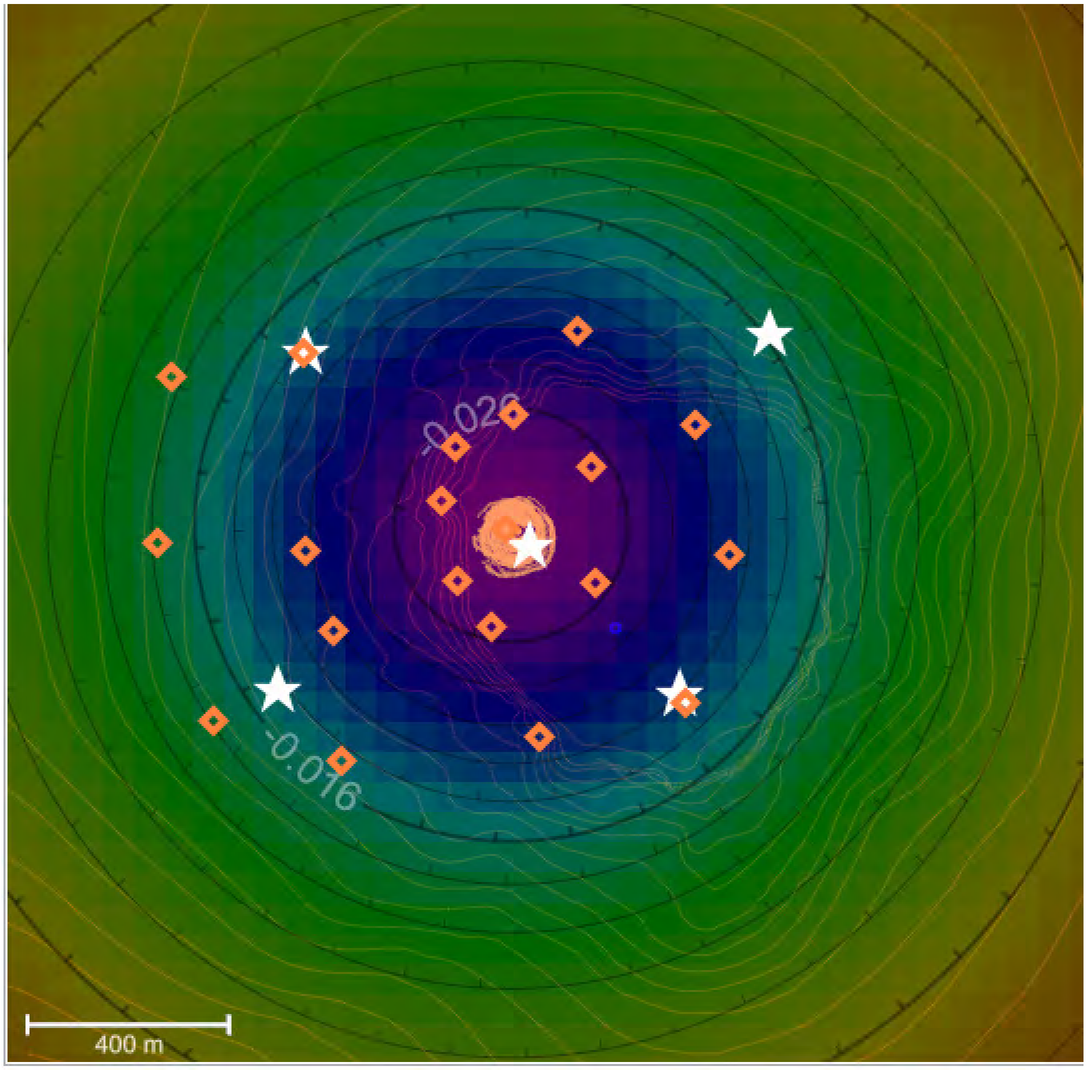

Figure 5. Pinnacle's proposed tiltmeter (orange diamond) and GPS (white stars) locations overlain with colored and contoured map of the modeled vertical deformation pattern resulting from a point source at 3000 ft depth at Cavern 7 as described in text.

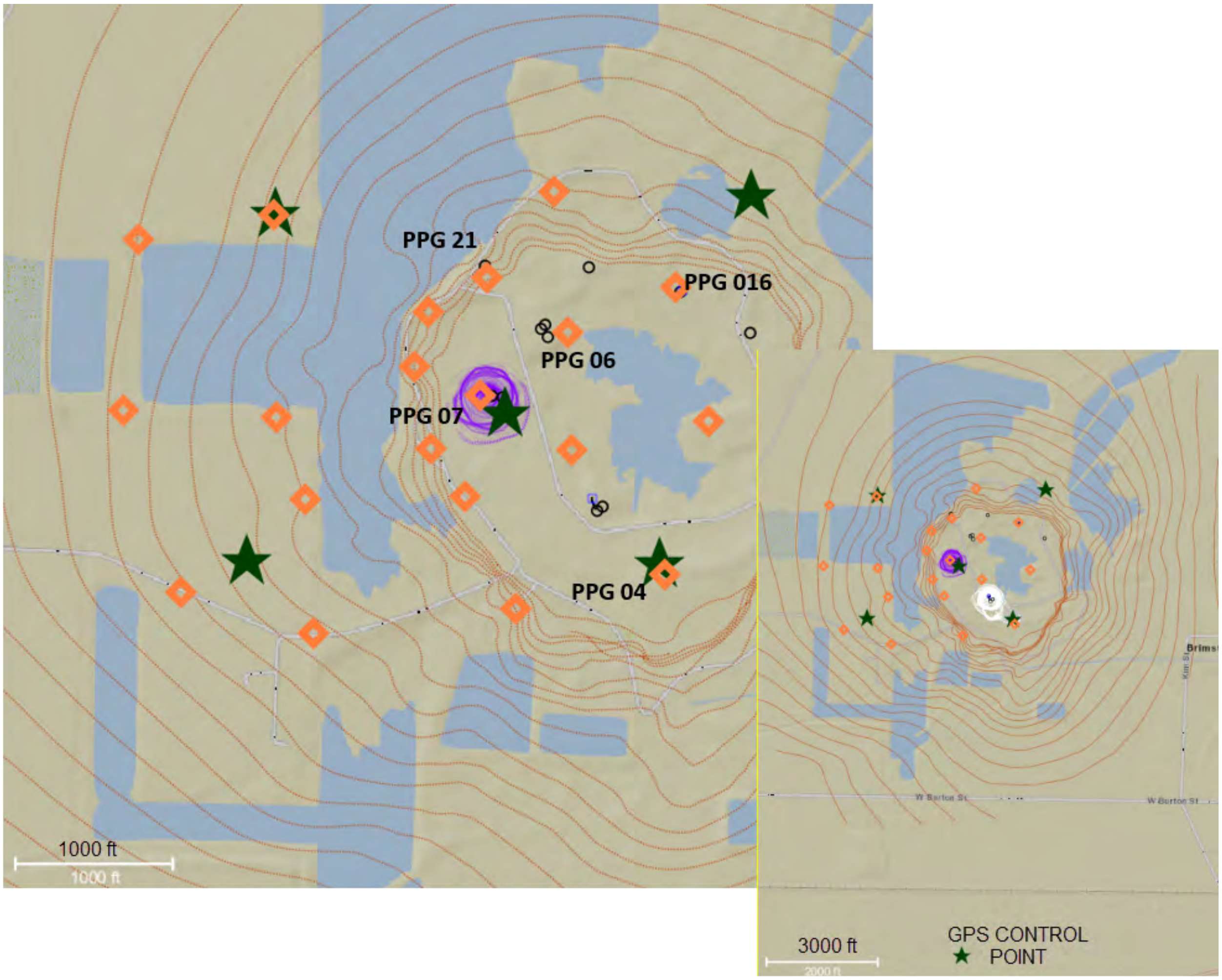

Figure 6. Pinnacle's proposed locations for a 20 station tiltmeter array (orange diamonds) and six station GPS array (stars) at Sulphur Mines salt dome. The salt contours are shown in orange and Cavern 7 sonar in purple. The inset to the right shows the location of the GPS Control point, south of Sulphur Mines dome.

Tilt and GPS Learning Period and Subsequent Reporting. Following the installation of the Differential GPS and tiltmeter arrays, Pinnacle will require a month or two of deformation data acquisition to establish background levels of ground motion. This will be revisited in six months to look for longer-period displacement patterns. After the establishment of a background level of ground motions, an initial anomalous displacement level will be proposed. The ground motions from both tilt and GPS are reviewed in almost real time, hence any large and unusual motions will be noted almost immediately. A reporting method and frequency will be established with Pinnacle and Lonquist following the learning period. Lonquist will provide updates on the progress with the installation and operation of the arrays during normal regulatory meetings.

References

Atzori, S., G. Baer, A. Antonioli, and S. Salvi (2015), InSAR-based modelling and analysis of sinkholes along the Dead Sea coastline, Geophys. Res. Lett., 42, 8383–8390, doi:10.1002/2015GL066053.

Mogi, K. (1958), Relations between the eruptions of various volcanoes and the deformations of the ground surface around them, Bull. Earthquake Res. Inst. Univ. Tokyo, 36, 99–134.

Tiampo, K., Rundlea, J. Fernandez, J. and Langbeinc, J. (2000), Spherical and ellipsoidal volcanic sources at Long Valley caldera, California, using a genetic algorithm inversion technique, J. Volcanol. Geotherm. Res., 102(3–4), 189–206, doi:10.1016/S0377-0273(00)00185-2.

Lisowski, M. & Dzurisin, D. (2006), Analytical volcano deformation source models. 10.1007/978-3-540-49302-0_8.

APPENDIX A: Pinnacle Proposal for Tiltmeter and Differential GPS Array.

Pinnacle
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December 11, 2023

Coleman Hale
Vice President / Sr. Petroleum Engineer
U.S. & Canadian Operations
Lonquist & Co., LLC
1415 Louisiana St., Suite 3800
Houston, Texas 77002
(713) 559-9997

Re: Halliburton proposal for a Pinnacle 6-station precision DGPS system and 20-site Precision Tiltmeter Array at the Westlake Sulphur Salt Dome near Lake Charles, Louisiana.

Mr. Hale:

Please accept Halliburton's proposal for the sale and installation of a 6-station PinnPoint automated precision DGPS system. Pinnacle's PinnPoint system is a unique DGPS positioning system that provides continuous, millimeter-level, 3-axis measurements of position using the GPS satellite-based positioning system. Pinnacle's PinnPoint DGPS system has more than two decades of proven service in locations such as California's Southern San Joaquin oilfields, gold mines in Indonesia, Superfund sites in New Mexico, landslides in central Mexico, and others. The system quoted here is for the third-generation of DGPS system developed by Pinnacle incorporating the latest improvements in measurement accuracy and system reliability. Pinnacle's PinnPoint DGPS system is the only near real-time DGPS measurement system with proven accuracy of ≤ 2 mm in three axes (see Rutledge & Meyerholtz, Using the Global Positioning System (DGPS) to Monitor the Performance of Dams – attached).

The following provides costs for the purchase, installation, and commissioning of a 5-station DGPS motion monitoring system (5 *rover* systems and one DGPS *reference* station) and rental of a 20-station Pinnacle precision tiltmeter array to be installed at Westlake Sulphur-Salt Dome location. Also included are the costs for Pinnacle's reconnaissance visit to assess the technical requirements of the location. Pinnacle anticipates installation and commissioning of the system at the Westlake Sulphur Salt Dome to begin 8-12 weeks after the order is confirmed, which means delivery of units and installation could begin as early as mid-to-late January. Lonquist's contractors will construct the GPS support poles and precision tiltmeter sites at the desired locations to Pinnacle's specifications, and Halliburton's Pinnacle personnel will install the instrumentation and initiate the ongoing monitoring and motion detection.

Thank you and regards,

William Roadarmel
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Table of Contents

Project Location

Installation of the PinnPoint DGPS monitoring system will take place at the Westlake Sulphur Salt Dome near Lake Charles, LA (Figure 1).

Figure 1: Location of Westlake Sulphur Salt Dome near Lake Charles, LA

Automated Precision GPS at select well pads and locations.

The following provides costs for the purchase of a 6-station DGPS system consisting of fiver GPS rover stations and one reference station. Each station consists of necessary DGPS sensing and processing equipment, cellular digital radio telemetry, solar panels, and power conditioning components, NEMA4 enclosures, antennas, cables, batteries, and clamps configured to be bolted onto a monument support pole (5-inch diameter, cement-filled, steel support pole cemented to a minimum depth of 6-feet.) provided by Lonquist's contractors (Figure 2).

This proposal includes one reconnaissance visit by Halliburton to assess the technical requirements of these locations. The reconnaissance will determine, among other things…

Figure 2: Pinnacle DGPS station. In this application the support column will be cemented into a borehole to a depth of at least six feet and the GPS equipment will be bolted to it.

- If cellular comms will function as anticipated, or if gateway radios will be necessary to serve as repeater stations to guarantee successful radio telemetry to/from each site.
- Availability of full GPS constellations at station locations.
- Solar availability.
- Suitability of existing facilities for support functions (if needed).
- Location and suitability of planned reference station location.

Also included are the costs for on-demand servicing and repair visits and equipment replacement costs. These GPS stations have proven extremely robust in locations around the world (very hot suppers and freezing winters), so equipment failures are rare, but they have been known to happen. Lonquist personnel can be trained in battery replacement so as-needed repair availability should be sufficient.

Project completion should occur as follows.

- System design approved or amended to accommodate findings of site reconnaissance.
- Lonquist approval of site locations.
- Construction of monument supports (to spec.) completed and placed at final GPS locations ahead of installation.
- Halliburton delivery of DGPS equipment to project location.
- Delivery of GPS components to final locations for installment.
- Attachment of DGPS, solar power, and coms equipment to support pole.
- Initiation of the system & confirmation of position data being transmitted into Halliburton's secure cloud.
- Tuning.
- Training of local personnel in basic site inspection and maintenance.
- Validation of final data delivery and training of Lonquist personnel in use of measurements.
- Method of transfer from Halliburton's secure cloud to Lonquist solution. TBD.

Halliburton will rely upon local Lonquist support for the transportation of DGPS equipment to their final installation locations. Initially system measurements will pass through Halliburton's secure cloud and then on to the customer. Halliburton will eventually rely upon Lonquist IT personnel to devise the means by which the system measurement data will penetrate the customer's security firewall (Figure) to deliver the results to intended recipients. Pinnacle will work with Lonquist IT personnel as much as is possible to help facilitate this.

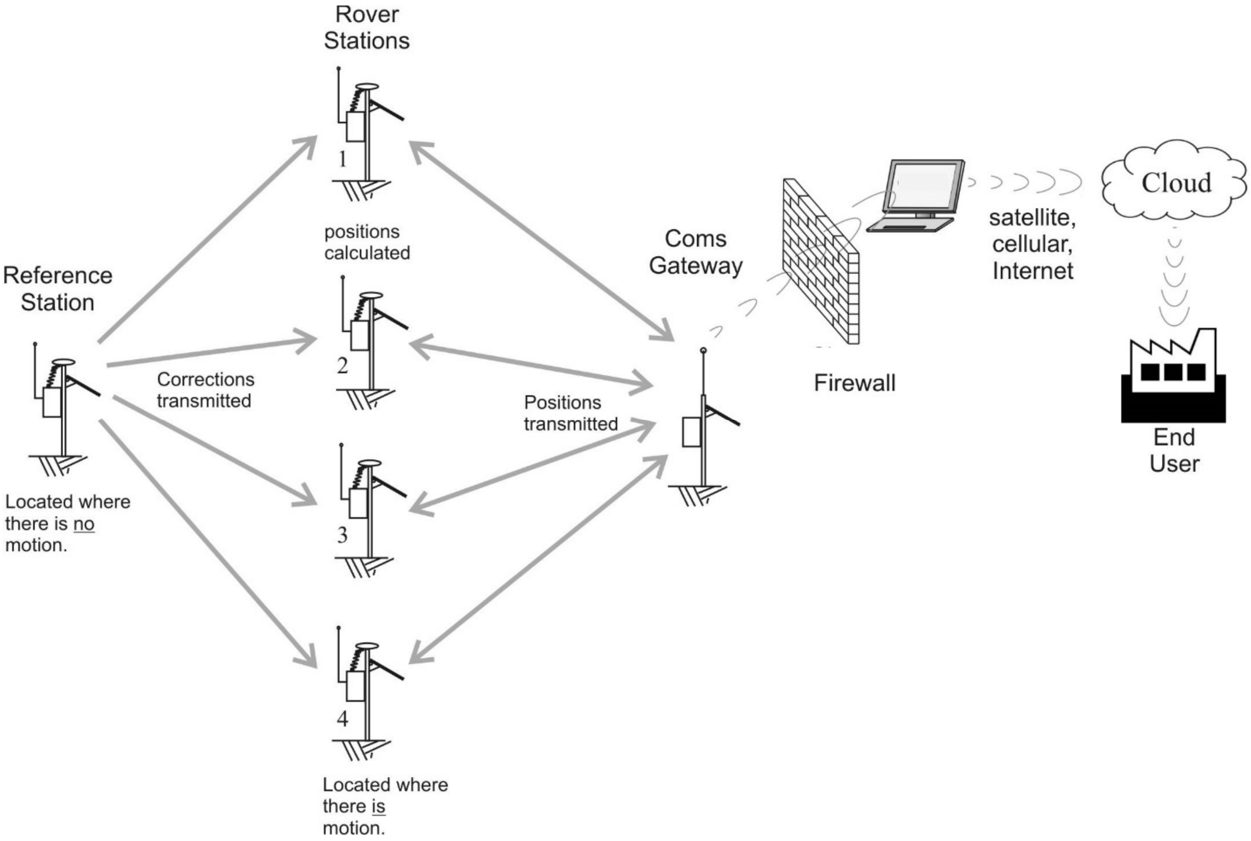


Figure 3: Schematic of Pinnacle DGPS system proposed for installation at Lonquist location. NOTE: Four stations are shown below, but six stations are planned for this project.

Project Timing

Some of Pinnacle's specialized GPS components are manufactured on-demand by our domestic supplier. We anticipate that installation and commissioning of the system at the Westlake Sulphur Salt Dome might begin 8-12 weeks after the order is confirmed, which means delivery of units and installation could begin as early as mid-to-late January of 2024.

Specifications for the support columns will be transmitted to Lonquist so that procurement of the materials and the drilling contractor may begin immediately and construction of the sites may be completed before arrival of the system components. The target installation time at the Sulphur salt dome is thus tentatively late January to early February of 2024.

Radio Towers

It has been stated that this particular location possesses good cellular phone coverage by Verizon Wireless. If this is the case then there is an excellent chance that the cellular data system being employed at each of these instrumented sites will have a good cellular connection to transmit measurements to Halliburton's secure cloud. In the event that good cellular coverage is not available at this location, Halliburton will procure a "small" antenna tower to be installed at this Westlake project location to serve as a radio-repeater station and boost the cellular signal to each site. Westlake will need to approve the location and installation of such a tower, should one be necessary. At the time of this proposal the cost and supplier of a small tower is not known.

Pinnacle Precision Tiltmeter Sites.

Halliburton recommends the rental of precision tiltmeters for this project, as the manufacture of these instruments for sale has a long lead-time. The following provides costs for the installation of a 20-station Pinnacle Precision Surface Tiltmeter array. Each tiltmeter site consists of a rented Pinnacle Series 5000 precision surface tiltmeter, cellular digital radio telemetry, solar panel, and power conditioning components, NEMA4 enclosures, antennas, cables, batteries, and clamps. Each tiltmeter instrument will be installed within a PVC-cased borehole located, as closely as possible, to the positions indicated in the map of Figure 5. Each borehole will be drilled to a depth of between 20 – 40 feet by Westlake contractors, and completed to Halliburton specs (Appendix 1).

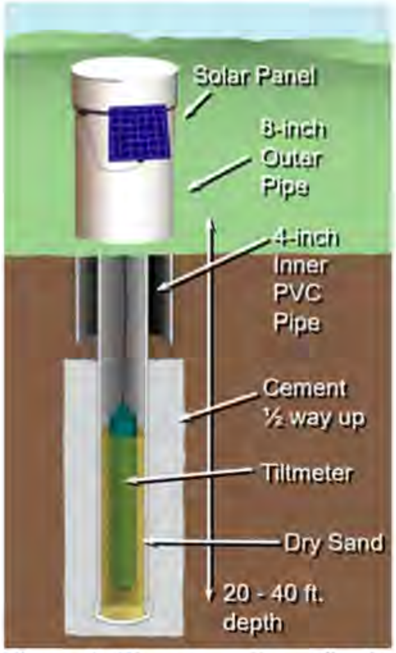


Figure 4: Pinnacle surface Tilt site. This economical design provides isolation from surface noise and temperature variations.

This proposal includes one reconnaissance visit by Pinnacle to assess the technical requirements of these locations. The reconnaissance will determine, among other things…

- If cellular Comms will function as anticipated or if radio repeaters will be necessary.
- Suitability of proposed locations for good measurement.
- Accessibility.
- Solar availability.
- Suitability of existing facilities for support functions (if needed).
- Potential noise sources and alternative locations.

Also included are the costs for on-demand servicing and repair visits and equipment replacement costs. These tiltmeters have proven extremely robust in locations around the world so equipment failures are rare, but they have been known to occasionally happen. Westlake personnel can be trained in battery replacement and basic site maintenance so as-needed repair availability should be sufficient.

Project completion should occur as follows.

- System design approved or amended to accommodate findings of site reconnaissance.
- Lonquist approval of site locations.

- Construction of precision tiltmeter sites (to spec.) completed final Tilt locations ahead of installation.
- Halliburton delivery of Precision Tiltmeter equipment to project location.
- Delivery of tiltmeters and support equipment to final locations for installation.
- Installation of precision Pinnacle tiltmeters into pre-constructed sites, installation of solar power, coms, and support equipment to the site.
- Initiation of the system & confirmation of position data being transmitted into Halliburton's secure cloud.
- Training of local personnel in basic site inspection and maintenance.
- Validation of final data delivery and training of Lonquist personnel in use of measurements.
- Method of transfer from Halliburton's secure cloud to Lonquist solution. TBD.

Halliburton will rely upon local Lonquist support for the transportation of DGPS equipment to their final installation locations. Initially system measurements will pass through Halliburton's secure cloud and then on to the customer. Lonquist may eventually desire for system data to be transmitted directly to Lonquist without passing through Halliburton's secure cloud. Halliburton's Pinnacle group could cooperate with Lonquist IT personnel as much as is possible to help facilitate this.

Site Locations

The proposed locations for the GPS and tiltmeter locations are shown in Figure 5. These exact locations may be adjusted to accommodate actual field conditions encountered.

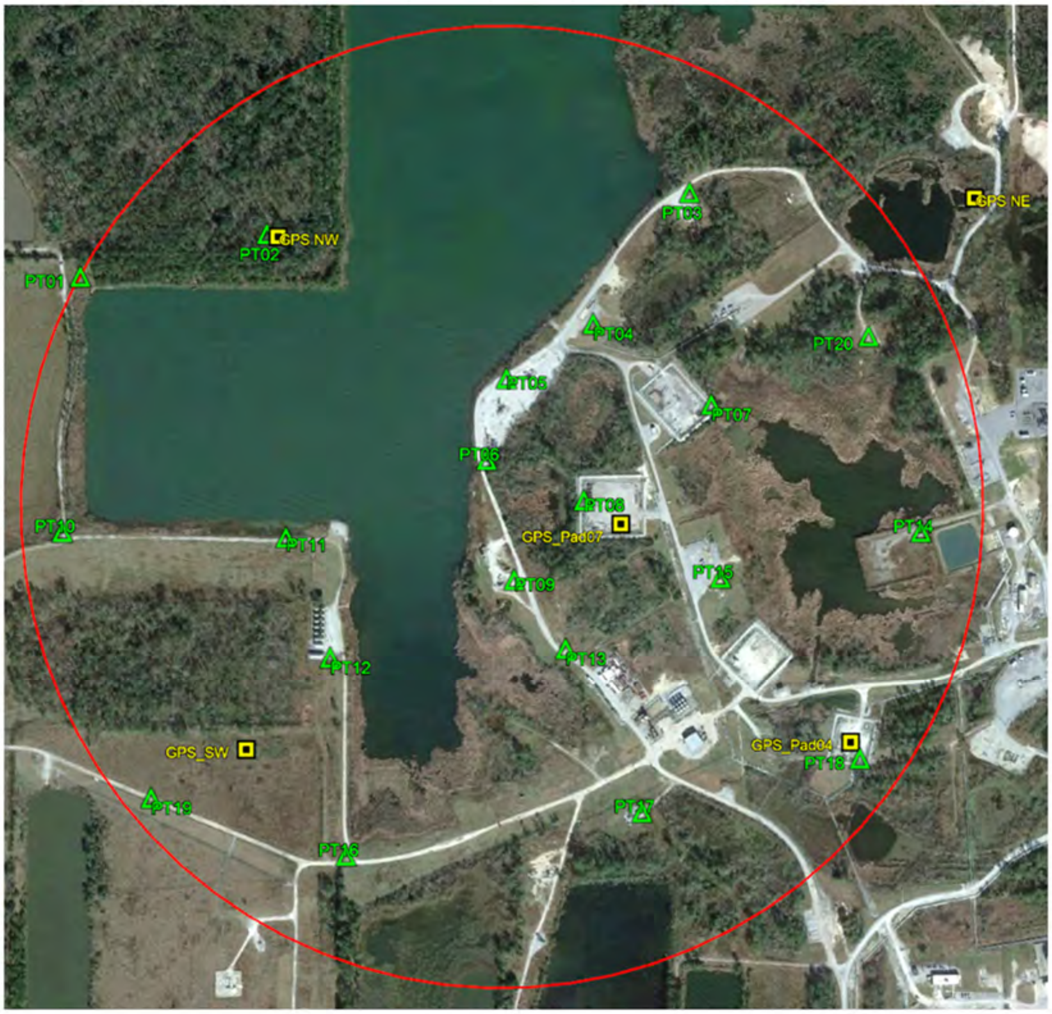


Figure 5: Proposed precision GPS and surface tiltmeter locations. Yellow boxes are GPS stations and green triangles are tiltmeter sites. As-built locations are subject to change as project design evolves to accommodate local conditions and project scope.

Project Timing

Some of Pinnacle's specialized radio communications components are manufactured on-demand by our domestic supplier. We anticipate that installation and commissioning of the system at the Westlake Sulphur Salt Dome might begin 8-12 weeks after the order is confirmed, which means delivery of units and installation could begin as early as mid-to-late January of 2024.

Specifications for the drilling and construction of the surface tiltmeter sites will be transmitted to Lonquist so procurement of the materials and the drilling contractor may begin immediately, and construction of the sites may be completed before arrival of the system components. The target installation time at the Sulphur Mines salt dome is thus tentatively late January to early February of 2024.

Appendix 1: Tiltmeter Site Construction

Overview of Tilt Site(s) Construction:

TILT SITE CONSTRUCTION OVERVIEW		
1	PVC casing materials should be delivered on site 1-2 days prior to commencement of drilling operations so materials can be cut, prepped, and staged at each location. PVC material staged at each tilt site should consist of: two (2) 4"x 20'ID PVC joints; one (1) 8"ID x 5' PVC joint; one (1) 4" end cap; and one (1) 8" end cap. Note: All of the 20' joints should have one belled end - All PVC material should be Sch. 40 wall thickness.	
2	Have the contractor drill site(s) down to the desired depth (approx. 20-30 feet) using a 7.78" to 12" auger. Air drilling is best suited for most sites. Auger styles can also be used but only for soft formations (i.e., clay or sand) If drilling unit has no self-level, use a carpenter's level to verify drilling is as close to vertical as possible. Note: When drilling the sites, make note of any ground water and the depth to avoide seepage into joints of PVC. Shovel excavated soil onto ground cloth/tarp for backfill into site at end of project (if site reclamation is desired).	

3	If necessary, after the initial hole is drilled, increase the diameter of the hole to 12” (2 foot depth) to accommodate the larger joint of PVC. If possible, use air to clean out any additional dirt that has fallen into the hole. Note: After each tilt site is drilled, make sure to cover the hole with plywood or suitable material to prevent debris from falling into the hole or injury to livestock and others. Weigh-down the cover with rocks or other suitable means (to prevent blow-away) and mark appropriately with warning.	

4.0	Cut one joint 4”x20’ pipe approximately 5’ from the belled end, flip it around and slip the belled end onto the cut section (no glue). It is advisable to use a battery-operated or generator-powered reciprocating saw to cut the PVC. This particular joint will be the top/surface joint. Note: During this process, make every effort to keep PVC joints dry and not allow any water to seep inside the joints. Watch for small animals that may enter the PVC over night.	
4.1	5 foot surface joint flipped and reconnected (but <u>not</u> glued)	

4.2	Apply primer and then glue the 4" end cap onto the un-cut 4" x 20' pipe joint (opposite end of the bell) Note: Glue should be applied very liberally as to prevent any water ingress through joints.	
5	Lower the joint of pipe (with the glued cap on the bottom) down into the hole, <u>securing it at the surface</u>. The joint can be temporarily secured by (a) resting the collar of the joint on a fabricated casing plate that can lay over the hole or (b) attaching the pipe to the drilling rig latch line via a rope/sling	
6	Apply primer and then glue to belled end of bottom joint to receive the top joint connection. Note: Apply glue liberally in order to ensure a good bond between joints to prevent water ingress. .	

7	Prime and glue top joint of PVC pipe (smooth end).	
8	Connect top and bottom glued joints. Allow a few minutes for glue to set and then lower the complete assembled joint to the bottom of hole. .	
9	Note: If the drilling rig can accommodate lifting the two sections of pipe when they are glued together, you can disregard steps 4-8 (listed above) and simply glue the two pipes together on the ground. Then when the glue is dry, the drilling rig can lower the pipe into the hole.	

10	Center and level the 4” PVC at the bottom of the hole as best as possible by turning it back and forth to move it. There should be approximately 1 foot of pipe above the ground. Hold the pipe to keep it in place so that it doesn’t move or shift to one side of the hole when you start pouring the concrete.	
11	The cementing process is ready to begin –This step can be achieved by multiple options depending on terrain or accessibility: 1. **Neat cement grout – no aggregate.** 2. Ready-mix cement trucks are best for easy access sites or oil infrastructure. 3. Using a vehicular mounted motorized cement mixer (shown) for hard to access. 4. Hand mixing cement in a container.	
12	Cement mixing process. The volume and consistency of the cement is dependent upon the hole size. Ensure that smaller diameter holes have a more fluid consistency to avoid cement from bridging while pouring.	

13	Pour the concrete or grout into the hole to surround the pipe. Move and twist the pipe to ensure complete flow around the pipe into the bottom of the hole. Avoid gaps and voids to ensure proper coupling between the pipe and the surrounding soil/rock. Continue checking to ensure that the pipe is as level as possible. Continue pouring the concrete until it comes within 10' of the surface	
14	When the cementing procedure is completed, the remaining open hole should be backfilled with the drill cuttings to within 2 ft from surface. Ensure proper backfilling by periodically tapping the pipe to keep the cuttings from bridging.	
15	After backfilling the hole (2 ft from surface), place the housing (larger joint of 8" x 5' PVC) over the smaller (inner) joint assembly. 	

16	The photo on the right is a view of the outer PVC housing – with the inner PVC centered within. 2’ of outer PVC is below surface leaving 3’ above ground. 1’ of inner PVC is above ground, leaving a 2’ area to place SMDM equipment. Note: Outer PVC housing is centered so there isn’t noise coupling that can resonate down to the tool that will be installed and interfere with data acquisition.	
17	Backfill any gaps holes around the outer PVC housing with drill cuttings to stabilize the joint.	
18	Place 8” end cap on top of PVC. DO NOT glue the cap! Its purpose is to cover/protect equipment from the elements. Equipment will be accessed from this cap throughout entirety of project.	

19	Barrier/fencing around the site is optional – typically it is installed when there is a chance of livestock interacting and damaging the sites / equipment.	

1.0 Water and Wet Sites:

If the sites are drilled using water or if water is encountered while drilling the sites and significantly fills the hole while drilling, the following additional steps may be required:

5.1. If water is in the hole, the 4” PVC pipe will “float” as it is run in hole and during the cementing operations. To prevent this, it is recommended to fill the PVC with water to neutralize the buoyancy and in turn, sinking the PVC to the bottom of hole. This eliminates the potential hazard of PVC buoyancy pushing upwards possibly causing damage or injury to nearby equipment or personnel throughout construction, cementing, and installation. Once site construction is complete, you can safely pump or bale water out of PVC for tool/equipment installation. **Note: The inner pipe should be as dry as possible because if the sand holding the tiltmeter in place gets wet the Tiltmeter could easily become stuck.**

5.2. Sometimes when the holes are wet/muddy, they tend to cave leaving sand and clay in the bottom. If this occurs, it may be necessary to “push” the pipe to bottom of the hole using a block and tackle and the drilling rig winch. To accomplish this, the block and tackle is placed near the base of the site on the drilling rig and cable is run to a hook, which is placed in the 4” PVC pipe. Using the rig winch the pipe is pushed into position. After getting the pipe into its final position, it will be necessary to fill the pipe with water as outlined above.

5.3. When cementing the 4” PVC pipe in water or wet conditions, it will not be possible to see the level of cement. The amount of cement must be calculated based on the hole size; it is better to overestimate the necessary cement ensuring the pipe is cemented to at least 15’ from the surface. Pour the cement into the hole slowly allowing it to displace the water. As the cement is poured into the hole, the displaced water can be channeled away using a small ditch.

5.4. In a hole containing water, the cement must be tremied to the hole bottom to ensure proper water displacement and good cement. Do not allow cement grout to fall through the water. Review proper tremie technique and ensure drilling contractor has proper tremie pump and tube equipment available.

5.5. In a site subjected to the risk of flooding the interior PVC casing pipe must extend above the ground surface an amount sufficient to place the opening well above potential flood waters. In the Westlake Salt Dome area near Lake Charles periodic flood waters are believed to get as much as 5-6 feet above ground level. It is thus recommended that the interior casing pipe and exterior protective pipe be sized to extend 7-8 feet above ground level to prevent flooding of the interior or the filling of the annulus with mud.

Appendix 2: Halliburton's PinnPoint DGPS System

DGPS Monitoring Overview

Initially developed by the United States Department of Defense, the **G**lobal **P**ositioning **S**ystem (**GPS**) is a satellite based system that allows for a precise determination of location anywhere on or above the Earth's surface. There are currently 27 NAVSTAR satellites operating as part of the GPS constellation, enough to ensure that at least eight are in view at any given time from an unobstructed location. The ability of civilian users of GPS to process and make use of the system has come a long way since its inception and the launch of the first satellite in 1989. The original accuracy was crude by today's standards, and was used for lower accuracy navigation and location purposes. GPS receivers were large, power-hungry devices that could only provide high accuracy by collecting and averaging thousands of measurements. In the past 15 years, however, GPS has enjoyed an explosion in development effort, accuracy, and applications.

Figure 6: Pinnacle GPS operating continuously in the environments of Northern Canada and New Mexico.

Reliable cost-effective monitoring

The Pinnacle DGPS monitoring system provides millimeter level 3-D displacement sensitivity with continuous, automated operation in remote, unattended locations. Unlike other DGPS systems on the market, Pinnacle's system combines the low noise and stability of a double-differencing processing engine with Pinnacle's own proprietary filtering technique to provide results that are truly optimized to measure surface deformation originating from sub-surface processes. For applications that require real-time geotechnical, infrastructure or hazard monitoring motion detection we also offer our proprietary PinnPoint DGPS technology. This unique DGPS offering from Pinnacle combines high sensitivity real-time measurements with long-term stability by implementing a custom tuned Kalman filter with double-difference carrier phase measurements calculated over time (known as triple differencing). Only Pinnacle offers such a full suite of DGPS monitoring capabilities that can be tailored specifically for the needs of your project.

Figure 7. A constellation of 54 NAVSTAR and Galileo satellites ensures that the Pinnacle DGPS monitoring system always sees an optimal number of satellites for millimeter accuracy.

DGPS Characteristics

The long-term stability of GPS combined with the fact that it constitutes a direct measurement of position (not an indirect one based on deformation shape) makes a GPS-based monitoring system an ideal source of 3-D ground truth for constraining the unknowns or potential sources of instability inherent in other measurement techniques. DGPS is therefore an ideal adjunct to Pinnacle's suite of technologies, augmenting their capabilities and mitigating shortcomings, to produce a composite system with truly remarkable characteristics.

In good sky visibility conditions, DGPS will yield measurement accuracies of approximately 3 mm in near real-time and 1-2 mm over a 24-hour period. Pinnacle uses a variety of permanent installations that are custom designed for the current project environment and application. Permanent DGPS stations have the benefit of reducing many sources of error that plague traditional survey techniques, particularly during repeated setups and installations.

Raw GPS data can be stored locally and collected for later processing, or be transmitted on-the-fly to a central computer for real-time processing and reporting. Real-time positioning has not only the benefit of continuous monitoring but also the ability to establish motion thresholds and setup alarms for automated notification when these thresholds are exceeded.

GPS Receiver	Multiple manufactures Single (L1 code/carrier) Dual Frequency (L1/L2 code/carrier)
Motion Sensitivity	• 3-Dimentional motion change detection • Real-Time: 1 cm • Near Real-Time: 3 mm (3-6 hours) • Post-Processed: 1 mm (24 hours)
Spatial Resolution	DGPS: Point Target Integrated with InSAR and Tiltmeter Arrays: 1 – 10's km
Key Strengths	• Operates continuously • Operates in most weather conditions • 3-D displacement monitoring • Integrates into Pinnacle processed InSAR and Tiltmeter arrays

Appendix 3: Tilt, DGPS, and InSAR Combinations

Strengths and Weaknesses

Technology	Precision	Measurement Output	Period	Cost / area
Tiltmeters	0.01 mm	$\frac{\partial z}{\partial x}, \frac{\partial z}{\partial y}$	Seconds	++
GPS	1 mm	Δx, Δy, Δz	Hours - days	+++
InSAR	1 cm	$\Delta x \sin(\varphi)\sin(\theta) + \Delta y \cos(\varphi)\sin(\theta) + \Delta z \cos(\theta)$ θ,φ = satellite look angle	Days - Weeks	+

Figure 8: Three tiers of measurements sensitivity and spatial resolution. Tiltmeters measure the gradient of the deformation. When implemented in an array Tiltmeters are capable of measuring surface deformation morphology with micrometer sensitivity in near real-time. DGPS can measure motion changes of a single point in 3-axes with 1 mm accuracy and no drift over time, but the costs may limit the spatial coverage. InSAR is the least accurate or robust of the technologies (vulnerable to surface and Tropospheric moisture), but the tremendous spatial coverage makes it by far the most economical for large areas.

Error induced by lateral motions in InSAR results.

In its simplest case the measured vertical distance is trigonometrically defined.

$$\Delta x \sin(\varphi)\sin(\theta) + \Delta y \cos(\varphi)\sin(\theta) + \Delta z \cos(\theta)$$

θ,φ = satellite look angle

Years of measurement with GPS have shown lateral motions in areas with topography can be as much as 2/3 the true vertical motion. This will introduce large errors in the vertical calculations from InSAR.

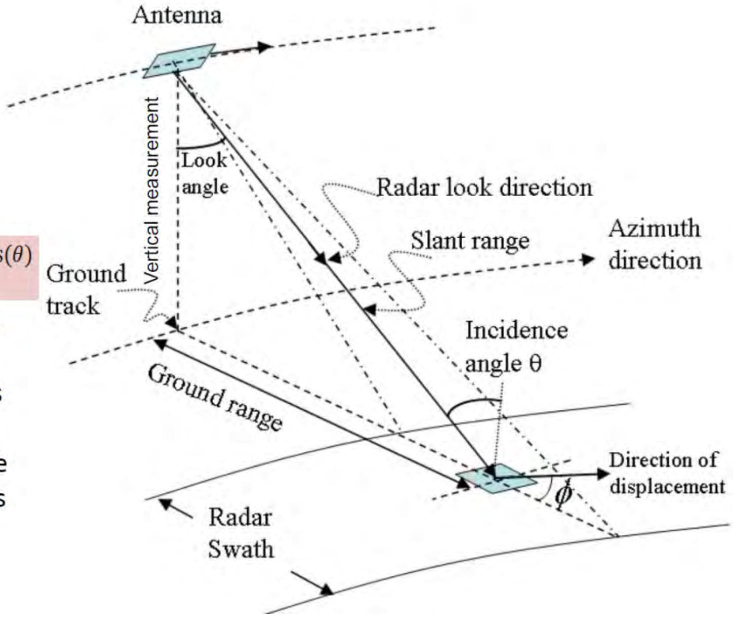
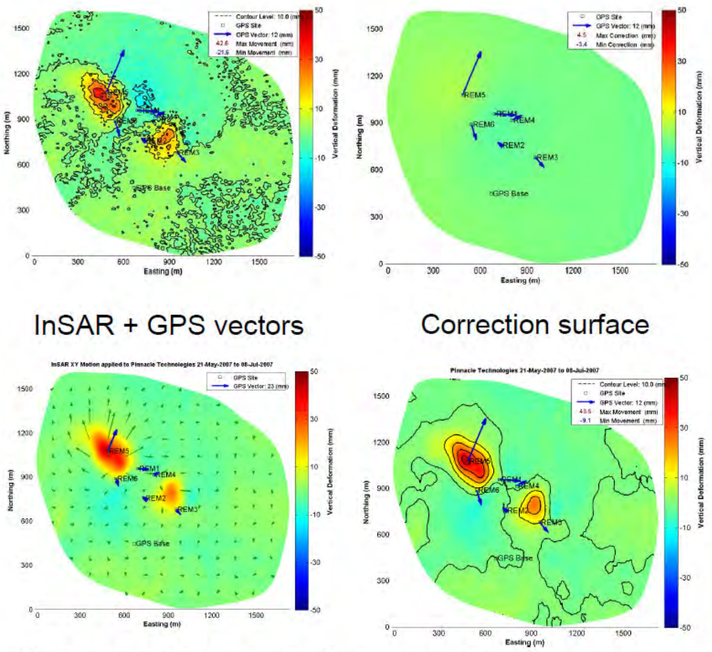


Figure 2

Higher-precision GPS excellent for correcting/stabilizing InSAR.

- Huge spatial coverage of InSAR accessed
- Deconvolved motion vectors
- Higher precision of GPS/Tilt available nearer instrumented locations
- Continuous data at instruments supplemented by periodic data from InSAR
- Lateral motions and decorrelation errors of InSAR compensated for with GPS anchors.
- Increased robustness to failure. Measurement redundancy.



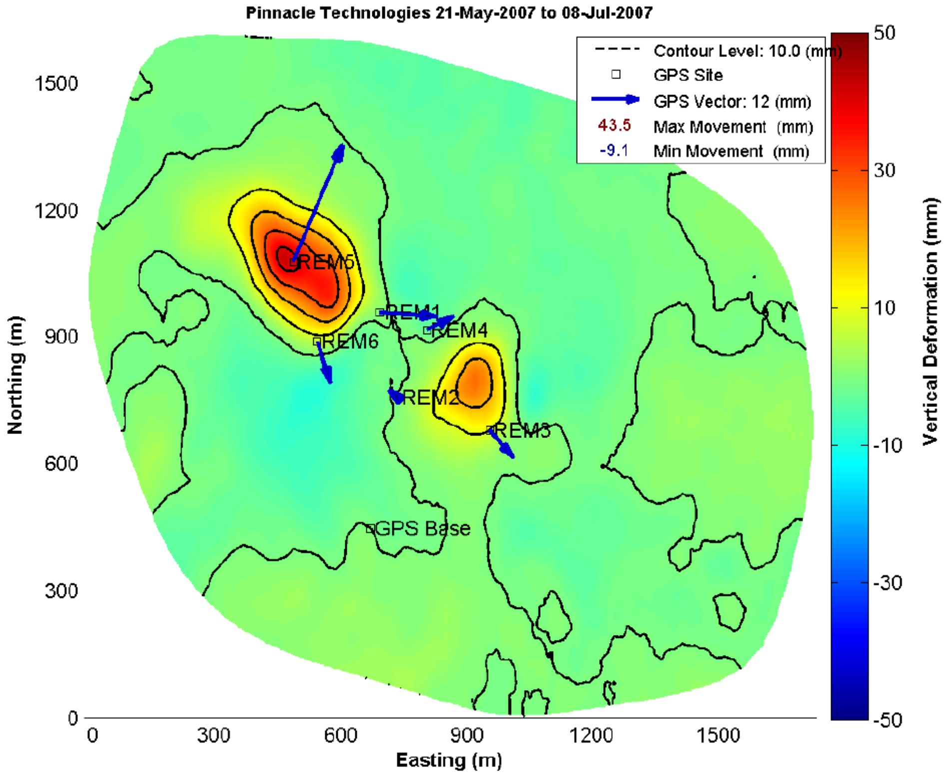
InSAR + GPS vectors

Correction surface

Motion vector deconvolution

Combined solution, Δz

US Patent 7768441 "Geodesy Via GPS and InSAR Integration"



Combined solution, Δz

ATTACHMENT B

Alternate Source of Water Plan

Sulphur Brine Field

Alternate Water Source

Submitted by:

Westlake

12-27-2023

LOUISIANA BOARD OF PROFESSIONAL GEOSCIENTISTS
SCOTT A. HIMES
570
Est. 2011

TABLE OF CONTENTS

APPENDIX

Attachment 1 - Chicot Aquifer Water Quality
Attachment 2 - Sabine River Water Quality
Attachment 3 - The Chlorine Institute Pamphlet 152 Edition 4

1.0 BACKGROUND

Order 5.a. of the Third Supplement to Compliance Order No. IMD 2022-027 issued by the State of Louisiana Department of Natural Resources Office of Conservation requires Westlake US 2, LLC (Westlake) to submit an assessment for the use of an alternate source of freshwater, such as surface water, in lieu of withdrawing from the Chicot Aquifer for Westlake's operations at the Sulphur Mines Salt Dome cavern facility.

In response to the order, an assessment for using additional sources of fresh water was completed. This assessment focuses on the following viable fresh water alternatives to the Chico Aquifer:

- Sabine River Water from the Sabine River Water Authority (SRA) canal
- Groundwater from the Evangeline Aquifer System

2.0 INTRODUCTION

Currently well water from the 500-foot sands of the Chicot Aquifer is used to inject into the salt dome for mining salt. Chicot Aquifer water, at its current composition, only requires adjusting of its pH in to be suitable to inject into the salt domes at the Sulphur Mines Salt Dome cavern facility. Current demand for the solution mining process is approximately 1,500 gallons per minute, or approximately 2.16 million gallons per day. Chicot Aquifer water does not require treatment to remove any other constituents. See attachment 1 for currently injected water quality properties.

3.0 SABINE RIVER DIVERSION SYSTEM

According to the SRA, "the Sabine River Diversion System was created by Act's 90 and 117 of the 1970 Legislature as part of the program for utilization of the waters impounded in Toledo Bend Reservoir, for the purpose of transporting and delivering fresh raw water from the Sabine River to the various industries located in the Lake Charles industrial area, and for furnishing water for the municipal use and the irrigation requirements of farms located along the route." (see srala-toledo.com)

According to the USGS, approximately 54 million gallons per day of surface water are used from the Sabine River Diversion System in Calcasieu Parish (USGS, 2010, Water Resources of Calcasieu Parish, Louisiana). The SRA canals account for approximately 45% of all surface water withdrawals in the parish.

3.1 SABINE RIVER WATER EXTRACTION

It may be possible to pump Sabine River water from the SRA canal east of the Sulphur Brine Field and transfer to the brine field by way of a pipeline. This effort would require a new pumping station.

Extraction pumps would need to be sized to pump the SRW approximately 4700' to the Sulphur Brine Field. A potential path for the pipeline will be to route the piping parallel to the SRA canal south to an existing East-West pipeline right of way. The pipe would then head west to the Sulphur Brine Field in the existing pipeline right of way.

Permitting and permission will be required from the SRA, owners of the pipeline right of way, and possibly local landowners for this pumping station and pipeline route.

Electrical power will need to be routed to this location. The closest power available will be from Entergy and not from the Sulphur Brine Field power system.

3.2 SABINE RIVER WATER QUALITY

Sabine River water (SRW) is surface run off water that flows into the Sabine River along its path from its origin to the point where it is pumped in the SRA canal at Starks Louisiana. Based on information provided by the Sabine River Authority, this water contains solids and organic matter that is not present in the Chicot Aquifer ground water. See attachment 3 for SRW water quality properties. Nitrogen compounds found in SRW include ammonia, nitrates, and nitrites. When introduced to the process of manufacturing chlorine, nitrogen can produce an explosive compound, nitrogen trichloride. This poses a major risk and introduces process safety issues, which do not arise when Westlake's Chlor-Alkali production process utilizes brine solution-mined using the current source of injection water.

3.3 SABINE RIVER WATER AVAILABILITY

According to the SRA, approximately 150,000 gallons per minute of water is pumping into the diversion canal at Starks, with nearly 20 billion gallons pumped each year. In 2014, the total capacity was approximately 75 million gallons per day more than the contracted capacity. While the specific availability is unknown, there is likely sufficient supply to support an additional 2.16 million gallons per day for brine mining.

4. Evangeline Aquifer Groundwater

Groundwater underlying Calcasieu Parish occurs within the Gulf Coast Regional Aquifer system which is comprised of several individually identified aquifers in Calcasieu Parish: the Chicot aquifer, the Evangeline aquifer, and the Jasper Aquifer. The Catahoula aquifer is present in the northwestern corner of the parish but is not present near the Salt Dome. A regional geologic cross-section (Figure 2) is provided for reference. The geological units of the Gulf Coast Regional Aquifer dip to the south, becoming thicker, toward the Gulf of Mexico. In the Sulphur area, the Chicot Aquifer is approximately 800 feet thick and is the principal aquifer used for water supply. The Evangeline typically has large, but laterally discontinuous sands. The freshest portion of the Evangeline is generally between 800-1,000 feet deep and salinity increases with depth.

This assessment includes the utilization of the Evangeline aquifer as a viable fresh water supply alternative to the Chicot aquifer. The Jasper aquifer is encountered at depths approximately 4,000-feet bgs, and the Catahoula aquifer is only present in the northwestern corner of Calcasieu Parish and not in the Sulphur area.

4.1 EVANGELINE AQUIFER GROUNDWATER EXTRACTION

Groundwater can be extracted from water wells installed within the sands of the Evangeline. Current industrial wells installed in the Chicot could be over drilled to extend into the Evangeline sands, or additional water well(s) could be drilled. The same piping network would be utilized to distribute water to the brine wells.

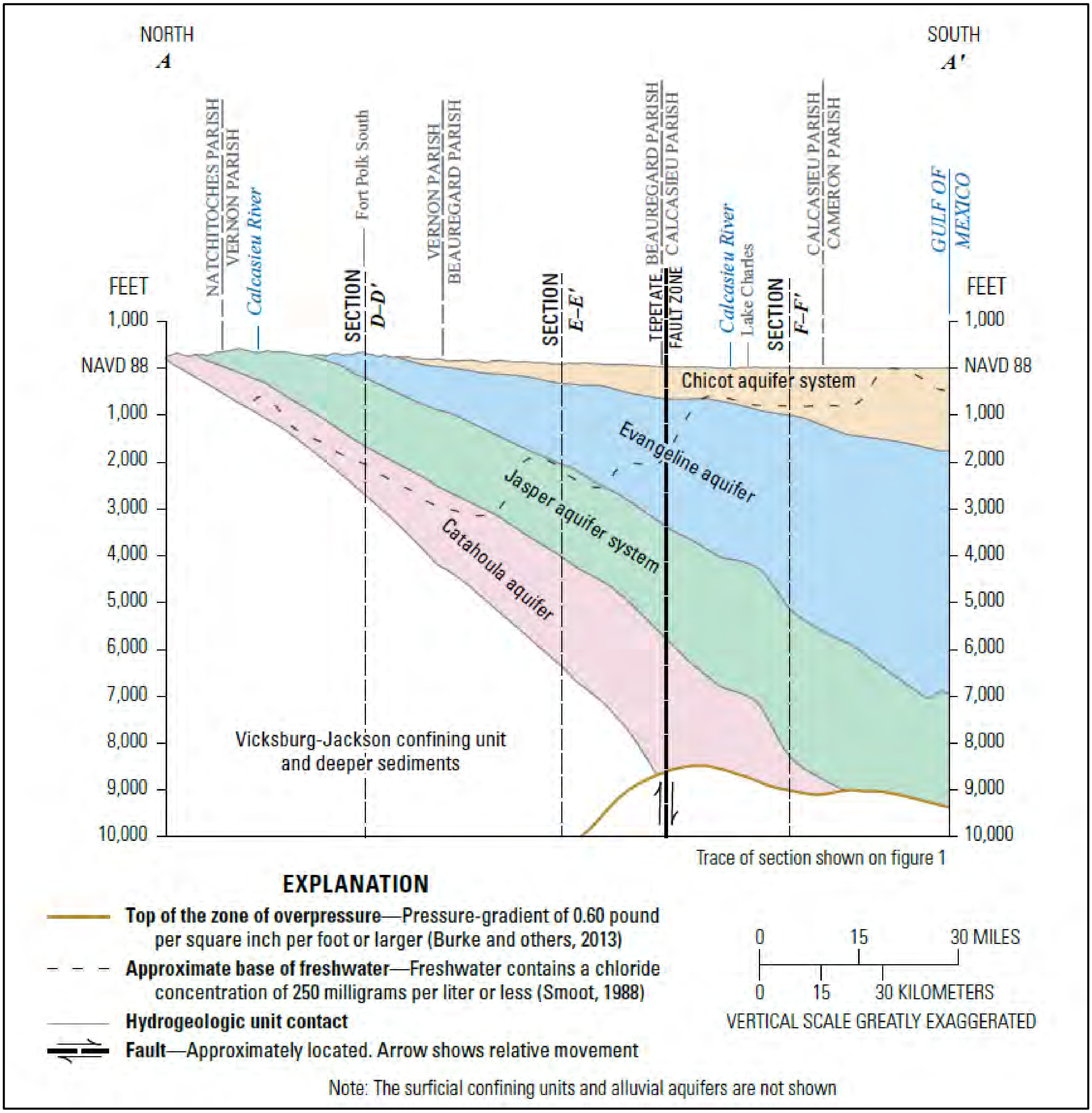


Figure 2 – Idealized north-to-south cross-section through southwestern Louisiana (from Lindaman, M.A., 2023, Hydrogeologic Framework of Southwestern Louisiana, Scientific Investigations Report 2023-5004, U.S. Geological Survey, 31 pp.)

4.2 EVANAGELINE AQUIFER GROUNDWATER QUALITY

The Evangeline aquifer contains fresh water (<500 mg/L TDS) in the northern quarter of the parish. In the southern three-fourths of the parish, the Evangeline aquifer contains saline water (TDS >500 mg/L). The sands of the Evangeline aquifer are variable in thickness and are generally discontinuous on a regional scale.

There is very little documentation of the Evangeline aquifer in the vicinity of the Salt Dome. Aquifer depth determinations have been assigned based on electric logs from oil and gas wells, but no water wells within 5 miles of the Salt Dome are known to be installed in the Evangeline below the Chicot.

However, within the Evangeline aquifer are substantial sands that would likely yield large quantities of water. Harder (1960) suggests that the individual sands of the Evangeline aquifer are hydraulically connected with other sands forming a single hydrogeologic unit. A monitoring well (019-1243) was installed in 1985 approximately 8.2 miles northeast of the Salt Dome in the Evangeline with a reported chloride concentration of 4,050 mg/L in 1985. Based on the electric logs for oil and gas wells, it is reasonable to assume the chloride concentration within the Evangeline is between 2,500 and 5,000 mg/L.

The water quality of the Evangeline is much poorer than the Chicot. From well 019-1243 analytical data, chloride, sodium, and TDS are all much higher in the waters of the Evangeline sands. Barium and radium are also high, which may have significant impact on the processing of the brine. The radium is considered naturally occurring radioactive material (NORM).

4.3 EVANGENLINE AQUIFER GROUNDWATER AVAILABILITY

Harder (1960) estimated the hydraulic conductivity of the Evangeline sands to be between approximately 33 and 133 ft/day, which is lower than that of the Chicot sands. No aquifer testing data are available for the Evangeline aquifer near the Salt Dome.

The hydraulic connection between the Chicot and Evangeline is not well known. The Chicot lower confining layer is generally greater than 30 feet thick near the Salt Dome. The storativity values published by Harder (1960) for the “700-foot” sand of the Chicot indicate that it is a leaky confined aquifer. There is no data indicating whether the leakage is between the other sands of the Chicot or with the sands of the Evangeline. The likelihood of leakage across the “700-foot” sand lower confining layer into the Evangeline is considered to be low and not likely a significant source of water into the upper Evangeline sands.

It is estimated that the water within the Evangeline would have a large confining head based on the Chicot well measurements. Using the average published values for hydraulic conductivity of the Evangeline (83 ft/day, 0.03 cm/sec), and assuming 100-feet saturated thickness, with 700-feet of confining head, it is estimated that the shallow sands (~800-1,000 feet deep) could potentially yield over 10,000 gallons per minute (RECAP Appendix F, confined aquifer well yield), which would be sufficient for the brine mining operation.

The LDNR Groundwater Resources Program is charged with managing the state of Louisiana’s groundwater resources. The LDNR requires water well notification form be submitted 60-days prior to water well installation. The use of groundwater is under the jurisdiction of the LDNR.

Figure 1 – Sabine River Water Extraction

5.0 WATER TREATMENT

Sabine River Water used to solution mine salt must be treated prior to being transferred to the Chlor-Alkali facility. Injection water containing high levels of organics and/or nitrogen compounds is detrimental to the process equipment in the chlorine liquefaction unit, shipping operations and at customer sites.

Nitrogen compounds found in SRW include ammonia, nitrates, and nitrites. When introduced to the process of manufacturing chlorine, nitrogen can produce an explosive compound, nitrogen trichloride. This poses a major risk and introduces process safety issues, which do not arise when Westlake's Chlor-Alkali production process utilizes brine solution-mined using the current source of injection water

Introduction of nitrogen compounds, solids, precipitates, and radium (NORM), into the manufacturing process also creates waste and risks not encountered with the use of Chicot Aquifer water. Handling of the potentially hazardous additional waste would likely require additional permitting, regulatory oversight, and potentially a redesign of the facility.

5.1 CLARIFICATION

Suspended solids need to be removed prior to being used for mining. Suspended solids (other than salt) that are transferred to the Chlor-Alkali facility are detrimental to downstream process equipment. Clarifiers could potentially be used to drop out any solids suspended in the water. In most clarification systems a flocculant is added to assist in separating out solids. The two discharge streams on the clarifier are clean water and waste (silt, mud, etc.). The clean water moves on in the process and the sludge is separated out and disposed of. The creation of waste as a result of the clarification process is a negative factor in assessing the use of this water as an alternate to using groundwater. Elevated NORM within the waste stream would require additional assessment.

The clarification system consists of rake clarifiers, polymer tanks, water storage tanks, transfer pumps and sludge dewatering equipment. Depending on the downstream process sand filters may be required.

Dewatering can be accomplished with centrifuges, belt press and screw press.

5.2 ORGANIC COMPOUND ELIMINATION

Sabine River water contains organic compounds that, at certain levels seen within the past water samples, could create hazardous conditions when used in the production of chlorine. This is recognized by The Chlorine Institute in Pamphlet 152 Edition 4 which is in the Appendix of this document. Other technical papers have been written on this subject and are referenced in Pamphlet 152.

The organic compounds can possibly be removed by different methods with each process requiring the installation of specific equipment. These processes potentially include the following, alone, or in combination:

5.2.1 De-ionization – mixed beds use anion and cation resins to remove the positive and negative charged ions in the water.

Nitrates are one of the ions that mixed beds will remove. A mixed bed system consists of a resin tank(s), acid tank, caustic tank, activated carbon tank and pumps. With respect to the other systems the mixed bed unit has a larger footprint, larger installed cost, and larger maintenance cost. Mixed bed systems also present safety hazards due to the need for handling of strong acids and caustics.

5.2.2 Reverse osmosis uses a membrane to separate out the undesired compounds. With respect to the other options a RO unit has a smaller footprint, lower installed cost, larger operating cost, and larger maintenance cost due to membrane cleaning. Redundant systems are required to reduce outages due to maintenance.

5.2.3 Break point chlorine is the process of adding chlorine to the water until free chlorine levels exceed the amount required to destroy nitrogen-based oxidants. This can be achieved with a process like treating potable water which is either injecting chlorine gas into the water stream or using chlorine tablets. Once treated, free chlorine levels are checked downstream, and the process is adjusted as necessary. This system requires either liquid chlorine cylinders or a vessel with calcium hypochlorite tablets. Liquid chlorine cylinders do have specific security and safety requirements associated with them. Due to the length of discharge pipe a retention tank may not be required. This system has a low installation cost and a low maintenance cost.

5.3 PH ADJUSTMENT

The alternative waters will likely need to have the pH adjusted prior to injection into the suction of the cavity pumps. Currently there is a pH control system on the suction of the cavity pumps. A study will need to be performed to see if the existing equipment is adequate for Sabine River water, or Evangeline groundwater usage.

6.0 COST BENEFIT ANALYIS

The use of Sabine River water as a means for mining salt from the salt dome does reduce the local demand for water from the Chicot Aquifer. The use of surface water for mining salt is used at other chlorine facilities that were designed for such. It appears that use of surface water as an alternative to groundwater may be technically feasible. Use of surface water does, however, create risks and waste which are not currently a part of the Westlake manufacturing process.

The use of groundwater from the Evangeline Aquifer would reduce the water usage of the Chicot, and would require very little infrastructure improvements to implement as an alternative to Chicot water. The water chemistry of the Evangeline is poor, which may require a redesign of fresh water lines to accommodate the higher salinity and dissolved solids load.

With any manufacturing process the introduction of a change creates a potential for adverse events. In this case the use of SRW introduces the possibility of nitrogen compounds being transferred from the brine field to the main facility where an explosive compound, nitrogen trichloride, can be formed in the process. This explosive compound can be destructive to equipment in the facility and at customer facilities creating safety concerns. As pointed out by The Chlorine Institute the use of water with organic compounds to mine salt does present issues downstream in chlorine manufacturing and shipping. The Chlorine Institute in Pamphlet 152 Editon 4 Table 2.1 list thirteen explosions in different parts of the world that were associated with Nitrogen Trichloride.

Sabine River water analysis confirms the presence of nitrogen compounds at concentrations that have the potential to form nitrogen trichloride at levels above the recommended safe limit. The plant is currently not designed with any safeguards to mitigate high nitrogen trichloride concentrations. Even with the installation of treatment technologies, the risk of a process safety event from a nitrogen trichloride explosion is increased.

Increased levels of TOC (Total Organic Carbon) are also a concern since it can cause foaming that may result in upsets that reduce process safety. Additionally, some TOC compounds react with chlorine to form chloromethane compounds that are an impurity in the chlorine product and not easily removed. The plant is also not designed to handle the increased load of suspended solids (silt, mud, etc.). This causes concern for plugging and can disrupt some of the brine purification reactions and put additional load on filters.

Clarification and organic compound elimination will also create a waste stream which must be disposed of. If water from the Evangeline is used, NORM would need to be monitored and managed with the waste stream.

The risks presented by using an alternative water source may be mitigated to some degree by the treatment processes described above. The benefits of any additional risks are, however, not clear. There is no indication that the use of Chicot groundwater is negatively impacting other aquifer users. There is also no indication that the use of Chicot groundwater is related in any way to the issues currently being experienced with Cavern 7. Thus, while Westlake is currently evaluating the feasibility of installing the necessary treatment systems, it is not clear that whatever benefits might result will outweigh the risks described or the creation of the waste stream which will result.

APPENDIX

ATTACHMENT 1

CHICOT AQUAFIER WATER QUALITY

ChemTreat
10041 Lickinghole Road - Ashland, Virginia 23005 · t/ 804.935.2418 · www.chemtreat.com
Analytical Lab

Certificate of Analysis

Dec 13, 2023

Laboratory No.	W-231212-035
Company	AXIALL STARKS BRINE FIELD (C63710.25)
Address	1043 HIGHWAY 109 S STATION 190, VINTON, LA, 70668-5612, USA
Account Manager	Jay Brown
Request Date	Dec 12, 2023
Sample Class	Water

Analysis	WATER WELL 11	WATER WELL 19	WATER @ BW18	WATER @ SMP PUMPS
	Dec 11, 2023	Dec 11, 2023	Dec 11, 2023	Dec 11, 2023
Lab pH	6.99	7.00	7.00	7.01
Conductivity	311 umho	370 umho	361 umho	361 umho
P-Alkalinity, as CaCO3	<1 mg/L	<1 mg/L	<1 mg/L	<1 mg/L
M-Alkalinity, as CaCO3	107 mg/L	115 mg/L	112 mg/L	113 mg/L
Calcium Hardness, as CaCO3	61 mg/L	68 mg/L	66 mg/L	66 mg/L
Magnesium Hardness, as CaCO3	33 mg/L	33 mg/L	32 mg/L	32 mg/L
Iron, as Fe	2.7 mg/L	1.9 mg/L	2.0 mg/L	2.0 mg/L
Copper, as Cu	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L
Zinc, as Zn	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L
Sodium, as Na	24 mg/L	31 mg/L	32 mg/L	30 mg/L
Potassium, as K	3.4 mg/L	3.2 mg/L	3.1 mg/L	3.2 mg/L
Chloride, as Cl	20 mg/L	33 mg/L	32 mg/L	30 mg/L
Sulfate, as SO4	4.5 mg/L	4.0 mg/L	4.2 mg/L	4.2 mg/L
Nitrate, as NO3	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L	0.69 mg/L
Ortho-Phosphate, as PO4	<0.25 mg/L	<0.25 mg/L	<0.25 mg/L	<0.25 mg/L
Silica, as SiO2	61 mg/L	62 mg/L	62 mg/L	62 mg/L
Total Phosphate, as PO4	1.1 mg/L	0.56 mg/L	0.85 mg/L	0.93 mg/L
Fluoride, as F	0.35 mg/L	0.44 mg/L	0.36 mg/L	0.30 mg/L
Bromide, as Br	0.30 mg/L	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L

Comments

Respectfully Submitted,

JO Phillips

Joel Phillips
Manager Applied Technology Analytical Lab
ChemTreat International, Inc.

Certificate of Analysis

Dec 13, 2023

Laboratory No.	W-231212-035
Company	AXIALL STARKS BRINE FIELD (C63710.25)
Address	1043 HIGHWAY 109 S STATION 190, VINTON, LA, 70668-5612, USA
Account Manager	Jay Brown
Request Date	Dec 12, 2023
Sample Class	Water

Analysis	WATER WELL 11	WATER WELL 19	WATER @ BW18	WATER @ SMP PUMPS
	Dec 11, 2023	Dec 11, 2023	Dec 11, 2023	Dec 11, 2023
Ammonia, as NH3	0.10 mg/L	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L
Aluminum, as Al	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L	<0.01 mg/L
Barium, as Ba	0.37 mg/L	0.23 mg/L	0.21 mg/L	0.21 mg/L
Manganese, as Mn	0.44 mg/L	0.36 mg/L	0.35 mg/L	0.35 mg/L
Molybdenum, as Mo	0.14 mg/L	<0.05 mg/L	<0.05 mg/L	<0.05 mg/L
Strontium, as Sr	0.37 mg/L	0.24 mg/L	0.23 mg/L	0.23 mg/L
TOC	<0.5 mg/L	<0.5 mg/L	2.0 mg/L	2.3 mg/L
Turbidity, as NTU	53 ntu	50 ntu	91 ntu	63 ntu

Comments

Respectfully Submitted,

JOPhillips

Joel Phillips
Manager Applied Technology Analytical Lab
ChemTreat International, Inc.

ATTACHMENT 2

SABINE RIVER WATER QUALITY

SABINE RIVER WATER QUALITY

Sabine River at HWY 12 Deweyville, TX

Station	Date	Time	Depth (m)	Temp (C)	PH	DO (mg/l)	DO (% sat)	Spec Conductivity (uS/cm)	TDS (Calculation)	Turbidity (NTU)	NITROGEN, KJELDAHL, TOTAL (MG/L AS N)	PHOSPHORUS, TOTAL, WET METHOD (MG/L AS P)	NITROGEN, AMMONIA, TOTAL (MG/L AS N)	NITRITE NITROGEN, TOTAL (MG/L AS N)	NITRATE NITROGEN, TOTAL (MG/L AS N)	NITRITE PLUS NITRATE, TOTAL ONE LAB DETERMINED VALUE (MG/L AS N) (Calculation)	CARBON, TOTAL ORGANIC, NPOC (TOC), MG/L	ALKALINITY, TOTAL (MG/L AS CACO3)	HARDNESS, TOTAL (MG/L AS CACO3)	CHLORIDE (MG/L AS CL)	SULFATE (MG/L AS SO4)
10397 (SR2)	2/14/2018	9:00 AM	0.3	11.8	5.5	9	83	43	27.95	79.7	0.9	0.08	*	<0.05	<0.05	0.5	11	*	*	<5	6
10397 (SR2)	3/20/2018	9:25 AM	0.3	18.7	6.4	8.1	87	122	79.3	17.6	0.5	<0.06	<0.1	<0.05	<0.05	0.5	6	24	28	11	15
10397 (SR2)	4/11/2018	8:37 AM	0.3	16.7	6.2	8	82	95	61.75	31.2	0.6	<0.06	*	<0.05	0.05	0.75	7	*	*	9	11
10397 (SR2)	5/9/2018	8:39 AM	0.3	24.2	6.3	7.5	90	116	75.4	33.4	0.6	0.06	*	<0.05	0.04	0.65	5	25.3	28	8	15
10397 (SR2)	6/13/2018	9:00 AM	0.3	29.9	7.4	6.7	89	132	85.8	20.7	0.6	<0.06	<0.1	<0.05	<0.05	0.5	5	*	40	11	21
10397 (SR2)	7/11/2018	9:05 AM	0.3	28.5	7.8	6.5	84	104	67.6	32.8	0.58	0.08	*	<0.05	<0.05	0.5	8	21	20	7	14
10397 (SR2)	8/22/2018	8:50 AM	0.3	31.1	6.8	6.3	85	163	105.95	24.6	0.4	<0.06	*	<0.05	<0.05	0.5	5	*	*	11	25
10397 (SR2)	9/12/2018	8:47 AM	0.3	27	6.5	6.4	81	154	100.1	28.3	0.6	0.06	0.1	<0.05	<0.05	0.5	5	28	24	9	26
10397 (SR2)	10/10/2018	8:50 AM	0.3	26.9	6.8	6.6	83	158	102.7	20.9	0.5	0.06	*	<0.05	0.06	0.85	6	*	*	11	25
10397 (SR2)	11/7/2018	8:45 AM	0.3	20.5	6.3	7	78	119	77.35	30.6	0.6	0.06	*	*	*	*	8	24	24	11	13
10397 (SR2)	12/13/2018	8:48 AM	0.3	11.9	6	8.5	79	85	55.25	26.3	0.58	<0.06	0.05	<0.05	0.05	0.75	8	*	*	8	9
10397 (SR2)	1/9/2019	8:48 AM	0.3	12.5	6.2	8.7	82	98	63.7	37.3	0.32	<0.06	*	<0.05	0.09	0.115	7	<20	24	10	10
10397 (SR2)	2/13/2019	9:03 AM	0.3	12.8	6.9	9.1	86	107	69.55	31.7	0.6	<0.06	*	<0.05	0.18	0.25	6	*	*	10	14
10397 (SR2)	3/20/2019	8:47 AM	0.3	14.7	6.7	9.2	90	105	68.25	27.9	0.6	<0.06	<0.1	<0.05	0.12	0.145	6	22	28	9	16
10397 (SR2)	4/24/2019	2:11 PM	0.3	19	6.8	7.8	84	88	57.2	32	0.6	<0.06	*	<0.05	0.08	0.15	8	*	*	8	12
10397 (SR2)	5/15/2019	8:40 AM	0.3	21.4	6.4	6.7	76	64	41.6	42.1	0.7	<0.06	*	<0.05	0.05	0.75	8.75	<20	36	7	9
10397 (SR2)	6/12/2019	8:30 AM	0.3	27.3	6.6	5.6	70	111	72.15	26.8	*	*	<0.1	<0.05	<0.05	0.5	8	*	40	11	15
10397 (SR2)	7/10/2019	8:45 AM	0.3	29.4	6.6	5.2	67	*	*	27.7	*	*	*	<0.05	<0.05	0.5	8	23	28	8	11
10397 (SR2)	8/7/2019	8:45 AM	0.3	29.4	6.5	5.6	74	120	78	19.6	0.7	0.1	*	<0.05	<0.05	0.5	6	*	*	10	12
10397 (SR2)	9/11/2019	8:53 AM	0.3	29	6.6	6.4	83.2	150	9.75	22.3	0.6	*	<0.1	<0.05	<0.05	0.050	4	35	40	8	17
10397 (SR2)	10/9/2019	8:25 AM	0.3	26.3	7.4	6.8	84.3	122	7.93	27.1	0.5	<0.06	*	<0.05	<0.05	0.050	5	*	*	8	19
10397 (SR2)	11/6/2019	8:33 AM	0.3	15.6	6.7	7.7	77.3	49	3.185	36.1	0.6	<0.06	*	<0.05	0.06	0.085	11	<20	20	<5	9
10397 (SR2)	12/10/2019	8:40 AM	0.3	16.7	6.9	8.7	89.5	119	7.735	19.8	0.4	<0.06	<0.1	<0.05	0.06	0.085	5	*	*	8	14
10397 (SR2)	1/15/2020	8:45 AM	0.3	15.1	6.5	8.4	83.5	61	3.965	61.8	1	<0.06	*	<0.05	0.06	0.085	11	<20	32	7	8
10397 (SR2)	2/12/2020	9:13 AM	0.3	16.6	6.7	8.2	84.1	92	5.98	45.1	0.6	<0.06	*	<0.05	0.1	0.125	6	*	*	8	12
10397 (SR2)	3/11/2020	12:50 PM	0.3	16.2	7	9.2	93.6	112	7.28	17.6	0.6	<0.06	<0.1	<0.05	0.26	0.285	5	24	24	14	20
10397 (SR2)	7/15/2020	9:00 AM	0.3	31.3	7.2	6.6	89.3	146	9.49	21.2	0.4	0.11	<0.1	<0.05	<0.05	0.050	5	26	28	12	19
10397 (SR2)	8/12/2020	7:45 AM	0.3	31	6.9	6	80.8	142	9.23	29.5	0.5	*	*	<0.05	<0.05	0.050	7	*	*	10	19
10397 (SR2)	9/16/2020	8:00 AM	0.3	29.6	7	5.9	77.5	137	8.905	16.6	0.6	*	<0.1	<0.05	<0.05	0.050	6	25	28	11	15
10397 (SR2)	10/14/2020	7:50 AM	0.3	23.1	6	4.8	56.1	30	1.95	42.3	0.6	0.06	*	<0.05	<0.05	0.050	11	*	*	<5	<5
10397 (SR2)	11/18/2020	7:53 AM	0.3	18	7.2	8.4	88.7	160	10.4	23.1	0.5	0.07	*	<0.05	0.11	0.135	6	32	28	8	26
10397 (SR2)	12/9/2020	7:58 AM	0.3	12.1	7.3	9.1	84.6	80	5.2	26.9	0.5	0.06	0.1	<0.05	0.09	0.115	9	*	*	8	13
10397 (SR2)	1/14/2021	8:27 AM	0.3	9.7	7.1	10.2	89.7	76	4.94	22.7	0.5	0.06	*	0.05	0.08	0.130	7	20	32	9	11
10397 (SR2)	2/10/2021	8:25 AM	0.3	14.3	6.8	9.2	89.9	127	8.255	25.4	*	*	*	0.05	0.1	0.150	*	*	*	7	19
10397 (SR2)	3/16/2021	8:23 AM	0.3	16.9	7	9.3	96.0	126	8.19	14.3	*	*	*	<0.05	<0.05	0.050	6	25	48	12	15
10397 (SR2)	4/14/2021	8:56 AM	0.3	20.1	7.4	8.2	90.4	126	8.19	23	0.5	0.09	*	<0.05	<0.05	0.050	6	*	*	10	14
10397 (SR2)	5/12/2021	8:23 AM	0.3	22.5	6.7	6.6	76.2	102	6.63	35.1	0.5	<0.06	*	<0.05	<0.05	0.050	7	<20	24	9	11
10397 (SR2)	6/9/2021	8:04 AM	0.3	26	6.6	5.8	71.5	115	7.475	21.2	0.6	0.06	0.1	0.05	0.05	0.100	8	*	*	11	12
10397 (SR2)	7/21/2021	8:14 AM	0.3	27.8	6.2	4.8	61.1	102	6.63	54.5	0.7	0.11	*	0.05	0.06	0.110	9	22	24	8	11
10397 (SR2)	8/18/2021	8:25 AM	0.3	29.8	6.7	5.9	77.8	127	8.255	30.5	0.5	0.08	*	<0.05	<0.05	0.050	5	*	32	11	13
10397 (SR2)	9/29/2021	8:04 AM	0.3	23.1	6.3	6.6	77.1	67	4.355	138	0.6	0.11	0.2	<0.05	0.06	0.085	6	<20	32	<5	12
10397 (SR2)	10/20/2021	8:19 AM	0.3	6.8	6.8	7.5	61.5	130	8.45	22.5	0.5	<0.06	*	<0.05	<0.05	0.050	5	*	*	8	16
10397 (SR2)	11/17/2021	8:03 AM	0.3	17.7	7.1	8.4	88.2	146	9.49	20.8	0.4	0.07	*	<0.05	0.09	0.115	5	34	24	8	19
10397 (SR2)	12/15/2021	7:59 AM	0.3	17.6	7.2	8.5	89.0	152	9.88	23.3	0.6	<0.06	0.1	<0.05	0.14	0.165	6	*	*	9	22
10397 (SR2)	1/11/2022	7:55 AM	0.3	14.3	7.5	9.1	88.9	213	13.845	25.4	0.5	0.09	*	<0.05	0.17	0.195	5	46	32	8	41
10397 (SR2)	2/9/2022	8:07 AM	0.3	10.1	6.9	10.3	91.5	92	5.98	36.7	0.6	0.1	*	<0.05	0.07	0.095	8	*	*	8	12
10397 (SR2)	3/8/2022	7:55 AM	0.3	18.2	7	9	95.5	148	9.62	28	0.4	0.07	<0.1	<0.05	<0.05	0.050	5	29	28	10	23
10397 (SR2)	4/20/2022	7:51 AM	0.3	22.5	6.7	7.6	87.8	116	7.54	31.8	*	*	*	<0.05	0.09	0.115	*	*	*	8	17
10397 (SR2)	5/11/2022	8:15 AM	0.3	27.9	6.8	7.4	94.4	137	8.905	27	0.6	0.1	*	<0.05	<0.05	0.050	6	28	28	10	18
10397 (SR2)	6/15/2022	7:51 AM	0.3	31.2	7	6.4	86.4	162	10.53	36.3	0.6	0.09	<0.1	<0.05	<0.05	0.050	5	*	*	10	22
10397 (SR2)	7/12/2022	7:48 AM	0.3	31.8	7.2	6.9	94.1	171	11.115	22.4	0.5	0.07	*	<0.05	<0.05	0.050	6	34	40	14	21
10397 (SR2)	8/10/2022	7:57 AM	0.3	30.4	7.3	6.3	83.9	133	8.645	22.8	0.5	0.07	*	<0.05	<0.05	0.050	4	*	*	12	16

SABINE RIVER WATER QUALITY

10397 (SR2)	9/21/2022	8:05 AM	0.3	29.1	7.2	6.2	80.8	254	16.51	20.4	0.5	0.09	<0.1	<0.05	<0.05	0.050	*	70	52	12	55
10397 (SR2)	10/19/2022	8:06 AM	0.3	19.8	7.7	8.1	88.7	175	11.375	29.7	0.4	0.09	*	*	*	*	4	*	*	10	34
10397 (SR2)	11/9/2022	7:58 AM	0.3	23.3	7.8	7.5	87.9	258	16.77	33.5	0.5	0.12	*	<0.05	0.1	0.125	6	48	36	10	55
10397 (SR2)	12/14/2022	8:20 AM	0.3	19.3	6.3	6.5	70.5	93	6.045	85.3	0.9	0.11	*	<0.05	0.06	0.085	16	*	*	6	15
10397 (SR2)	1/11/2023	7:58 AM	0.3	15.1	7.1	7.7	76.5	85	5.525	29.2	0.5	0.06	<0.1	<0.05	0.06	0.085	9	20	28	11	11
10397 (SR2)	2/8/2023	8:05 AM	0.3	13.2	6.9	8.7	82.9	86	5.59	24.2	0.5	<0.06	*	<0.05	0.06	0.085	8	*	*	11	13
10397 (SR2)	3/15/2023	7:59 AM	0.3	17.7	6.8	8	84.0	154	10.01	28.5	0.6	0.09	<0.1	<0.05	0.06	0.085	6	31	32	13	18
10397 (SR2)	4/12/2023	8:03 AM	0.3	18.9	7.2	7.7	82.8	116	7.54	36.4	0.6	0.09	*	<0.05	<0.05	0.050	8	*	*	12	13
10397 (SR2)	5/10/2023	8:06 AM	0.3	22.9	7.1	6.3	73.3	139	9.035	24.9	0.6	0.06	*	<0.05	0.05	0.075	8	26	28	12	17
10397 (SR2)	6/14/2023	8:12 AM	0.3	30.4	7.1	6.7	89.3	123	80.0	22	0.5	0.06	<0.1	<0.05	<0.05	0.05	6	*	36	13	21
10397 (SR2)	7/19/2023	8:06 AM	0.3	31.4	7.3	6.2	84.0	128	83.2	24.1	0.5	0.07	*	<0.05	<0.05	0.05	6	43	36	15	19
10397 (SR2)	8/16/2023	8:20 AM	0.3	31.7	6.8	6.2	84.5	154	100.1	19.3	0.5	0.06	*	<0.05	<0.05	0.05	5	*	*	16	24

ATTACHMENT 3

THE CHLORINE INSITUTE PHAMPHLET 152

THE CHLORINE INSTITUTE

Pamphlet 152

Safe Handling of Chlorine Containing Nitrogen Trichloride

Edition 4

A LEGACY OF SAFETY STEWARDSHIP
since 1924

April 2018

Table of Contents

1. INTRODUCTION

1.1 SCOPE

This publication is intended to provide useful information to producers, distributors, repackagers, and users of chlorine. It discusses nitrogen trichloride, a trace impurity commonly found in chlorine that could lead to the explosive decomposition of nitrogen trichloride in chlorine containing systems. There has been a history of such destructive decompositions that have resulted in deaths and injuries, equipment destruction, and chlorine releases.

The following topics pertaining to nitrogen trichloride are discussed:

- hazard awareness
- physical and chemical properties
- sources and mechanisms of formation
- control and monitoring
- prevention of formation
- methods for destruction
- limiting levels
- design/operating concerns

In concert with the initial edition of this pamphlet, the Institute's Properties, Analysis and Specifications Committee (PASC) developed a method for analysis of nitrogen trichloride in liquid chlorine which was subsequently issued by ASTM (*9.2.1*). The PASC believed at the time that there were suitable appropriate instruments commercially available to measure ammonia concentrations in brine (*9.2.2*). Additionally, CI Pamphlet 21 *Nitrogen Trichloride - A Collection of Reports and Papers* (*9.1.1*) is a compilation of reports and discussions on the subjects that have been presented at past Chlorine Institute Seminars or otherwise provided to the Institute.

1.2 CHLORINE INSTITUTE STEWARDSHIP PROGRAM

The Chlorine Institute exists to support the chlor-alkali industry in advancing safe, secure, environmentally compatible, and sustainable production, distribution, and use of its mission chemicals[1].

Chlorine Institute members are committed to adopting CI's safety and stewardship initiatives, including pamphlets, checklists, and incident sharing, that will assist members in achieving measurable improvement. For more information on the Institute's stewardship program, visit CI's website at www.chlorineinstitute.org.

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[1] CI's mission chemicals: chlorine, sodium and potassium hydroxides, sodium hypochlorite, the distribution of vinyl chloride monomer (VCM), and the distribution and use of hydrogen chloride.

1.3 DEFINITIONS AND ACRONYMS

The definitions and acronyms listed below are to provide general guidance to the reader. For additional information, check the specific source.

Å	Angstrom
cm	centimeter
DIPPR	Design Institute for Physical Properties
gm	gram
Institute	The Chlorine Institute
kPa	kilopascal
kW	Kilowatt
NCl_3	Nitrogen Trichloride
PASC	Properties, Analysis and Specifications Committee
PHA	Process Hazard Analysis
ppmv	parts per million by volume
ppmw	parts per million by weight
psi	pounds per square inch
SPC	Statistical Process Control
TNT	Trinitrotoluene; explosive
VP	Vapor Pressure

1.4 DISCLAIMER

The information in this pamphlet is drawn from sources believed to be reliable. The Institute and its members, jointly and severally, make no guarantee, and assume no liability, in connection with any of this information. Moreover, it should not be assumed that every acceptable procedure is included, or that special circumstances may not warrant modified or additional procedures. The user should be aware that changing technology or regulations may require changes in the recommendations contained herein. Appropriate steps should be taken to ensure that the information is current when used. These recommendations should not be confused with federal, state, provincial, municipal, or insurance requirements, or with national safety codes.

1.5 APPROVAL

The Health, Environment, Safety and Security Issue Team approved Edition 4 of this pamphlet on April 2, 2018.

1.6 REVISIONS

Suggestions for revisions should be directed to the Secretary of the Institute.

1.6.1 Significant Revisions in Current Edition

Edition 4 of this pamphlet contains a completely new section, Appendix B – Sample Nitrogen Trichloride Calculations. New guidance was added on:

- brine contamination (section 4.1.1),
- nitrogen compounds that are not converted to nitrogen trichloride (section 4.1.3),
- process parameters (section 5.1),
- removing ammonia compounds from brine (section 6.1.2), and
- limiting levels of nitrogen trichloride (section 7.2),

Smaller changes to clarify guidance were added throughout the pamphlet.

1.7 REPRODUCTION

The contents of this pamphlet are not to be copied for publication, in whole or in part, without prior Institute permission.

2. HAZARD AWARENESS

Nitrogen trichloride (NCl_3) is one of the most hazardous materials in the chlor-alkali industry. Fatalities have occurred and workers have been injured by nitrogen trichloride explosions. The explosive power of small quantities of nitrogen trichloride can be catastrophic and large scale damage to personnel and plant equipment and releases of chlorine have resulted from nitrogen trichloride explosions.

The detonation of pure nitrogen trichloride in an enclosed vessel is capable of generating a pressure of 5,361 atmospheres (78,785 psi; 543,203 kPa). A typical chlorine vessel with a wall thickness of ½ inch (1.27 cm) can be fractured with the detonation of a film thickness of 1.5 gm/cm^2 of liquid nitrogen trichloride coating the inside surface. Further, the detonation of film thickness of 0.3 gm/cm^2 is capable of over stressing the metal to the point of cracking and fissuration (*9.2.3*). Exposure of nitrogen trichloride to impact, heat, light, ultrasonic irradiation, or other energy sources may cause detonation (*9.2.4*).

Nitrogen trichloride has an explosive force that is approximately 30 to 40% that of TNT. Decomposition of 6-8% nitrogen trichloride in chlorine can result in a significant pressure rise in the vessel containing the chlorine depending on the amount of vapor space in the vessel (See Figure 3.2). It is believed that a concentration of 13% nitrogen trichloride in chlorine (*9.2.3*) has the potential for a catastrophic detonation and must be avoided.

Nitrogen trichloride was first identified in 1811 from the action of chlorine on a solution of ammonium chloride by Dulong who lost an eye and three fingers as a result of an explosion. Dulong assigned the formula nitrogen trichloride to the yellow explosive oil. Other early workers prepared nitrogen trichloride in the same manner, accumulating only small quantities, but even so, several were injured by explosion.

Following the discovery of the explosive yellow oil, early workers tested it with practically all of the chemicals and substances common to the laboratory at that time. The oil was found to explode violently when 1) heated to greater than 199°F (93°C); 2) exposed to light; or 3) brought into contact with substances such as ozone, phosphorous, arsenic, alkali, and organic matter.

The presence of nitrogen trichloride in liquid chlorine is the suspected cause of violent, and, sometimes, catastrophic explosions that have infrequently occurred in chlorine containers during the twentieth century. Nitrogen trichloride, because of its higher boiling point, becomes concentrated as chlorine is vaporized from a container. Relatively small quantities of nitrogen trichloride can cause an explosion or detonation.

The potential hazard of a nitrogen trichloride explosion is always present when nitrogen trichloride is accumulated in a chlorine system. Whether or not an explosion is experienced depends on many factors, some peculiar to a particular facility's operations. However, once a facility recognizes and completely evaluates this potential hazard, the operation and maintenance of a chlorine system can be controlled to eliminate the possibility of an unsafe concentration of nitrogen trichloride.

Reports from different companies have identified nitrogen trichloride as the possible/probable cause of explosions. Several such incidents are described in Reference (*9.1.1*). Table 2-1 presents some incidents where nitrogen trichloride was suspected to be the cause of explosions:

Table 2-1. Explosions Suspected to be Caused by Nitrogen Trichloride

Incident	**Location**	**Date**
One ton container exploded that was part of a Suction Chiller System[2]	Not known	2010s
Detonation in copper tubing	Australia	July 1998
Explosion of an empty chlorine railcar which had been unloaded via the gas phase	Belgium	February 1995
Chlorine suction chiller explosion; major equipment damage	Louisiana	March 1994
Compressor suction chiller drain piping explosion killing two people and severing one person's leg above the knee	Colombia	November 1993
Purification column pot exploded killing one	West Virginia	March 1983

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[2] A full description of this incident is available in CI Pamphlet 21, under the listing “Summary of a Nitrogen Trichloride Decomposition Event that occurred early 2010's”

Table 2-1. Explosions Suspected to be Caused by Nitrogen Trichloride (continued)

Incident	Location	Date
Cooling tower (believed to be compressor suction chlorine cooler) exploded killing one	Michigan	November 1978
Two Explosions in chlorine vaporizers have been reported, no details available	Brazil	Not Known
One-ton container exploded	Not Known	February 1949
One-ton container exploded	Not Known	November 1948
Tank car cover blew off killing two	Norway	January 1940
Three interconnected storage tanks (45 tons total capacity) at a pulp mill exploded releasing 21 tons of chlorine	Romania	December 1939
Two one-ton containers exploded	Not Known	July 1928

3. PROPERTIES OF NITROGEN TRICHLORIDE

3.1 SELECT PHYSICAL PROPERTIES

Appearance	Yellow, Volatile Oil
Odor	Pungent
Molecular Weight	120.38
Specific Gravity	1.65 @ 68°F (20°C)
Melting Point	<-40°F (<-40°C)
Boiling Point	159.8°F (71°C)
Solubility	Practically insoluble in water~2,000 ppm Readily soluble in the following: • Benzene • Carbon Disulfide • Chloroform • Carbon Tetrachloride • Chlorine See Reference (*9.2.5*)
Vapor Pressure	Figure 3.1 shows the vapor pressure of nitrogen trichloride as a function of temperature.

3.2 THERMODYNAMIC PROPERTIES

Heat of Formation	54.7 kcal/mole (*9.2.6*)
Heat of Vaporization	5.49 kcal/mole (Calculated from Vapor Pressure data)
Pressure Rise vs. Nitrogen Trichloride	Figure 3.2 shows decomposition pressure rise as a function of concentration

3.2.1 Heat of Decomposition

The heats involved in the decomposition reaction are as follows (*9.1.1, Volger*):

NCl_3 (solution) $\rightarrow \frac{1}{2} N_2$ (g) + $^{3}/_{2} Cl_2$ (g) ΔH = -54.7 kcal/mole

The chain initiation step is proposed as:

$NCl_3{}^{k1} \rightarrow NCl_2 + Cl$ ΔH = +53.9 kcal/mole

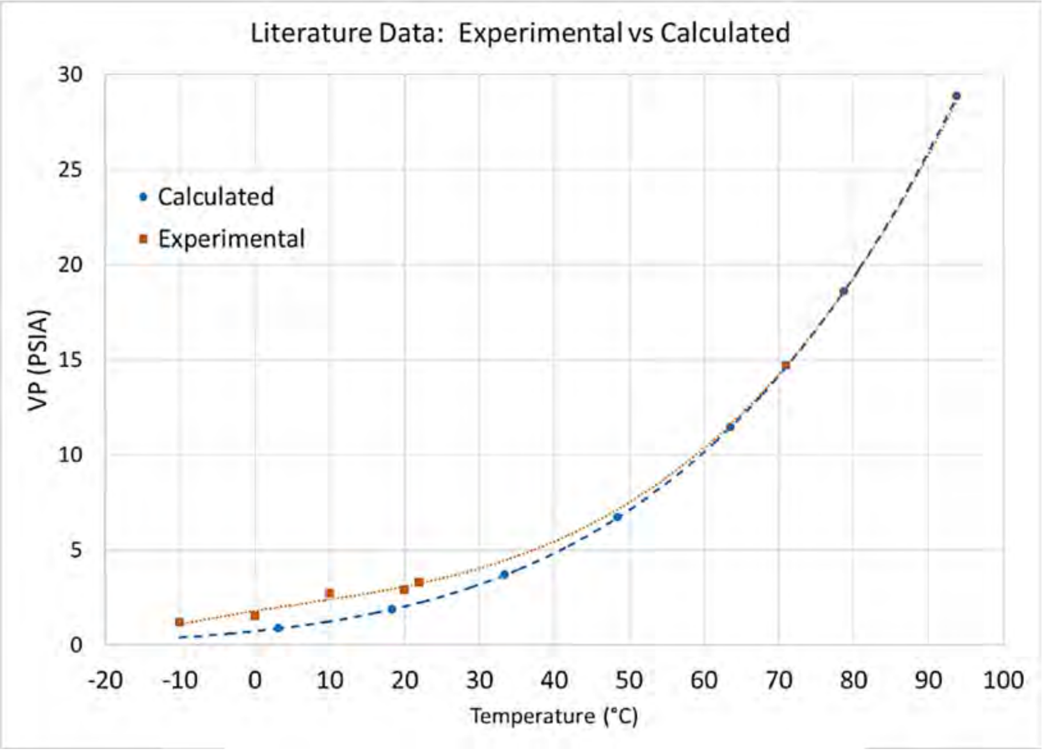
It is hypothesized that this step is followed by the following highly exothermic propagating steps:

$Cl + NCl_3{}^{k2} \rightarrow NCl_2 + Cl_2$ ΔH = -3.08 kcal/mole

$NCl_2 + NCl_3{}^{k3} \rightarrow N_2 + 2\ Cl_2 + Cl$ ΔH = -106.2 kcal/mole

Even though the propagating steps are highly exothermic, a significant amount of energy is required to initiate the decomposition. This energy may be provided by various means including heat, light, or a spark.

Figure 3.1 - Vapor Pressure of Nitrogen Trichloride As a Function of Temperature



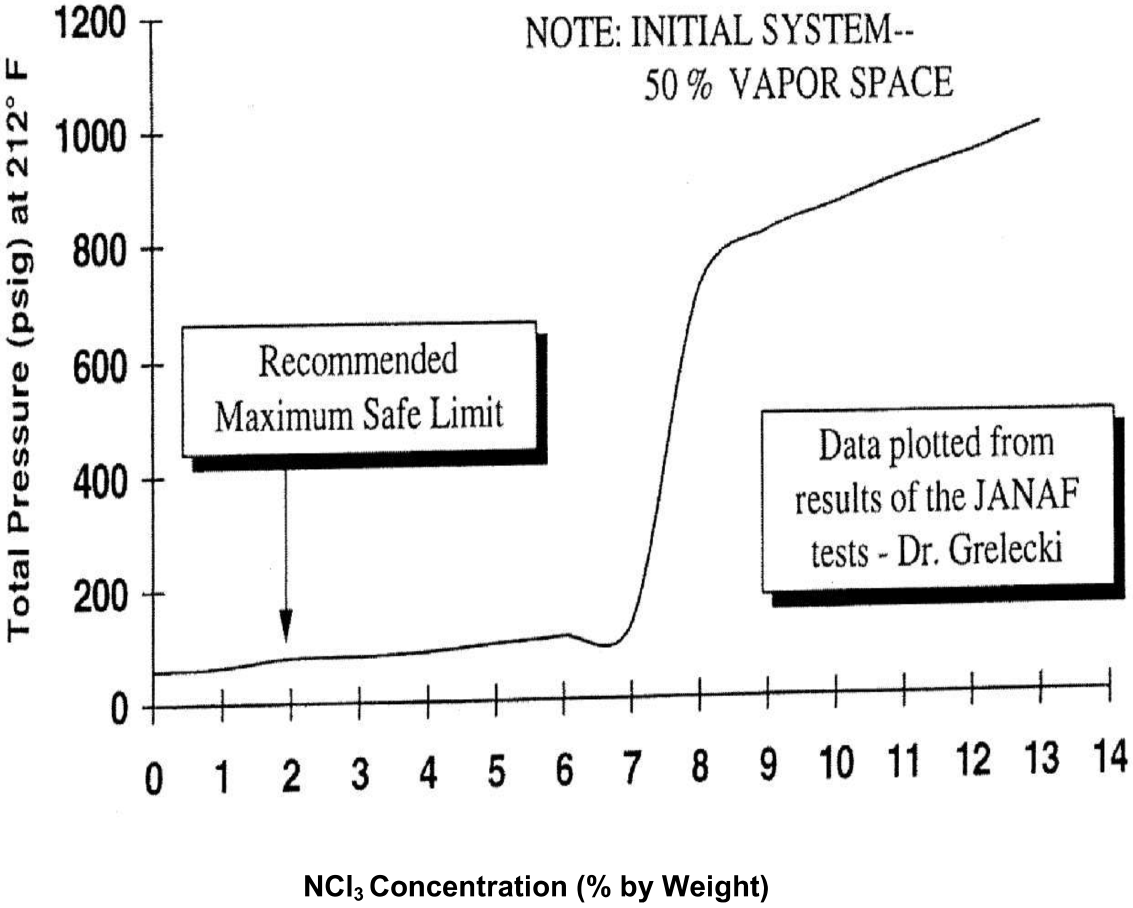
Literature Data: Experimental vs Calculated

References

Calculated Data: ChemCad "Physical and Thermodynamic Properties of Pure Chemicals" Design Institute for Physical Property Data (*9.2.16*)

Experimental Data: (*9.1.1,* Argade)

Figure 3.2 - Total Decomposition Pressure Versus Nitrogen Trichloride Concentration



4. SOURCES AND MECHANISMS OF FORMATION OF NITROGEN TRICHLORIDE

4.1 Sources

Many compounds in the brine feed to chlor-alkali cells (including salt source and mining water), in a chemical added to the processes (e.g., hydrochloric acid), or in a fluid that contacts the process (e.g., direct contact cooling) which contain a nitrogen atom are suspect as a source which could generate nitrogen trichloride in the chlorine production process.

4.1.1 Brine Contamination

A common source of nitrogen that easily converts to nitrogen trichloride in a chlorine cell is ammonia in the brine. The ammonia could come from the contamination of mining water or from naturally occurring ammonia or other nitrogen compounds present in the solid salt.

Industry and academic literature cite several examples of nitrogen compounds and/or ammonia contamination of the brine that have led to elevated nitrogen trichloride in both product chlorine and chlorine residues.

Heilborn (*9.1.1*) suggests that changing from dynamite to ammonium nitrate/fuel oil in the salt mining operations may produce salt which contains higher concentrations of nitrogen compounds which leads to higher nitrogen trichloride in the chlorine. Similarly, sodium hydroxide used in raw brine treatment could be a source of ammonia contamination if the sodium hydroxide was purified utilizing the ammonia salt removal process. Even ground water has been known to leach ammonia compounds and humic acid from fertilized fields into brine wells.

4.1.2 Other Sources of Contamination

Contaminants in brine or utility (water and steam) treatment chemicals in a chlor-alkali plant can be a source for potential formation of nitrogen trichloride. Urea is a particular concern as it is hydrolyzed to ammonia. Urea contamination during a salt unloading operation was a possible cause of high nitrogen trichloride formation leading to a 1993 explosion which resulted in two fatalities (Table 2.1).

Sulfuric acid contaminated with ammonia used in the chlorine drying process has been shown to cause an increased formation of nitrogen trichloride. Direct contact cooling water or steam that is treated with amines, ammonia based flocculants, or chloramines, are other sources of increased formation of nitrogen trichloride.

4.1.3 Nitrogen Compounds that are Not Converted to Nitrogen Trichloride

Not all nitrogen compounds are converted to nitrogen trichloride. For example, water contaminated with caprolactam (Hexahydro-2H-azepin-2-one, 2-Oxohexamethyleneimine) was inadvertently used to mine brine at a facility in Texas. Increased monitoring of the process was implemented but no detectable rise in nitrogen trichloride was measured.

Nitrogen gas introduced into the chlorine gas stream is not converted to nitrogen trichloride under normal operating conditions existing in current chlor-alkali production facilities. Fully oxidized forms of nitrogen, such as nitrate salts (potassium nitrate or sodium nitrate), are not likely to form nitrogen trichloride upon interaction with chlorine. However, some fully oxidized nitrogen compounds can become reduced compounds such as ammonia and other non-fully oxidized nitrogen containing components at the cathode.

These compounds may then be recycled via direct contact hydrogen gas cooling, evaporator condensate as brine make-up water or catholyte used for brine treatment and find their way back to the brine system where it is possible to form nitrogen trichloride in the cells. Management systems should be in place to minimize the possibility of recycling nitrogen containing species in the brine via catholyte.

4.2 MECHANISMS OF FORMATION

Chlorine reacts with anhydrous gaseous ammonia or with aqueous solutions of ammonia or ammonium salts (ammonium hydroxide, ammonium chloride, ammonium sulfate, etc.) to form nitrogen trichloride.

The primary location of nitrogen trichloride formation is in the chlorine cells, where the pH and other process parameters are ideal for formation.

In a typical chlorine cell anolyte, (pH<5), nitrogen trichloride forms rapidly and quantitatively in the presence of ammonia and/or ammonia compounds per the following reactions:

$$NH_3 + 3\ Cl_2 \rightarrow NCl_3 + 3\ H^+ + 3\ Cl^-$$

$$NH_4^+ + 3\ Cl_2 \rightarrow NCl_3 + 4\ H^+ + 3\ Cl^-$$

$$NH_4^+ + Cl^- + 3HClO \rightarrow NCl_3 + H^+ + Cl^- + 3\ H_2O$$

Contaminants in brine, utility treatment chemicals, or chlorine drying agents will also follow one of these reactions.

5. CONTROL AND MONITORING OF NCL_3 AND NCL_3 SOURCES

Whenever chlorine manufacturing processes or sources of raw materials are changed (e.g., water, salt, brine, brine chemicals, drying acid), a check should be made to ensure that a new nitrogen trichloride source has not been introduced.

5.1 PROCESS PARAMETERS

The ammonia compounds in raw brine, cell feed brine and other additives introduced in the process (e.g., H_2SO_4, HCl) and nitrogen trichloride in liquid chlorine product should be measured to determine baseline levels for the process. Any modification to the materials used in the process should always be accompanied by a check against any potential problems connected with nitrogen trichloride.

The parameters that can affect the concentration of nitrogen trichloride (e.g., ammonia compounds in the various streams and process conditions such as temperature and flow rate) should be identified and monitored. Statistical Process Control (SPC) or some equivalent method can be used to decide the frequency of monitoring. If parameters that can affect the concentration of nitrogen trichloride are increasing, the frequency should be increased. A process hazard review should be conducted to identify other abnormal operating scenarios that could lead to increased ammonia compounds.

Nitrogen trichloride accumulation points (e.g., reboiler, coolers that use evaporating liquid chlorine as the cooling fluid, purge line from vaporizers, storage vessels) should be identified and a monitoring frequency based on variability and nitrogen trichloride concentration should be established.

During periods of startups, shutdowns, process modifications, maintenance, process upsets, or process fluctuations there may be a higher risk of nitrogen trichloride formation or accumulation. As a result, the frequency of monitoring should be increased.

6. PREVENTION AND DESTRUCTION

The following discussion provides information that should be considered as a facility examines alternative methods to prevent nitrogen trichloride levels from exceeding safe levels. When practical, steps should be taken to prevent nitrogen trichloride from being formed.

When prevention is not practical, destruction techniques, coupled with appropriate control and monitoring techniques (Sections 5 and 8), should be employed to prevent concentrations from exceeding safe levels.

6.1 PREVENTING THE FORMATION OF NITROGEN TRICHLORIDE

6.1.1 Avoiding Sources of Ammonia Compounds in Brine

Since nitrogen trichloride primarily forms in electrolytic cells from the reaction of chlorine with ammonia compounds, the best method to prevent its formation is to keep ammonia compounds away from the process in the first place. The following are general principles that should be considered:

Users of Rock Salt

- Use rock salt that has been mined without ammonium nitrate explosives. Explosives are available that do not contain ammonia compounds.
- Avoid anti-caking agents that contain compounds that can form nitrogen trichloride.
- Establish specifications limiting the content of compounds that can form nitrogen trichloride.
- Ensure there is no contamination, during salt handling or shipment, with compounds that can form nitrogen trichloride.

Users of Solution-Mined Brine

- Minimize contamination of make-up water due to events such as fertilizer run-off in surface water drainage.

All Facilities

- Avoid the introduction of compounds that can form nitrogen trichloride in brine treatment chemicals, utility (water and steam) treatment chemicals and drying (sulfuric acid) agents.

6.1.2 Removing Ammonia Compounds from Brine

If ammonia compounds are in the process, significant amounts can be removed by reacting with chlorine (*9.1.1, Myers*) either through direct chlorination or through addition of hypochlorite (bleach) (*9.2.7*). The target range for free chlorine concentration is 10 to 20 ppm with sufficient residence time. The amount of residence time depends on the system and on brine quality. To determine this time for the facility, downstream samples of ammonia or nitrogen trichloride are needed. This must be done under alkaline conditions, pH greater than 7, optimally 7.5-8.5 for faster reaction rates. Under acidic conditions nitrogen trichloride may be formed instead, so pH control is important. Another vessel may be needed to provide for sparging, and equipment must be protected from corrosion due to the sparging and the hypochlorite addition. The preferred reaction may be expressed as:

$$NH_4Cl + 1.5\ HOCl \rightarrow 0.5\ N_2 + 1.5\ H_2O + 2.5\ HCl$$

Additional references concerning breakpoint chlorination to reduce ammonia-containing nitrogen and potential results are found in the Chlorine Institute Pamphlet 21, in the section entitled, "*Nitrogen Compounds in Brine and Their Fate*" (*9.1.1*) and the *Handbook of Chlorination* (*9.2.8*). These references address reactions and reaction rates along with ancillary results, such as solids formation and brine clarity.

6.2 DESTRUCTION OF NITROGEN TRICHLORIDE

Several ways have been found to destroy nitrogen trichloride. Many of them give substantial elimination.

6.2.1 Catalysts

While the Institute is not aware of any current commercial applications, the catalysts listed below have been reported to have some activity in the destruction of nitrogen trichloride:

- activated carbon
- Monel® shavings/turnings
- alumina
- iron and iron compounds
- silica
- copper chloride
- silver chloride
- various other metal chlorides

Catalysts should be used with dry chlorine gas or liquid where they will not be fouled by water or salt. Metal salts can be used with a substrate, such as alumina or carbon.

The exhausted catalyst can often be reactivated with hot, dry air. During initial startup of a catalyst bed, care must be taken to prevent overheating from two sources: (1) reaction of small amounts of hydrogen with the chlorine in the gas, and (2) absorbed water on the catalyst reacting with chlorine (*9.2.9*).

6.2.2 Ultraviolet Light

Nitrogen trichloride will decompose when exposed to ultraviolet light. Several facilities use this technique successfully. The method is used on chlorine gas rather than liquid due to partial absorption of the light by chlorine. The required wavelength range is 3600-4780 Å. Usually, mercury vapor lamps are used due to their intensity and wavelength emissions. Other lamps emitting the correct wavelengths have been tested successfully in the laboratory. Typically, lamps are arranged in series for good coverage of the chlorine stream. Wall effects can be significant, and the chlorine gas itself will block the light. The design should consider the size and arrangement of the chlorine piping and layout of the lamps.

The lamps have been used successfully both on wet and on dry chlorine systems.

Depending on the kW rating, a lamp can produce a reduction of up to 80% in the nitrogen trichloride concentration. Lamps are usually installed and operated in series down the length of a pipe or vessel to reach the required nitrogen trichloride removal.

Since ultraviolet light can trigger reaction of hydrogen and chlorine, operating procedures should address the possibility of initiating such a reaction (*9.2.10*).

6.2.3 Thermal

Nitrogen trichloride will decompose at a significant rate at temperatures above 104-122°F (40-50°C). This is the basis for a few methods of nitrogen trichloride destruction. However, this destruction efficiency is both temperature and residence time-dependent. Each site needs to verify the destruction efficiency for its unique system, especially if this system is the primary removal system for nitrogen trichloride.

Often, chlorine systems include a compressor suction cooler to cool the gas and possibly to remove impurities from it. This cooling is usually provided by flashing liquid chlorine in the suction chiller. The liquid that accumulates at the bottom of this vessel dilutes the nitrogen trichloride and is higher in nitrogen trichloride concentration than the chlorine gas entering the suction chiller. The liquid is often drawn off into a tower of refluxing solvent, e.g., carbon tetrachloride. The reboiler of the tower operates at a temperature above the decomposition point for nitrogen trichloride so that the nitrogen trichloride is continuously destroyed. Historically, this type of system has had several nitrogen trichloride explosions. The design must be carefully reviewed to be sure it provides adequate controls to maintain nitrogen trichloride destruction and prevent nitrogen trichloride accumulation (Section 8.2).

6.2.4 Acidification

Wet chlorine gas can be treated with aqueous hydrochloric acid, which will decompose the nitrogen trichloride and remove some water and other impurities.

This method is typically used at acid concentrations between 23 and 30%, and at a temperature of about 50°F (10°C).

A dilute acid stream is produced that is high in ammonia content. This can be treated to remove the ammonia, making the acid suitable for use in brine pH adjustment. Concentrated sulfuric acid and iron can be used together to decompose nitrogen trichloride but a milky precipitate is formed that would foul equipment (*9.2.11*).

6.2.5 Reducing Agents

Reducing agents, such as sulfites, thiosulfates, sulfides and phosphites, will destroy nitrogen trichloride. They can be added to the solution from the refluxing solvent tower described above. This further decomposes the nitrogen trichloride. Since the solvent and the reducing agent are not miscible, they must be agitated (*9.2.12 and 9.2.13*).

6.2.6 Nitrosyl Chloride

Nitrosyl chloride normally will decompose nitrogen trichloride when added to liquid chlorine.

It has been used for storage containers to reduce the nitrogen trichloride content. The desired reaction may be inhibited if very high nitrogen trichloride concentrations or organic contamination are present.

6.3 SPILLS OF MATERIALS CONTAINING NITROGEN TRICHLORIDE

Nitrogen trichloride is less volatile than chlorine and some solvents, so it may be present after the chlorine or solvent from a liquid spill has evaporated or been absorbed. The nitrogen trichloride will be an oily, yellowish-green liquid, with an odor similar to chlorine. Access to the area of the spill should be restricted until it has been decontaminated. If an explosion occurs, it may not detonate all the nitrogen trichloride present.

Of the destruction methods described above, the reducing agents (section 6.2.5) may be the best choice for decontaminating an area contaminated with nitrogen trichloride. They are readily available, and have relatively less environmental impact than other options. They should be applied cautiously in a dilute form, (approximately 5%) sprayed in a mist over the affected area.

After application, sumps and low spots should be inspected to ensure there are no remaining puddles of nitrogen trichloride. The area should then be washed down thoroughly with water.

7. LIMITING LEVELS OF NITROGEN TRICHLORIDE

7.1 SPECIAL PRECAUTIONARY NOTE

The historical analytical method (*9.2.14*) for determining nitrogen trichloride levels in chlorine, frequently called Kjeldahl method, is not nitrogen trichloride specific. As a result, certain other nitrogen compounds that may be present in the chlorine will have been reported as nitrogen trichloride. Consequently, the historical database for nitrogen trichloride levels in chlorine is suspect. Actual nitrogen trichloride levels in chlorine may have been lower than reported in the literature.

The inaccuracies in the measurement of nitrogen trichloride in chlorine are believed to be greatest where actual levels of nitrogen trichloride are the lowest, i.e., the finished chlorine product. The difference in the methods of measuring nitrogen trichloride levels at process accumulation points, where nitrogen trichloride concentrations can approach 1 - 2 wt. %, should be insignificant.

A nitrogen trichloride analytical method was developed by the Institute and has been approved and issued by the ASTM (*9.2.1*). Individual facilities need to determine for themselves whether it is warranted to switch to this method.

The recommendations discussed in Section 7 are, in reality, based on the historical Kjeldahl method. Facilities should not use the recommendations contained in this pamphlet in conjunction with the new nitrogen trichloride specific analytical method as justification for increasing current nitrogen trichloride levels in chlorine. The Institute recommends that each facility, if it switches to the new method, do a site-specific comparison between the two methods to determine the site-specific limiting value for nitrogen trichloride levels in chlorine.

7.2 BASIC PRINCIPLES

The concentration of nitrogen trichloride in a chlorine system must be limited because nitrogen trichloride can decompose exothermically. Although the decomposition occurs at all concentrations of nitrogen trichloride, the decomposition can result in a significant pressure rise when the nitrogen trichloride concentration reaches 6-8 wt. % nitrogen trichloride (*9.1.1, Eakin*) depending on the amount of the system volume. In concentrated form, the liquid behaves as a sensitive explosive capable of rapid deflagration and detonation. It is believed that a concentration of 13 wt. % of nitrogen trichloride in chlorine is needed to cause a detonation (*9.2.3*).

Nitrogen trichloride can be shown to accumulate in liquid chlorine heels during vaporization. Maximum nitrogen trichloride concentrations occur when liquid chlorine is removed as vapor from a container and/or when removed at very low pressure (low temperature).

In addition to containers and tanks, nitrogen trichloride will accumulate in evaporators even when liquid chlorine is fed containing low levels of nitrogen trichloride at steady state conditions. The accumulation in the liquid is often referred to as “concentration factor”. The following graph shows the concentration factor of nitrogen trichloride for varying temperature.

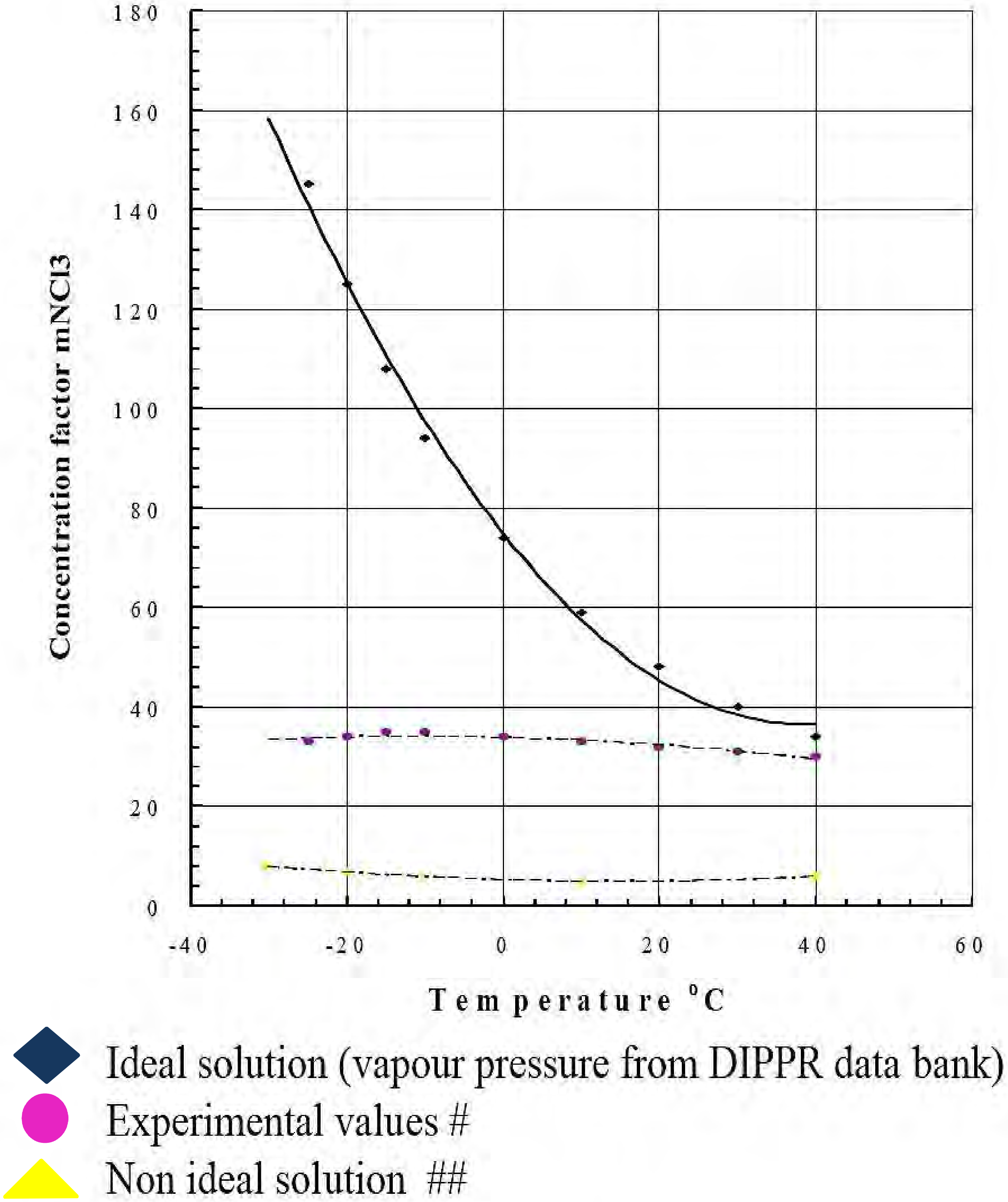
For example, as shown in figure 7.1, a chlorine evaporator operating at 77°F (25°C) will concentrate the nitrogen trichloride up by 40 times in the liquid. So for a liquid feed stream containing 10 ppmv, the equilibrium concentration of nitrogen trichloride in the evaporator will be approximately 400 ppmv, or 670 ppmw.

In this example, the accumulated nitrogen trichloride level in the liquid is still in the safe region. However, if the feed is stopped and the remaining liquid chlorine is all evaporated to near dryness, the nitrogen trichloride will accumulate to dangerous levels, particularly if evaporated at a low temperature.

Appendix B has another example of how to calculate the accumulated nitrogen trichloride in a steady state evaporator/vaporization system.

A number of literature sources show different vapor pressures for nitrogen trichloride. This is not surprising due to the instability of nitrogen trichloride. Only one source shows measured vapor pressure (*9.2.15*). The Design Institute for Physical Properties(DIPPR) (*9.2.16*) has estimated vapor pressure data for nitrogen trichloride using a prescribed methodology. The vapor pressures agree near the boiling point of nitrogen trichloride but are different by as much as an order of magnitude at lower temperatures (-22°F to +86°F or -30°C to +30°C). These vapor pressure differences result in different values when calculating the nitrogen trichloride content of liquid heels.

Figure 7.1 - Concentration Factor (ml NCl^3) vs. Temperature



7.3 MAXIMUM LEVEL INSIDE ANY PROCESS EQUIPMENT

Any part of the chlorine system where impurities can collect can be an accumulation point for nitrogen trichloride. Of particular concern is any part of a system or container where liquid chlorine can be vaporized allowing the nitrogen trichloride to remain behind and concentrate. An adequate safety margin should be set that takes into consideration the following:

- The potential for accumulating nitrogen trichloride in the process
- The inherent risk of exceeding any safety margin
- The normal variation of measured nitrogen trichloride in the process
- Any imprecision introduced by the method of sampling and analysis
- The period of time between analyses

A safety margin should be incorporated into the prescribed levels of nitrogen trichloride for different situations. It is, therefore, recommended that in order to avoid reaching a level of 6 wt. % nitrogen trichloride, the concentration should be limited to 2 wt. % (20,000 ppm) in any part of the installation where nitrogen trichloride could concentrate during normal operations, shutdowns, special procedures, and transient conditions.

The relative risk of the solvents used with respect to the 2% limit should be considered. Solvents with a boiling point higher than nitrogen trichloride reduce the potential risk. Solvents with a boiling point lower than nitrogen trichloride increase the potential risk.

7.4 MAXIMUM LEVELS OF NITROGEN TRICHLORIDE IN CHLORINE INTRODUCED INTO SHIPPING CONTAINERS AND PRODUCT STORAGE CONTAINERS

The maximum recommended nitrogen trichloride levels have been established by taking into account the potential accumulation of nitrogen trichloride, particularly where there is intended or unintended vaporization of the chlorine.

The calculations carried out for a specific installation should take into account:

- the quantity of nitrogen trichloride which might be present after complete vaporization of the chlorine
- the capacity and the geometry of the container

The Chlorine Institute recommends that the maximum level of nitrogen trichloride in liquid chlorine not exceed 20 ppm (by weight). This recommendation is based on the collective operating and technical experience of the Institute's members. The recommendation should be considered as an interim one since uncertainties related to historical analytical techniques used to measure nitrogen trichloride (prior methods were not nitrogen trichloride specific), vapor-pressure equilibrium data of chlorine-nitrogen trichloride solutions, detonation concentration of nitrogen trichloride, the potential diluent effects of chloromethyl and chloroethyl impurities in chlorine, and possibly other factors draw into question some of the reported results.

If appropriate safeguards are in place, it is possible for a facility to introduce chlorine containing higher concentrations of nitrogen trichloride into these containers on an interim or permanent basis.

7.5 VAPOR UNLOADING OF SHIPPING CONTAINERS

The Chlorine Institute recommends that bulk shipping containers (barge tanks, railcars and tank trucks), **not** be unloaded by the gas phase. Because nitrogen trichloride has a significantly higher boiling point than chlorine, nitrogen trichloride will concentrate in the liquid phase if the container contents are removed via the gas phase. The gas phase will have a greater concentration of chlorine than the liquid phase. Because of the relatively large amount of chlorine in the container, the nitrogen trichloride levels in the liquid phase could concentrate to dangerous levels if only gases are removed.

Because the actual amount of nitrogen trichloride present in a one-ton container or any smaller size cylinder that has been filled with chlorine that is within the Institute's recommendation (20 ppm Section 7.4) is quite small, it is the opinion of the Chlorine Institute that such containers can be safely unloaded by either the gas or liquid phase. Cylinder and ton container owners should have a defined procedure to limit the number of times a ton container or cylinder is refilled between complete container evacuations to prevent the accumulation of nitrogen trichloride.

8. DESIGN/OPERATING CONCERNS AND CONSIDERATIONS

The predominant concern with nitrogen trichloride has been in chlorine production or related processes where vaporization effects have resulted in the accumulation of dangerous levels of nitrogen trichloride. Therefore, it is imperative that any process that could allow nitrogen trichloride to concentrate must be designed to accommodate or mitigate the risk of accumulation in a safe manner.

8.1 BRINE TREATMENT EQUIPMENT

The primary source of nitrogen trichloride in chlorine systems is from ammonia conversion in the feed brine during the brine electrolysis process. A system to minimize or destroy ammonia should be considered prior to the electrolytic cell process to reduce the rate of generation of nitrogen trichloride. A destruction system may significantly reduce the quantity of nitrogen trichloride in the chlorine process and final product, but precautions must still be followed since the destruction efficiency is not 100% effective. Use of an on-stream analyzer for ammonia in raw brine should be considered especially for situations where the ammonia concentration can vary significantly.

8.2 GASEOUS CHLORINE CHILLING/PURIFICATION EQUIPMENT

Safe design and operation of a process (i.e., purification column, compressor precooler or intercooler, or suction chiller) where gaseous chlorine is chilled by direct contact with liquid chlorine resulting in the condensation of the higher boiling nitrogen trichloride **must** be predicated on moving any collected nitrogen trichloride to a place where conditions are such that it is diluted and removed or decomposed to a safe nitrogen trichloride concentration. Special attention must be given to ensure that free flow of gas and liquid exists within the column, i.e., use of pressure drop indication.

A plant shutdown or other appropriate procedures should be mandated if a flow restriction becomes evident. The liquid chlorine feed to the column should be controlled such that the feed rate is not cyclical and is sufficient to prevent a dry tray or packing condition where nitrogen trichloride could concentrate to dangerous levels.

If an organic solvent is used, its selection for use as a diluent should consider the reactivity with nitrogen trichloride and chlorine, relative boiling points, solvent stability, and solubility characteristics. The reboiler design should consider corrosion potentials and heating designs that minimize the possible intrusion of water vapor. In batch removal systems, special precautions must be used to establish the removal frequency of the nitrogen trichloride containing stream. These systems should have operating procedures to ensure the discharge line is not plugged, and to limit the heat transfer and temperature during the chlorine degassing step.

8.3 CHLORINE COMPRESSORS

Ross and Bowling (*9.1.1*) states that at a 203°F (95°C) compressor discharge temperature, nitrogen trichloride will be reduced by more than 90% as the chlorine gas passes through the compressor. However, this destruction efficiency is both temperature and residence time dependent. Other information indicates the destruction efficiency can be less than 50% in some (centrifugal compressor) installations. Each site needs to verify the destruction efficiency for its unique system, especially if this system is the primary removal system for nitrogen trichloride.

8.4 STORAGE/BULK TRANSPORTATION EQUIPMENT

In the case of pressure storage, where a progressive loss of contents by vaporization occurs, greater care must be taken to ensure that the nitrogen trichloride remains at a low and predictable level. This becomes most important when the container is nearly empty, particularly prior to being taken out of commission such as for testing or maintenance. A diluent (e.g. liquid chlorine) that is later removed in the liquid phase can be added to the vessel to ensure that the nitrogen trichloride concentration cannot exceed 2% by weight.

If any container and associated piping system has low points (sump, branches, etc.) where liquid chlorine could collect, and which is not readily removed during the emptying operation, the system should be flushed with liquid chlorine or a suitable diluent should be added to assure that the nitrogen trichloride concentration cannot exceed 2%.

Other situations where nitrogen trichloride can accumulate are vacuum sniffing to recover returned liquid chlorine heels in railcars, barges, or other containers, vapor unloading of liquid chlorine from a shipping container, chlorine vaporizer operation, chlorine knock-out pots or flash separators, coolers using liquid chlorine as the coolant, and preparation of storage tanks, vessels, and piping systems for maintenance via evacuation. The highest nitrogen trichloride concentrations in liquid chlorine occur during low temperature/low pressure vaporization of a pool of liquid chlorine. Appropriate procedures and practices must exist to purge, dilute, or monitor these situations to ensure that safe levels of nitrogen trichloride are not exceeded. To minimize nitrogen trichloride accumulation, remove as much chlorine as possible as liquid prior to removing gas.

In addition, any chlorine processing system should be designed with a minimum number of low points and have a means to monitor and/or purge low points.

8.5 CHLORINE VAPORIZERS/REBOILERS

Chlorine vaporizers and reboilers have a potential of concentrating the nitrogen trichloride that is present in the chlorine feed. These systems are typically operated for long periods of time and depending on their design, can concentrate the nitrogen trichloride. Vaporizers for liquid chlorine typically operate in the 77-122°F (25-50°C) range, resulting in part of the nitrogen trichloride in the liquid being destroyed in the vaporizer. The design of the system should be reviewed critically to minimize collection of a residual and a provision for a normal flush of the low areas should be provided. The limit of 20,000 ppm nitrogen trichloride should be maintained for the residues in all reboilers and vaporizers. The concentration of nitrogen trichloride should be estimated for vaporizers using Appendix B. If unsafe levels are calculated, then appropriate connections or sampling ports should be added to purge liquid chlorine in order to prevent nitrogen trichloride accumulation. Consult CI Pamphlet 9 (*9.1*) for detailed information on chlorine vaporizers.

8.6 CHLORINE CYLINDER AND TON CONTAINERS

Chlorine cylinders and containers of up to one-ton are frequently used for extraction of chlorine gas rather than liquid. Adequate cleaning procedures must be practiced at the packager facility to assure no build-up of nitrogen trichloride after several cycles (Refer to CI Pamphlet 17, (*9.1*)). Packager facilities utilizing chlorine recycling systems (i.e., using recovered chlorine from returned cylinders in newly filled cylinders) should take appropriate precautions to ensure that nitrogen trichloride does not build up to dangerous concentrations.

Each chlorine user and/or repackager should identify potential nitrogen trichloride accumulation points (e.g., vaporizers, chlorine storage vessels) in the process or installation. It is recommended to have discussions with the supplier to verify the risk of nitrogen trichloride accumulation, and to define procedures to purge or dilute the system.

8.7 GENERAL DESIGN CRITERIA

Other design guidelines and concerns that must be considered in any chlorine production or use process are as follows:

- Instrumentation should be provided so that the critical process data for any system where nitrogen trichloride can accumulate can be recorded and alarmed to emphasize the critical nature of these variables. Use of data charting, such as statistical process control (SPC), should be encouraged for the critical process parameters from ammonia in brine to nitrogen trichloride in the final chlorine product.

- The design of chlorine processing or use systems including any nitrogen trichloride destruction system, should consider the use of simulation calculations as a tool to aid the Process Hazard Analysis (PHA) in defining the potential situations for the development of high concentrations of nitrogen trichloride.

- Raw materials and operating chemicals should be monitored for ammonia-containing compounds especially during the process of changing suppliers or sources of the materials.

- If using chlorine in processes where ammonium compounds are present, safeguards must be in place to prevent the accumulation of nitrogen trichloride to dangerous levels.

9. REFERENCES

9.1 CHLORINE INSTITUTE REFERENCES

The following publications are specifically referenced in CI Pamphlet 152. The latest editions of CI publications may be obtained at http://www.chlorineinstitute.org.

Pamphlet & DVD #	**Title**
9	Chlorine Vaporizing Systems, ed. 8; rev 1; Pamphlet 9; The Chlorine Institute: Arlington VA **2018**.
17	Packaging Plant Safety and Operational Guidelines, ed. 5; Pamphlet 17, The Chlorine Institute: Arlington, VA **2017**.
21	Nitrogen Trichloride – A Collection of Reports and Papers, ed. 7; The Chlorine Institute: Arlington, VA **2017**.

9.2 OTHER REFERENCES

9.2.1 Nitrogen Trichloride: Sampling and Analysis ASTM E 2036-07, "Standard Test Method for Nitrogen Trichloride in Liquid Chlorine by High Performance Liquid Chromatography (HPLC)," ASTM International. This standard can be ordered and downloaded from the ASTM website at www.astm.org.

9.2.2 Ammonia Analysis in Brine. Memo dated March 14, **1996** from David Hildebrand to Steve Fitzgerald. This memo provides information on a commercially available ammonia ion specific electrode.

9.2.3 Maximum Levels of Nitrogen Trichloride in Liquid Chlorine, ed. 12; Euro Chlor: Brussels, **2012**.

9.2.4 Mellor's Comprehensive Treatise on Inorganic and Theoretical Chemistry; Vol. 8, pp 598-605.

9.2.5 Noyes, W.A.; Tuley, W.F. Jacs. **1925**, 47, 1336.

9.2.6 Taylor, J. et al; J. Physi. and Coll. Chem. **1947**, 51.

9.2.7 U.S. Patent 3,597,156, **1971**.

9.2.8 Handbook of Chlorination and Alternative Disinfectants, 4th Edition, **1998**, Geo. Clifford White, John Wiley & Sons, Hoboken, NJ.

9.2.9 U.S. Patent 2,692,818, **1954**.

9.2.10 U.S. Patent 2,705,219, **1955**.

9.2.11 U.S. Patent 3,568,409, **1971**.

9.2.12 U.S. Patent 4,138,296, **1979**.

9.2.13 U.S. Patent 4,230,673, **1980**.

9.2.14 The Determination of Nitrogen Trichloride in Liquid Chlorine, Analytica Chimica Acta, 156 (**1984**), pg. 221-233, Elsevier Science Publishers, Amsterdam, The Netherlands.

9.2.15 Some Explosive Properties of Nitrogen Trichloride, Published in Acta Physicochimica URSS, Vol 13, No. 3 (**1940**) pp 405-422.

9.2.16 Design Institute for Physical Property (DIPPR), American Institute of Chemical Engineers, 3 Park Avenue, New York, NY 10016-5991.

APPENDIX A - PAMPHLET 152 CHECKLIST

This checklist is designed to emphasize major topics for someone who has already read and understood the pamphlet. Taking recommendations from this list without understanding related topics can lead to inappropriate conclusions.

Place a check mark (✓) in the appropriate box below:

Yes	No	N/A		
☐	☐	☐	1. Are new sources of nitrogen trichloride checked when changing the process or raw materials?	{5}
☐	☐	☐	2. Are baseline levels for ammonia determined in compounds in brine and nitrogen trichloride in chlorine?	{5.1}
☐	☐	☐	3. Is there a system in place to monitor for components that can affect the concentration of nitrogen trichloride?	{5.1}
☐	☐	☐	4. Is there a procedure in place to determine accumulation levels for nitrogen trichloride and establish a monitoring frequency?	{5.1}
☐	☐	☐	5. Are nitrogen trichloride monitoring intervals increased during abnormal periods?	{5.1}
☐	☐	☐	6. Are ammonia levels minimized in rock salt or brine raw material?	{6.1.1}
☐	☐	☐	7. Are compounds that introduce nitrogen trichloride avoided?	{6.1.1}
☐	☐	☐	8. Has the destruction efficiency of thermal systems been determined?	{6.2.3}
☐	☐	☐	9. Is there a procedure in place for handling of spilled materials containing nitrogen trichloride?	{6.3}
☐	☐	☐	10. Has the facility performed site-specific comparison of the two analytical methods of switching to the new method to determine site specific limiting levels of nitrogen trichloride in chlorine?	{7.1}
☐	☐	☐	11. Are there established maximum level of nitrogen trichloride in chlorine process equipment?	{7.3}
☐	☐	☐	12. Are there established maximum levels of nitrogen trichloride in chlorine shipping containers and product storage containers?	{7.4}

☐ ☐ ☐ 13. Is chlorine only unloaded in the liquid phase in bulk shipping containers? {7.5}

☐ ☐ ☐ 14. Have there been considerations to install an ammonia destruction system? {8.1}

☐ ☐ ☐ 15. Are there operational checks on chlorine chilling/purification equipment? {8.2.}

☐ ☐ ☐ 16. Has the process been evaluated on the need to purge/flush of nitrogen trichloride? {8.4-8.5}

☐ ☐ ☐ 17. Are there procedures to prevent concentration of nitrogen trichloride in cylinders and one-ton containers? {8.6}

☐ ☐ ☐ 18. Is there a compilation of critical process data where nitrogen trichloride can accumulate? {8.7}

REMINDER:

Users of this checklist should document exceptions to the recommendations contained in this pamphlet.

APPENDIX B - SAMPLE NITROGEN TRICHLORIDE CALCULATION

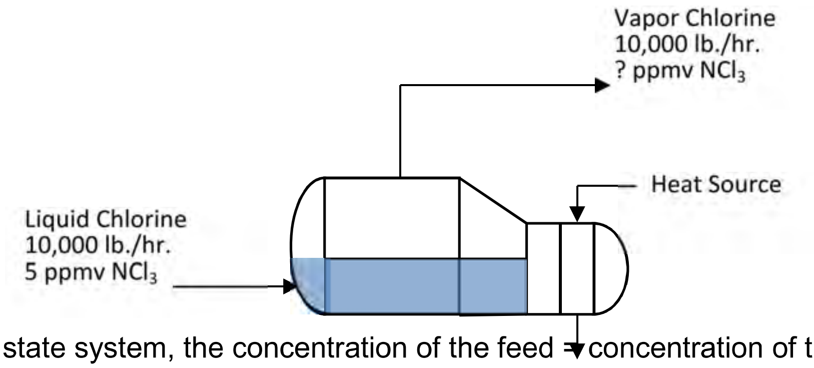
Calculate the concentration of nitrogen trichloride in the liquid within the reboiler in the following case:
Evaporator pressure: 100 psig, 26°C (78.8°F)
Feed: 10,000 lb./hr. containing 5 ppmv nitrogen trichloride

The equilibrium concentrations for a two component system chlorine – nitrogen trichloride can be calculated assuming an ideal solution with:
Dalton's Law: $Y_{Cl2} = p_{Cl2}/P_t$, $Y_{NCl3} = p_{NCl3}/P_t$
And Raoult's Law: $X_{Cl2} = p_{Cl2}/P^o_{Cl2}$, $X_{NCl3} = p_{NCl3}/P^o_{NCl3}$

Where:
Y_{Cl2} = mole fraction chlorine in vapor phase
X_{Cl2} = mole fraction chlorine in liquid phase
Y_{NCl3} = mole fraction nitrogen trichloride in vapor phase
X_{NCl3} = mole fraction nitrogen trichloride in liquid phase
p_{Cl2} = partial pressure chlorine
p_{NCl3} = partial pressure nitrogen trichloride
P_t = Total pressure
P^o_{Cl2} = saturated pressure chlorine
P^o_{NCl3} = saturated pressure nitrogen trichloride

At steady state conditions, the partial pressure of nitrogen trichloride in the gas phase is the same as the liquid phase, so the equations above can be rewritten as:

$$Y_{NCl3}P_T = X_{NCl3} P^o_{NCl3}$$



In a steady state system, the concentration of the feed = concentration of the vapor, so vapor chlorine will have 5 ppmv.

From saturation data tables, P^o_{NCl3} = 2.7 psia at 26°C (78.8°F).

The equation, $Y_{NCl3}P_T = X_{NCl3} P^o_{NCl3}$ can be rearranged as

$$X_{NCl3} = Y_{NCl3}P_T / P^o_{NCl3}$$

Y_{NCl3}= 5 ppmv
P_T = 100 +14.7 psia
P^o_{NCl3}= 2.7 psia

$$X_{NCl3} = (5 \text{ ppmv}) \times (114.7 \text{ psia}) / (2.7 \text{ psia})$$

$$X_{NCl3} = 212 \text{ ppmv}$$

Mass fraction in the liquid = 367 ppmw nitrogen trichloride

For an evaporator operating at 100 psig, and 26°C (78.8°F), the concentration of nitrogen trichloride in the reboiler liquid is 367 ppmw.

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ATTACHMENT C

Backfilling Feasibility Report

Feasibility Review of Backfilling Caverns 6 & 7 at Sulphur Mines Dome

In response to Order 5b of the 3rd Supplement of Compliance Order No. IMD 2022-027, Westlake tasked its experts to perform a feasibility review of backfilling Caverns 6 and 7 at Sulphur Mines Dome. The IMD's Order specifically being referenced is the following:

5. *Westlake must as soon as possible, but in no event later than sixty (60) days after receipt of this Supplement, submit all of the following to IMD:*
    b. *A plan for back-filling for cavern stability.*

The operation of backfilling Caverns 6 and 7 would require a significant amount of time and resources. Aside from the operational and logistical challenges, there are also engineering, reservoir, and geomechanics principles that should be considered to evaluate if a backfill operation would yield "cavern stability" as suggested from the Order. This feasibility review evaluates the following topics presented as sections of this report:

- Pressure and Geomechanics Influences
- Fill Volume Estimate
- Facility Considerations
- Cavern Operational Considerations
- Timeline Estimate
- Risks, Advantages, and Disadvantages

Pressure & Geomechanics Influences

An inactive solution-mined cavern (such as Caverns 6 and 7) is typically filled with saturated brine. The pressure of a cavern system is created from applied surface pressure (if any), and the hydrostatic head gradient of the brine or other fluids which produces increasing pressure with depth. Other pressure influenced variables can also be considered when necessary, such as frictional losses due to fluid flow conditions. The resulting fluid pressure acts in all directions on the cavern system. The fluid pressure acting on the walls of the cavern helps support the geologic loads acting on the surrounding rock. The pressure magnitude, distribution, and rate of change in pressure impacts the geomechanical stresses/loads within the surrounding rock. If the geomechanical stresses/loads exceed the strength of a rock, then the rock could fail. Lonquist tasked RESPEC with developing a supplementary memo (Attachment A) which elaborates further on these basic geomechanics principles.

Incorporating a fill material into a cavern system to displace the brine (at least in part) does not provide an equivalent pressure condition as a fluid does. Fluid exerts pressure at a given depth/location on the cavern geometry equally in all directions (vertically, horizontally, etc.). In contrast, a fill material would exert dissimilar pressures on the cavern geometry as compared to fluid. The specific pressure implications of a fill material being introduced into a cavern can produce a complex pressure regime on the cavern walls and would be determined by way of various soil mechanics, geotechnical engineering, and civil engineering principles. Some variables that can impact the ultimate pressure magnitude and regime are grain size, grain shape, bulk density, internal friction angle, angle of repose (which can be different than friction angle), porosity, compaction ratio, cavern geometry, and interconnected influence of all those variables, which is not intended to be an exhaustive list. The detailed engineering analysis to understand the specific pressure regime of backfilling a cavern was not completed in the development of this feasibility review. With the aforementioned caveat understood, the pressure impact of a fill material can be generally estimated in the vertical (downward) and lateral (outward) directions to provide an example of how the pressure implications contrast to that of solely fluid. The vertical (downward) component can be determined in a similar method to that of fluid, in that the density of the fill material over a given height exerts a certain pressure at the bottom of the fill column (i.e. the "base of the cavern"). The lateral (outward) pressure of the fill material can be generally estimated using Rankine's Theory[1]. When utilizing certain assumptions for the conditions of these Caverns, these general calculations and theory indicate that a fill material could produce an additional lateral pressure between 0.22 to 0.37 psi per vertical foot (where fill material is present) on a vertical cavern wall. RESPEC utilized 0.22 psi/ft of additional lateral pressure where fill material is present within the Figures presented in Attachment A. This lateral fill pressure is in addition to the pressure exerted by the hydrostatic head of brine fluid (and any applied surface fluid pressure). As stated previously, the determination of the actual pressure magnitude at any point on the cavern "wall" due to fill material is a complex problem and which would directly impact the geomechanics stresses within the rock surrounding the cavern. RESPEC discusses geomechanics considerations within Attachment A.

The backfilling of Caverns 6 and 7 could occur simultaneously to produce as little differential stress between the two caverns as possible, and to further reduce the potential effects of sub-surface rock movement into the two-cavern system if a salt structural collapse were to occur. From a geomechanics perspective RESPEC believes that backfilling Cavern 6 should not be required to maintain a nominal pressure differential between the Caverns. However, Lonquist has incorporated backfilling Cavern 6 into this feasibility review due to several unknown conditions that currently exist regarding the relationship between the two Caverns, and which backfilling operations of one or both caverns will undoubtedly impact/change. Lonquist currently views the backfilling of both Caverns 6 and 7 as a conservative approach. Due to Cavern 6 having a slightly deeper true vertical depth as compared to Cavern 7, it is likely that Cavern 6 would need to be filled first until the fill pile reaches a specific depth relative to the geometry of Cavern 7. Figure 1 illustrates this comparative depth between the Caverns.

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[1] Weber, Richard, "Earth Pressure and Retaining Wall Basics for Non-Geotechnical Engineers", PDH Online, 2012

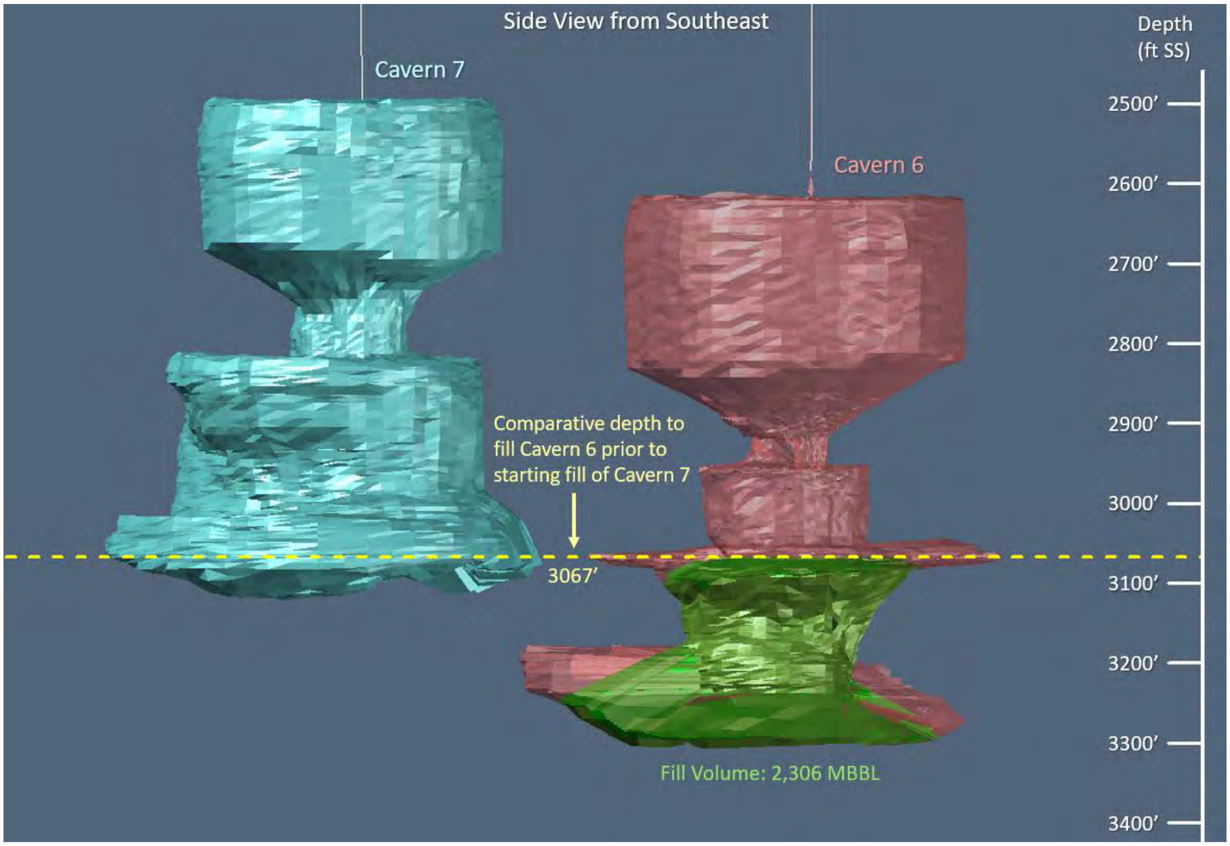

Figure 1 – Cavern 6 Required Fill Depth in Comparison to Cavern 7 Prior to Starting Fill of Cavern 7

Another important consideration is that the geometry of the Caverns inevitably will produce "unfillable volume" due to the angle of repose of the fill pile and peak of the fill pile being generally located along the center vertical axis of the cavern. Figures 2, 3, and 4 below illustrate the areas of the Caverns that would remain "unfilled" with backfill material, and Table 1 presents the volumes of "filled" versus "unfilled" space. The unfilled areas would not be exposed to any lateral load and would only be exposed to the remaining fluid pressure within the cavern system that should propagate through any fill material porosity and permeability above the "unfilled" area. This produces a pressure regime on the cavern wall that is complex and would require the development of a detailed technical model to produce a discrete three-dimensional pressure profile for utilization within a geomechanics simulation. These "unfilled" areas coincide with the depths of minimum web thickness between Cavern 6 and 7, and between Cavern 7 and the salt dome flank.

volume description	Cavern 7	Cavern 6	units
total sonar	55,922,873	55,234,014	ft^3
unfillable	9,828,361	16,279,817	ft^3
fillable	46,094,512	38,954,197	ft^3

Table 1 – Cavern Volumes, Total Sonar, Unfillable and Fillable (cubic feet)

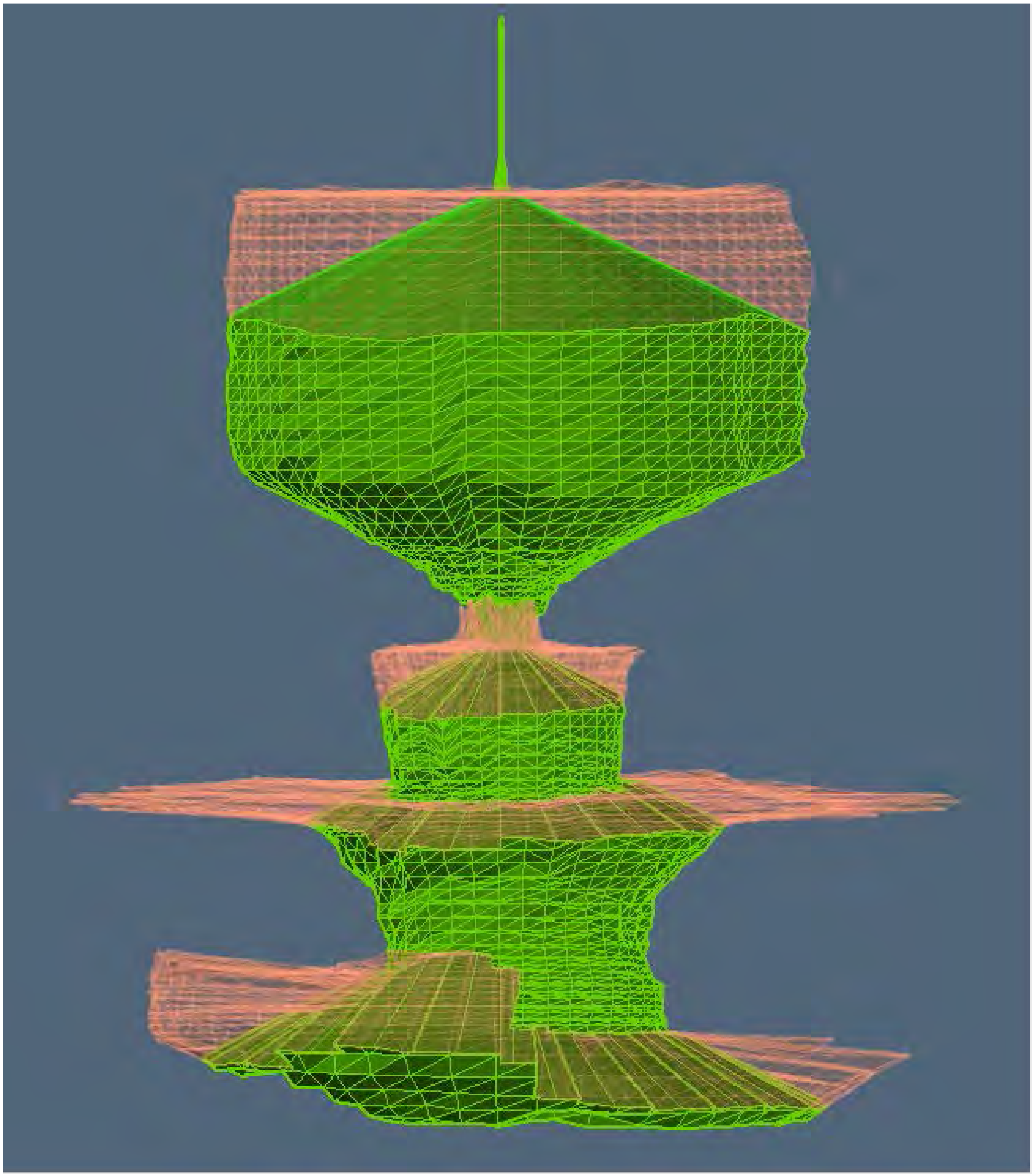

Figure 2 – Cavern 6 "Unfilled” Volume Represented in Peach Color; “Filled” Volume with 25 Degree Angle of Repose Represented in Green Color

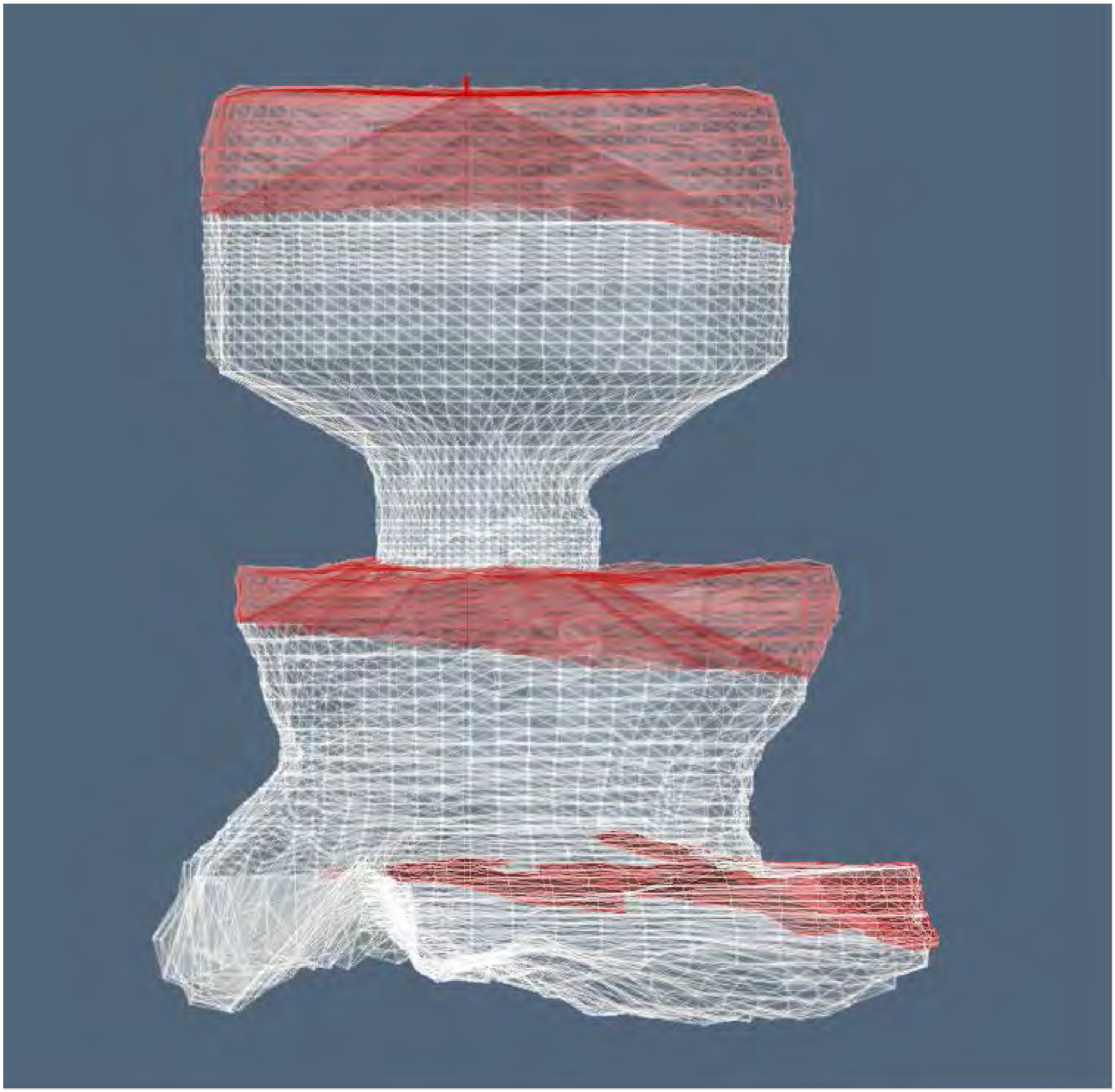

Figure 3 – Cavern 7 "Unfilled” Volume Represented in Red Color; “Filled” Volume with 25 Degree Angle of Repose Represented in White Color

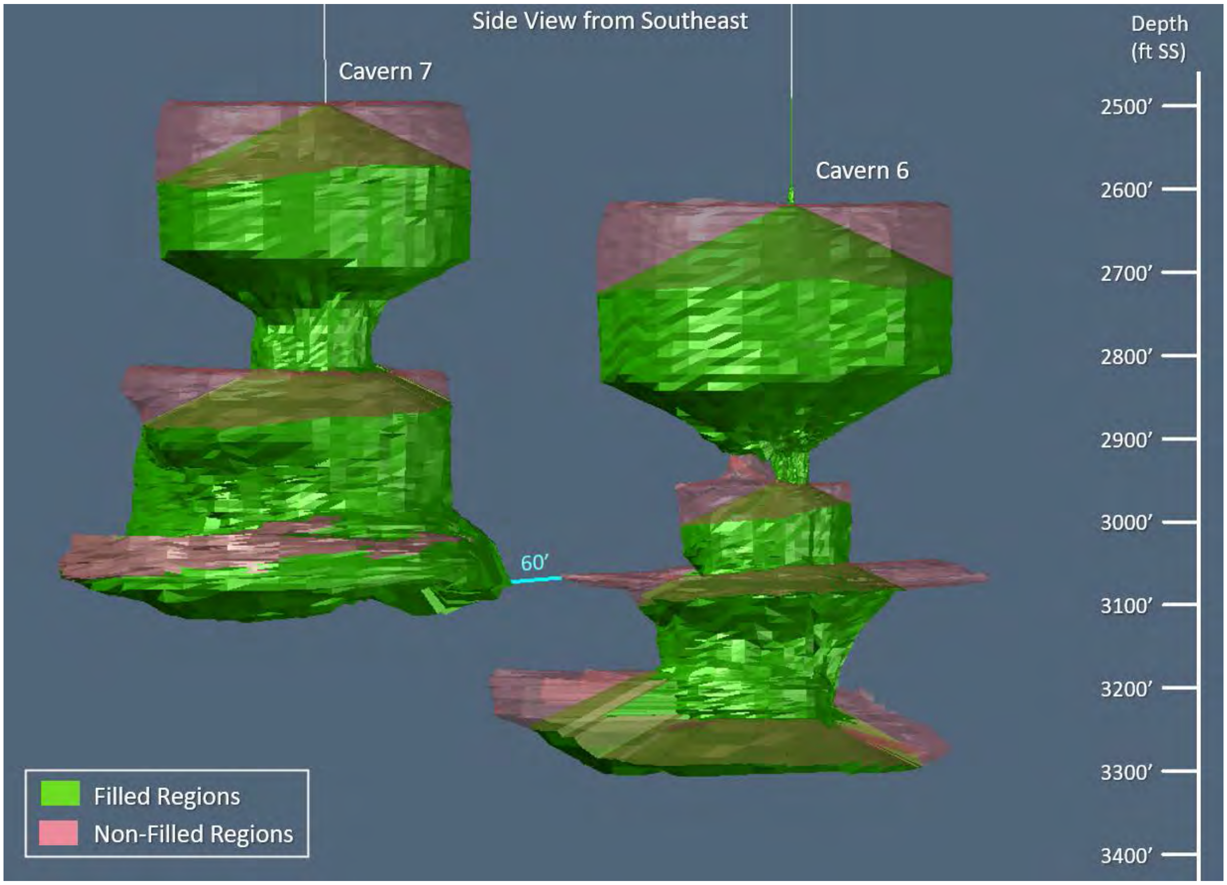

Figure 4 – Cavern 6 and 7 Comparison of "Unfilled" and "Filled" Volumes w/ Respect to Relative Cavern Depths

The pressure and geomechanics topics presented herein illustrate that backfilling of Cavern 6 and 7 can introduce complex pressure (and possibly stress) regimes on the Caverns which could be contrary to minimizing the risk of salt dilation and, as a result may lead to cavern failure.

Fill Volume Estimate

Cavern 7

Recent sonar data obtained in November 2023 indicates the size of Cavern 7 is approximately 9.96 million barrels. In addition, comparison of the most recent sonar data to previous studies dating back to the 1970's indicates there is possibly an additional 3.6 million barrels (roughly) of cavern void below the most recent sonar-derived floor termed herein as "unobservable volume". The development of visualizations and further technical discussion regarding the unobservable volume is still underway. The unobservable volume is due to the accumulation of insoluble material during the solution mining operations, and from salt falls/sloughing that have occurred over time. It is likely that this unobservable volume is less than what can crudely be determined by comparing sonar surveys over the past 50 years because of salt creep closure. A discussion of what risks this unobservable volume presents to a backfilling operation is discussed later in this report, namely related to bulking and compaction.

The volume of solids required to fill the most recent sonar survey volume is 55,922,291 ft^3. As noted earlier, due to an angle of repose that will develop with the fill material (estimated herein at 25 degrees)[2] there will be volumes within the cavern geometry that will not be filled with material. Based on performing a three-dimensional volume analysis of the sonar survey, this "unfilled" volume is estimated to be 9,828,361 ft^3 (17.6% of sonar volume). Therefore, the total volume of solids required to backfill Cavern 7 is 46,094,630 ft^3. A perspective on this volume would be a standard football field (120 yards by 53 yards) as the "footprint" for a "blocked" mass with the height equivalent to a 60-floor building.

Cavern 6

Cavern 6 is adjacent to and in hydraulic communication with Cavern 7. Consideration must be given to backfilling Cavern 6 due to this communication, long term efforts to produce as minimal pressure differential between the Caverns, and in the event of a salt structure collapse the possible reduction of the extent and severity of that event. The most recent sonar survey of Cavern 6 from November 2023 indicates a volume of approximately 9.84 million barrels. The "unobservable volume" of Cavern 6 is estimated at 3.4 million barrels when crudely comparing historical sonar surveys over the past 50 years.

The volume of solids required to fill the most recent sonar survey volume of Cavern 6 is 55,234,452 ft^3. Similar to Cavern 7, the angle of repose developed by the fill material will allow for "unfilled" volume development within the cavern. This "unfilled" volume is estimated to be 16,279,822 ft^3 (29.5% of sonar volume). Therefore, the total volume of solids required to backfill Cavern 6 is 38,954,192 ft^3. Table 2 displays fill volumes for Caverns 6 and 7 in a variety of units.

Cavern 7	Cavern 6	total	units
8,209,174	6,937,524	15,146,698	barrels
46,094,512	38,954,197	85,048,709	cubic feet
1,707,204	1,442,748	3,149,952	cubic yards
121,943	103,053	224,997	trucks, 14 yd^3
14,183	11,986	26,169	44' rail cars, 3,250 ft^3
118	100	218	miles of 44' rail cars

Table 2 – Required Fill Volumes in Various Units

Facilities Considerations

Prior to initiation of backfilling operations, it will be necessary to construct a facility for the manufacture of the slurry mixture required for cavern fill. This facility could be on- or off-site as detailed in the following paragraphs.

Logistically, the best facility site would be adjacent to the location of fill injection, eliminating the need for construction of additional transportation for slurry and brine volumes. Available surface space needed to construct the required facilities may be limited proximal to the Caverns, likely requiring the facility to be located off-site. Also, a more important consideration for placing the facility off-site is to reduce surface activity and noise (which would be 24-hours per day) that may interfere with various

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[2] Rucker, Michael, "Observations and Experience Learned from Remediation to Prevent Collapse of I&W Brine Cavity in Carlsbad, New Mexico", SMRI, October 2023

monitoring systems at Sulphur Mines (e.g. micro-deformation monitoring and micro seismic monitoring). However, the facility needs to be close enough to facilitate efficient brine transport from Sulphur Mines Dome (presumably) to the mixing site and slurry transport to the injection site (the Caverns). This will necessitate a dedicated transport method for each fluid. Pipeline transport of the fill/brine slurry should minimize monitoring system interference at the injection site.

At a minimum, this facility should include the following:

- Necessary off-loading space (trucks/rail) for solid fill material brought to mixing facility site.
- Sufficient storage area for inventory of solid fill material at the mixing facility site.
- Access and/or storage of brine at mixing facility site required for slurry manufacture.
- Mixing capabilities sufficient for 24/7 continuous slurry manufacture.
- Handling facilities for “displaced” brine from the Caverns, including systems for recycling of this brine into the slurry.
- Consideration for multiple transport methods (pipeline preferred) of brine to mixing facility and of slurry to injection site.
- There would need to be processing, monitoring, and measurement capability of the injected slurry to ensure the sodium chloride concentration was sufficient to negate salt dissolution effects within the Caverns.

A detailed engineering design of the facility would need to be completed. Additionally, a study of possible available fill markets/sources and locations that could be sustained for multiple decades (as estimated within the Timeline section of this report) should be completed. An assessment of the environmental and local stakeholder impacts should be considered. The brine volume necessary to continuously manufacture and inject a slurry must also be considered, which ideally would be supplied from active solution mining operations from the Sulphur Mines and/or Starks Dome.

Cavern Operational Considerations

Cavern 7 is only accessible with one wellbore. Current injection rates are continuous at approximately 320 gallons per minute (GPM) and withdrawals are occasional nominal oil volumes. Injected volumes are through tubing and withdrawals are from the tubing/casing annulus. Cavern 6, also accessible through only a single wellbore, and currently has no injection or withdrawal activity.

Brine injection rates into Cavern 7 are determined by cavern pressure behavior with the primary objective being to maintain stable pressures. The current injection rates correspond well with current estimated leak volumes. Maintaining this balance to keep pressures stable (and by association geomechanics stress conditions) may limit the injection rate into Cavern 7 to the current 320 GPM. It may be possible to increase injection rates into Cavern 7 if brine returns are taken from the cavern simultaneously through the existing entry casing annulus, and/or if there are additional entries into the cavern. However, withdrawal of brine from the annulus of the existing entry will complicate the monitoring/measurement of residual crude oil that is occasionally being withdrawn, and there are risks associated with the development of additional entry into Cavern 7.

Injection into Cavern 6 would be comparatively at a very slow rate if limited to the rate of brine movement from Cavern 6 to Cavern 7 (currently estimated at ~6 to 7 GPM). Therefore, it is most likely that brine returns from Cavern 6 would be required via the existing entry casing annulus, to fill the cavern more expeditiously. There has been no recent withdrawal of oil or other fluids required from Cavern 6. An additional entry would increase injection and withdrawal capabilities, but as with any drilling in proximity to the Caverns, presents risk.

As discussed previously in the Pressure and Geomechanics section, it is believed that Cavern 6 would need to begin backfilling operations first until the depth of the fill pile reaches the same true vertical depth within Cavern 7. At that time, then both Cavern 6 and 7 could be filled simultaneously. Periodic sonar surveys would need to be performed of both Caverns to verify backfill progress, calibrate fill volume assumptions/projections, and for monitoring of any anomalous or unwanted cavern geometry changes. Depending upon additional detailed geomechanics analysis and modeling, the cavern pressures would be monitored and maintained as needed to produce/maintain favorable stress states in the surrounding rock.

The cavern pressures would likely only be measured via surface pressures. There is currently a downhole pressure/temperature gauge in Cavern 7, and it is planned to install a micro seismic monitoring array and downhole pressure gauge in Cavern 6. If slurry injection via the hanging string of Cavern 7 were to be performed, then it is likely that the downhole gauge would need to be removed due to concerns with material erosion. If any flow of fluids in/out of Cavern 6 were to be required then the downhole tools would need to be removed due to concerns with material erosion, wellbore access limitations, and "noise" interference the fluid movement operations would cause with the monitoring.

Timeline Estimate

Cavern Fill

The time required to fill the cavern is dependent on injection rates and solids concentration within the slurry. Figures 5 and 6 present the duration in years estimated to fill Cavern 6 and 7 with various injection rates and various fill concentrations within the fill/brine slurry. Figure 7 presents the total duration in years of filling Cavern 6 and 7. Figure 7 duration estimate assumes the following:

- Cavern 6 will be filled first up to a specific depth (as discussed previously) at a rate of 300 GPM which was generally determined to be appropriate for the wellbore configuration and maintenance of a constant cavern pressure.
- The fill concentration within the slurry is 20%.
- The total slurry manufacturing/injection rate is limited to 500 GPM.

The fill concentrations evaluated within Figures 5, 6, 8, and 9 were 10%, 15%, 20%, 25% and 30%. At this time, it is unclear what fill concentration would be possible as that value is driven by, in part, the location and design specifications of a new fill handling, mixing, and injection facility and associated pipelines. All duration estimates assume 100% fallout of the solids within the Caverns, and that there is no loss of the solids due to leaks or due to return of fill within a withdrawal brine stream from the Caverns (if required). It is possible that in the later stages of cavern backfill operations suspended fill material could be returned with the brine as the top of the fill pile grows closer to the brine withdrawal casing. This would reduce overall process efficiency and possibly require additional handling or pumping equipment for the facility, or could limit the maximum filled volume of the Caverns (i.e. increasing the unfilled volume).

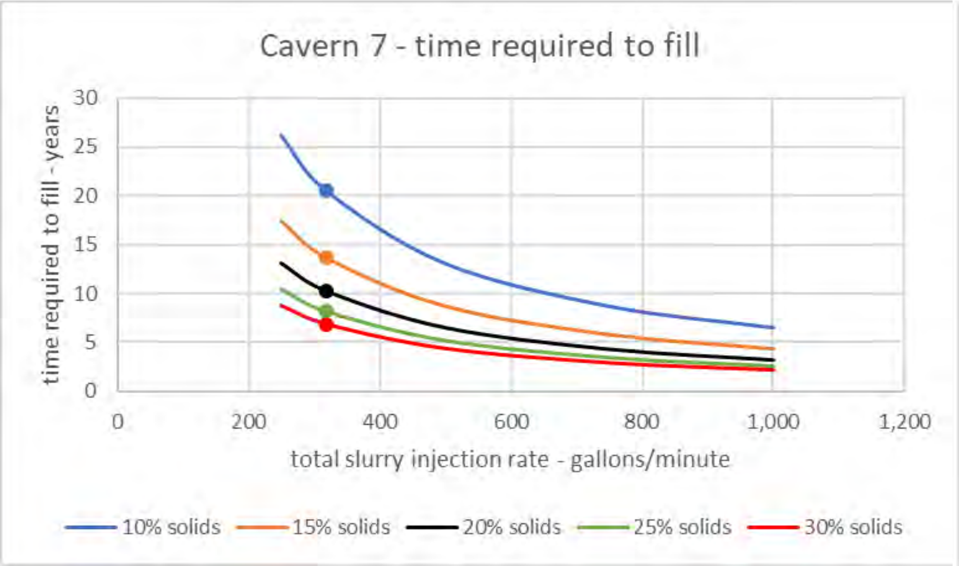

Figure 5 – Time to Fill Cavern 7 vs. Slurry Injection Rate for Various % Solids (320 GPM indicated)

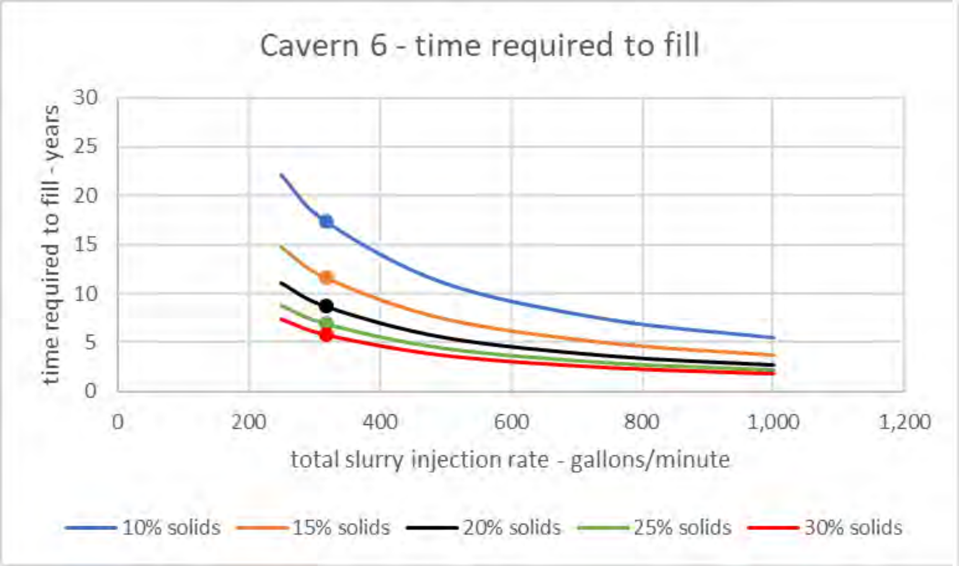

Figure 6 – Time to Fill Cavern 6 vs. Slurry Injection Rate for Various % Solids (320 GPM indicated)

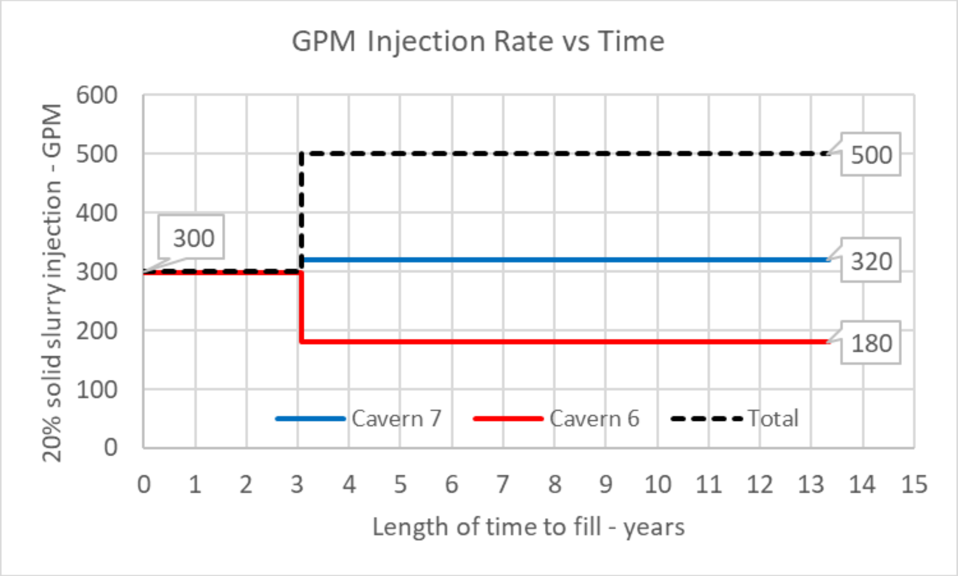

Figure 7 – Cumulative Time to Fill Caverns 6 and 7 Under Conditional Assumptions Stated Previously

Fill Material Transport

The source of the fill material and method of transport is currently not clearly understood. However, due to the total volume and rate at which the fill will be needed it has been assumed herein that the most appropriate transport method is via truck and/or rail to the fill material handling facility. Figures 8 and 9 respectively present the truckloads or railcars of fill material required to support GPM slurry injection rates for percent solids by volume of 10%, 15%, 20%, 25% and 30%.

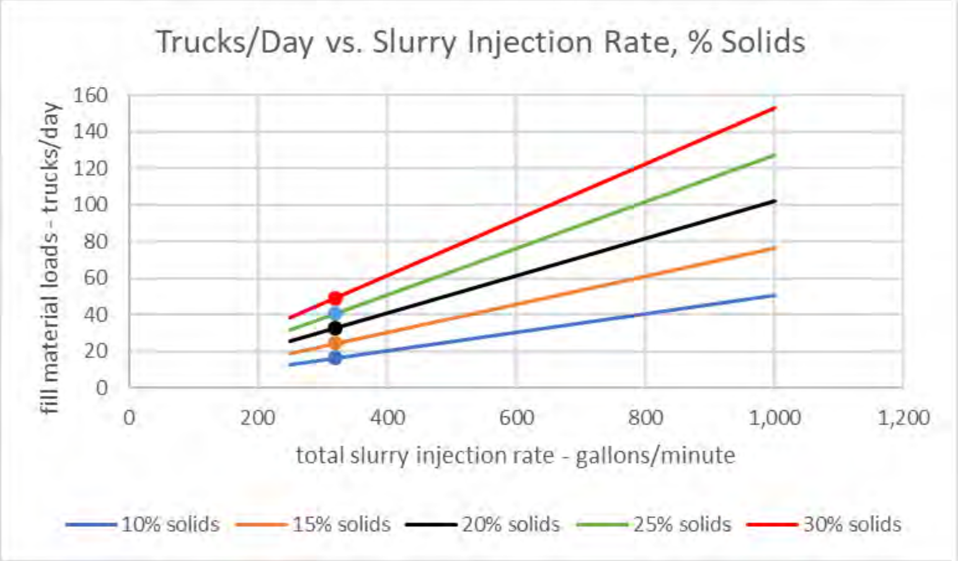

Figure 8 – Daily Trucks vs. Slurry Injection Rate for Various % Solids (320 GPM indicated)

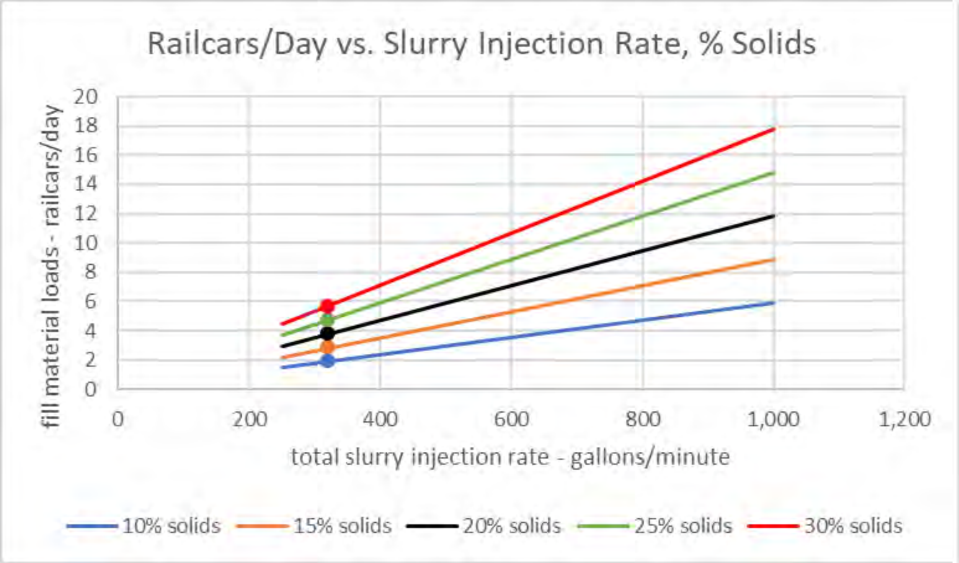

Figure 9 – Daily Railcars vs. Slurry Injection Rate for Various % Solids (320 GPM indicated)

Facility Construction

Relative to cavern fill time, facility construction time required is shorter. Timeline development for facility construction, permitting, and other associated studies cannot be estimated until a firm basis of design is developed and a more comprehensive facility engineering design study is completed.

Risks, Advantages, and Disadvantages

The information and analysis presented within this feasibility study is conceptual in nature, however, the evaluation has identified various risks and disadvantages with the Order suggested idea of backfilling for "cavern stability". These risks and disadvantages may outweigh the perceived advantages of backfilling the Caverns, and which may not be an exhaustive list. Careful consideration should be made regarding risk, and which may require further detailed and comprehensive studies to support a risk assessment. The risks and disadvantages listed herein were based upon the possibility of deviating from the ongoing efforts to maintain constant cavern pressures and by association geomechanics stress states.

Advantages

A perceived advantage of backfilling the Caverns is that if a collapse of the cavern structure were to occur, then it may reduce the severity and extent of sub-surface rock collapse/movement and perhaps reduce the severity and extent of a surface expression (sinkhole) if the sub-surface collapse leads to that. There are some risks and disadvantages presented herein that suggest backfilling of the Caverns may not meaningfully reduce the severity and extent of a sub-surface rock collapse due to the Caverns having notable unfilled volumes and the unknown compaction characteristics of the cavern fill material. Adjacent mineral owners, usable sources of drinking water, surface owners, and the environment could still be impacted in similar ways regardless of the Caverns being backfilled.

Risks and Disadvantages

The "base of the cavern(s)" is currently filled with material, and therefore the most recent sonar survey of the cavern(s) only illustrates the "line of sight" geometry and associated volume. This currently filled volume was previously termed as "unobservable volume". The material in the bottom of the cavern(s) could be insoluble content from the gross salt stock which commonly accumulates in the base of a cavern as it is solution mined; and could also be related to the accumulation of salt rubble from salt falls which have been observed to occur and/or could have occurred throughout the cavern history. This existing material in the base of the cavern(s) would have porosity, bulking, and compaction characteristics which are not known at this time. This existing material could compact when additional vertical pressure is applied to it by way of introducing a significant amount of backfill material. Therefore, the total required volume of backfill material is unclear, the pressure that could be exerted at the salt wall base of the cavern(s) is unclear, and the ultimate volume of collapse material (if it were to occur) that could migrate into the cavern(s) is unclear. It is also unclear if the fill within the "unobservable volume" would have the same compaction ratio for both Caverns.

The fill material will develop its own porosity and permeability characteristics and will most likely not stop the leak from Cavern 7 outright. The rate of brine loss may be reduced but likely will not stop. The fill material may lead to differing rates of brine loss from Cavern 6 and 7 as compared to currently, which may require brine injection operations on both caverns rather than only Cavern 7 (as is currently the case). The specific location of the brine egress from Cavern 7 is not currently known. If this brine egress point exists within an "unfilled" area of Cavern 7, then an under-pressured dynamic may develop within the "unfilled" area. The brine may tend to depart Cavern 7 more readily from the "unfilled" area without being efficiently replaced. This could be due to the permeability of the fill material not allowing enough brine volume flow into the "unfilled" area.

The actual long-term pressure conditions may be dynamic and are difficult to predict prior to backfilling the Caverns.[3]

The potentially unique pressure conditions resulting from backfilling Caverns 6 and 7 have not been thoroughly evaluated or modeled, nor have they been modeled for other caverns where backfill or disposal operations have been conducted. It is important to note that these other known cavern "filling" operations differ from the operating conditions and geologic setting of Caverns 6 and 7.

Proximity of a cavern to the dome flank may impact the stress state surrounding the cavern, potentially increasing the risk of hydraulic fracturing with increased cavern pressure. The complex stress distribution along the flank of the dome and the potentially complex lithology and rock properties within a possible dome edge anomalous zone may significantly impact the risks associated with backfilling a cavern. In general, the various unknown specifics regarding the stress conditions, material properties, backfill material, and resulting cavern pressures during and after backfill emplacement may impact the risks of the operation. The actual in situ stress conditions near Cavern 7 may differ from lithostatic and

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[3] Heiberger, Kevin, "Geomechanical Considerations for the Hypothetical Backfilling of Westlake PPG 7 at the Sulphur Mines Salt Dome (Revision 2)", December 22, 2023.

isotropic because of the proximity to the salt dome flank. Therefore, acceptable pressure limits for Cavern 7 may differ from what is typically used for salt caverns in a domal salt formation.[4]

Completing the backfill of the Caverns will significantly limit access to the Caverns for sonar surveys and downhole pressure monitoring. In consideration of some previous points, brine leakage from Cavern 7 (and by association Cavern 6) would likely continue even with backfill material in place, therefore the Caverns may still require brine injection pressure maintenance operations to maintain “cavern stability”.

If backfilling operations were conducted on Cavern 6 then the microseismic geophone array planned for installation in 2024 would need to be removed. If backfilling operations were conducted on Cavern 7 then the existing downhole pressure/temperature gauge will need to be removed.

Conclusion

The feasibility of backfilling Caverns 6 and 7 at the Sulphur Mines Dome is logistically challenging and technically uncertain to achieve the conclusion of “cavern stability” as suggested in the DNR Order. The operation of backfilling also introduces additional risk factors that could potentially increase instability to the multi-cavern system. The process of backfilling for “cavern stability” is not well understood within the solution-mined salt cavern industry, and there are no completed or ongoing projects to reference that are equivalent to the scope and conditions that Cavern 6 and 7 pose.

The pressure and geomechanics influences were evaluated at a high level for this study. It is evident that the influence the fill material will have on the pressure conditions of the caverns is not equivalent to that of the current fluid pressure maintenance operations. The analysis conducted indicates that the fill material will introduce lateral pressure loads in addition to the brine hydrostatic pressure on the cavern walls. The cavern geometry and angle of repose of the fill pile produce unfilled areas. Consequently, the pressure regime on the cavern walls is complex and deviates from the current pressure regime within Cavern 6 & 7.

Technically, it is uncertain whether backfilling the caverns would result in the suggested objective of “cavern stability”. The evaluation completed herein suggests that meaningful new risks would be realized if Caverns 6 and 7 were to be backfilled. Additionally, the risk and severity of a sub-surface rock collapse and possible surface expression cannot be fully mitigated. In the event of a salt collapse, the “unfilled” cavern volume may be filled with external sub-surface material of a volume significant enough to lead to progressive failure of the stratified formations adjacent to the salt dome. Even with the caverns “filled” with material, a collapse and movement of sub-surface rock could still impact other mineral owners, usable source of drinking water formations, surface owners, and the environment. Additionally, completing the backfill of the Caverns will likely not stop the brine leak from Cavern 7.

Caverns 6 and 7 are currently in hydraulic communication. A conservative approach is to backfill bother caverns simultaneously to mitigate certain risks. The time necessary to backfill both caverns is estimated at approximately 13.5 years after a new fill material processing facility is constructed. This is an ideal

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[4] Heiberger, Kevin, “Geomechanical Considerations for the Hypothetical Backfilling of Westlake PPG 7 at the Sulphur Mines Salt Dome (Revision 2)”, December 22, 2023.

case that assumes no compaction of fill material or impact from other variables. The logistics and feasibility of securing a long-term fill source and constructing an off-site facility to manufacture the slurry would be a significant undertaking.

At this time, Westlake views that backfilling Caverns 6 and 7 would introduce meaningful risk to the situation, that does not outweigh the perceived advantage. If there are any questions, please contact Josh Bradley (Westlake US 2, LLC), Coleman Hale (Lonquist Field Service, LLC), Ben Bergman P.E. (Lonquist Field Service, LLC) and Troy Charpentier (Kean Miller LLP).

Sincerely,

Coleman Hale

R. Coleman Hale
Vice President
Lonquist Field Service, LLC

BEN H. BERGMAN
License No. 40184
12/27/2023

Certified By:
Lonquist Field Service, LLC
Louisiana Registration No. EF-5853

Ben H. Bergman 12/27/2023 P.E.

Ben H. Bergman, P.E.
Senior Engineer
Louisiana License No. 40184

Date Signed: December 27th, 2023
Houston, Texas

Attachment List

A. RESPEC - Geomechanical Considerations for the Hypothetical Backfilling of Westlake PPG 7 at the Sulphur Mines Salt Dome (Revision 2) (12/22/2023)

ATTACHMENT A

RESPEC Geomechanical Considerations to Backfilling

CONFIDENTIAL MEMORANDUM

To: Coleman Hale
Vice President/Sr. Petroleum Engineer
Lonquist & Co. LLC
1415 Louisiana St., Suite 3800
Houston, TX 77002

cc: Project Central File M0170.23007

From: Kevin J. Heiberger Kevin Heiberger
Manager, Cavern Geomechanics

Joel Nieland Joel D Nieland
Louisiana License No. 0041550
Staff Consultant

RESPEC
3824 Jet Drive
Rapid City, SD 57703

JOEL D. NIELAND
License No. 0041550

Date: December 22, 2023

Subject: Geomechanical Considerations for the Hypothetical Backfilling of Westlake PPG 7 at the Sulphur Mines Salt Dome (Revision 2)

BACKGROUND

The fluid pressure in a solution-mined cavern helps support the geologic loads that act on the rock surrounding and overlying the cavern. As the cavern pressure decreases, the loads that must be supported by the surrounding rock increase. If the loads exceed the rock strength, the rock will fail and lose strength. Unlike brittle rock types that fail suddenly, rock salt around a solution-mined cavern will typically begin to fail through microfracturing along the grain boundaries, a process referred to as dilation (or damage). If dilatant states of stress are maintained, the microfractures will increase and coalesce, which, in turn, reduces the strength of the salt. Salt damage is a progressive process that can lead to the salt spalling from the roof and walls of the cavern and may lead to salt-web failure or roof collapse.

The cavern and salt-web stability between adjacent caverns and between the caverns and the edge-of-salt (i.e., dome flank) is a function of web thickness, web height, and cavern fluid pressures. If the web thickness is small and the cavern pressure is too low, the shear stresses in the salt surrounding the caverns can exceed the strength of the salt. It is desirable to design and operate salt caverns in a manner that precludes the onset of salt dilation to maintain cavern stability.

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Shear stresses are always present in the salt surrounding solution-mined caverns that are fluid-filled and unplugged because the internal fluid pressure is always less than the in situ stress in the surrounding salt stock. The in situ stress state in the salt is typically assumed to be isotropic (i.e., equal in three orthogonal directions with no shear stress) and approximately lithostatic (i.e., equal to the weight of the overlying rock strata). The assumption of salt's isotropic in situ stress state is generally accepted because laboratory testing suggests salt creep behavior will reduce (eliminate) shear stresses over geologic time scales.

In general, the in situ stress in the salt at a particular depth can be approximated by integrating the density of the overlying rock strata through depth. The fluid pressure in a cavern can generally be approximated by integrating the fluid density through depth to obtain the hydrostatic pressure of the fluid in the cavern, implying an assumption of a quiescent state for the fluid in the cavern and well.

Lower cavern pressure will increase shear stresses in the salt and potentially cause dilation, and higher cavern pressures have the potential to exceed the in situ salt stress and produce tensile stresses in the salt. Rock salt has considerable strength under compressive loading conditions yet is relatively weak in tensile loading scenarios, similar to most rock types. Therefore, it is desirable to design and operate salt caverns in a manner that precludes tensile stresses that can potentially lead to hydraulic fracturing.

Consequently, cavern pressures are limited to an upper bound that is typically about 80 to 90 percent of the approximate lithostatic in situ stress in the salt, assuming a lithostatic pressure gradient of 1.0 pound per square inch per foot (psi/ft) of depth, or an average overburden density of 144 pounds per cubic foot (lb/ft^3). This high-pressure limitation is typically defined in terms of a pressure gradient, such as 0.80 psi/ft of depth at the casing shoe depth. In practical terms, a pressure gradient limit of 0.80 psi/ft provides a factor of safety against exceeding the in situ lithostatic stress and causing a hydraulic fracture. The actual in situ stress conditions near the PPG 7 cavern may differ from lithostatic and isotropic because of the proximity to the salt dome flank (see below discussion). Therefore, acceptable pressure limits for PPG 7 may differ from what is typically used for salt caverns in a domal salt formation.

ELEVATED CAVERN PRESSURE FROM BACKFILL MATERIAL

Caverns with thin salt webs or that are at risk of experiencing extensive salt dilation and spalling can benefit from increased internal cavern pressure to reduce the shear stresses in the salt and the likelihood of salt dilation and spalling. Backfilling a cavern with solids is one potential risk mitigation strategy for increasing the internal cavern pressure through the backfilled depth interval because the solids material will have a higher density (i.e., higher pressure gradient) than the saturated brine in the cavern. Salt caverns have been used extensively for solids waste disposal for many years, such as in Canada for the oil sands production operations. Solids backfill has also been used as an attempted remediation measure to improve cavern stability, such as the recent case of the I&W Brine Cavity in Carlsbad, New Mexico[1]. The cavern operating conditions and geologic setting for these scenarios may differ from those of the Westlake caverns at the Sulphur Mines salt dome.

The increased cavern pressure resulting from solids backfill material will provide some additional support to the surrounding rock strata, potentially reducing the likelihood of salt dilation and spalling from the walls. In the event of ultimate web or roof collapse, the denser backfill material in the cavern

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[1] **Rucker M. and J. Lommler, 2023.** "Observations and Experience Learned from Remediation to Prevent Collapse of I&W Brine Cavity in Carlsbad, New Mexico," SMRI Fall 2023 Technical Conference, San Antonio, TX, October 2–3.

will likely be compacted by the rock material falling into the cavern, and will occupy a substantial volume of the cavern, which may reduce the extent of catastrophic failure or the progression of the failure away from the cavern. This may result in a lesser impact on surrounding wells and caverns, and lesser subsidence effects at the ground surface.

The specific backfill material and emplacement procedure is presently undefined, but certain generalities can be assumed to discuss geomechanical considerations. Assuming a brine-sand slurry is used to inject backfill material, it is useful to consider two state phases of the slurry from a density or pressure effects perspective. During injection, the slurry would be considered a mixture of sand and saturated brine with a consistent density, similar to a drilling mud or cement mixture. After the slurry has been distributed throughout the cavern and the fluid velocity decreases, the sand particles will ideally settle out of the mixture and begin to fill the cavern volume. If (or when) the solids settle out of the slurry, the resulting pressure conditions would be a combination of the hydrostatic pressure of the saturated brine and the effective weight of the solids suspended in the brine. Assuming some consolidation of the sand occurs, the sand will remain permeable and the hydrostatic pressure of the brine would be assumed present throughout the sand-filled volume. In this latter state of the backfill emplacement, the pressure exerted by the effective weight of the sand would differ in the vertical and horizontal directions, with the horizontal (lateral) pressure being less than the vertical pressure, assuming at rest conditions (i.e., prior to salt creep closure). The pressure contribution from the sand material would be additive to the hydrostatic pressure of the saturated brine.

Figure 1 illustrates hypothetical cavern pressures assuming brine and saturated, consolidated sand completely fills the cavern with minimal wellhead pressure, and a bulk density of approximately 130 $\mathrm{lbf/ft^3}$ for the backfill. The lateral pressure component would be the primary force acting against the cavern walls where backfill material fills the void space. The estimated backfill lateral pressure acting on the cavern walls is the summation of the hydrostatic brine pressure and the effective backfill lateral pressure. The approximate in situ stress through the middle of the salt dome with the top-of-salt at approximately 1,450 ft, and the limiting pressure gradient of 0.80 psi/ft are also illustrated in Figure 1 compared to the hypothetical pressure inside the cavern. The pressure profiles presented in Figure 1 assume static conditions in the well and cavern after a sufficient quiescent period to allow the sand to settle out of the slurry mixture and consolidate. Figure 1 illustrates that the hypothetical increased backpressure from the backfill is significantly below the limiting pressure gradient to avoid hydraulic fracturing of the salt, given the assumed in situ stress condition. If the in situ stress state near the cavern is not lithostatic and isotropic as assumed here (see below discussion), the risk of inducing a hydraulic fracture may be increased. The dynamic pressure conditions during emplacement of the backfill material would likely be greater than the static conditions illustrated here and should be considered with respect to exceeding the limiting pressure gradient.

BACKFILL EMPLACEMENT

The higher density of the backfill material can provide an elevated back-pressure (compared to saturated brine) where the material is able to fill against the walls of the cavern. Assuming the backfill material is able to arrest, or significantly impede the flow of brine out of the cavern, greater brine back-pressure could be achieved and maintained above the fill material where the backfill does not directly contact the cavern walls. The ability of the backfill material to fill the void space in the cavern is limited by the ability of the material to be distributed across the cavern diameter from the injection string located in the central part of the cavern. The distribution of the backfill material will be influenced, in part, by the grain size of the material used, concentration of the solids in the fluid, injection/circulation flow rate, cavern geometry and diameter, and the ability of the solids to settle out of the slurry during injection (circulation), and potentially outflowing from the cavern through the current leak path. Different backfill materials and different concentrations of the slurry being injected will behave differently during emplacement and achieve different levels of distribution and settlement throughout the cavern. Ideally, the grain size and concentration of the solids material is small enough to allow migration of the solids away from the center of the cavern while suspended in solution, but large enough to allow the solids to settle out of solution at lower fluid velocities to allow build-up of the material and avoid continual circulation. Similar behavior of solids backfill has been observed in waste disposal caverns (typically smaller diameter caverns than PPG 7) for oil sands production operations as evidenced by sonar surveys that indicate relatively even material distribution throughout the cavern and gradual floor depth rise over time. The type of material injected into waste disposal caverns can affect the distribution and resulting floor characteristics. Furthermore, the waste material may differ significantly from the material available for backfilling the Westlake cavern. Hypothetically, different slurry concentrations could be injected at different times to achieve optimal distribution and fill of the void space throughout the cavern—i.e., coarser material is used to fill large volumes more quickly, while finer material is used to fill more evenly across the span of the diameter and below flat surfaces/features of the cavern geometry. The availability of material and operational logistics are beyond the scope of this memo and the efficacy of backfill emplacement may be significantly constrained by numerous other factors.

Where solids backfill is unable to distribute to the cavern wall or overhanging sections, the remaining void space will be filled with saturated brine. The presence of two materials of different pressure gradients will result in a slope change in the pressure profile along the cavern wall, and the pressure difference will gradually increase away from the interface of the two materials. This loading condition is potentially unique for a back-filled cavern, but it is not considered to be significantly dissimilar from typical cavern conditions for brine-compensated liquid storage or gas storage caverns, based on current estimates of the potential pressure conditions. A similar type of pressure gradient transition is generally present in the sump of all caverns where there is typically tens (sometimes hundreds) of feet of insolubles or salt that has spalled from the cavern walls. The potentially unique pressure conditions resulting from backfilling a cavern have not been thoroughly evaluated or modeled for typical salt cavern geomechanical studies. The difference in pressure applied to the cavern walls between the saturated brine and backfill material is expected to be relatively minimal considering the hydrostatic pressure of the brine is assumed to be present throughout the sand-filled volume and is not a significant concern from a geomechanical perspective based on estimated backfill characteristics to-date.

LONG-TERM CAVERN PRESSURE

The amount of consolidation and compaction of solids backfill material emplaced in a brine-filled cavern is difficult to predict and even more challenging to predict if there is a leak path for the brine or slurry to drain from the cavern, resulting in continual flow of the brine and/or slurry. The continual flow of brine and/or slurry through the cavern is a complex hydrodynamic fluid and particle flow system that involves many interrelated and complex phenomena. Assuming the solids backfill material does settle out of the slurry and consolidate in the bottom of the cavern, it is expected that the sand-filled volume will always maintain some level of permeability, which will allow brine to continue to gradually flow out of the cavern over time. While brine may continue to flow from the cavern, the lower permeability of the backfill material (compared to the permeability of the current leak path) may reduce the flow rate of the brine, acting as a restrictor in the overall flow system. A reduction of the flow rate of brine out of the cavern may provide conditions within the cavern that allow more of the solids to consolidate and nominal back-pressure to build in the unfilled portions of the cavern that remain brine-filled. Assuming brine flows out of the cavern faster than it is able to flow through the sand-filled cavern, there is potential for isolated areas of the cavern to experience lower hydrostatic pressure. The actual long-term pressure conditions may be dynamic and are difficult to predict prior to back-filling the cavern. Completing the back-fill in stages and regular pressure data acquisition and sonar surveys may provide data to help refine engineering calculations and estimates for long-term conditions.

Assuming the brine continues to flow out of the cavern through the backfill material over a long period of time, the hydrostatic pressure of the brine within the cavern may eventually equilibrate with the formation pressure outside of the dome that is connected to the cavern. Current analyses and investigation by Lonquist estimate that the exterior formation pressure is approximately 0.469 psi/ft at the floor depth in PPG 7 at approximately 3,165 ft, or approximately 1,484 psi. Figure 2 illustrates hypothetical cavern pressures assuming the hydrostatic pressure equilibrating with an external formation pressure gradient of 0.469 psi/ft at the floor depth. The estimated backfill lateral pressure acting on the cavern walls is the summation of the hydrostatic brine pressure and the effective backfill lateral pressure. The hypothetical backfill scenario illustrated in Figure 2 results in a pressure gradient of approximately 0.46 psi/ft at the casing shoe depth in PPG 7. The estimated brine level in the well is approximately 310 ft below ground surface.

PRESSURE DIFFERENTIAL BETWEEN CAVERNS

The elevated cavern pressure gradient resulting from backfill emplaced in PPG 7 could potentially create a pressure differential with the adjacent brine-filled cavern, PPG 6. Assuming PPG 6 is brine-filled with no wellhead back-pressure applied to the brine-side of the well, the hydrostatic pressure at the approximate minimum web depth of 3,067 ft is about 1,595 psi and the estimated lateral pressure in PPG 7 for the hypothetical sand-filled scenario illustrated in Figure 1 is approximately 1,718 psi. This is an approximate 123 psi pressure differential between the caverns at this depth. Recent operations data suggests there has been roughly 100 psi pressure differential between the two caverns without evidence of significant web instability between the caverns to-date. Therefore, a nominal pressure differential between the caverns is not expected to create a significant increased risk of web instability. Ideally, the pressures in both caverns are maintained at nominally equivalent conditions to reduce the risk of web instability. The pressure balance may potentially be attainable by applying back-pressure to the brine-side of the PPG 6 well, assuming the backfill in PPG 7 achieves a manageable level of impediment for the brine outflow from the PPG 6 cavern.

IN SITU STRESS NEAR SALT DOMES

It is generally accepted that the in situ stress within a salt dome is isotropic; however, the in situ stress distribution in the surrounding sediments is anisotropic (i.e., the horizontal stresses are not equal to the vertical stress). The far-field stress conditions in a sedimentary basin are often assumed to be under gravitational loading (i.e., no lateral strain occurs during the formation of the overlying strata). A negligible difference is generally considered between the minimum and maximum far-field horizontal stresses[2]. Typically, the far-field horizontal stresses are a fraction of the vertical stresses; for example, a far-field horizontal-to-vertical stress ratio between 0.6 and 0.7 is often assumed to describe the stresses in the far-field sediments surrounding a salt dome in the Gulf Coast.

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[2] **Fredrich, J. T., D. Coblentz, A. F. Fossum, and B. J. Thorne, 2003.** "Stress Perturbations Adjacent to Salt Bodies in the Deepwater Gulf of Mexico," SPE-84554-MS, *Society of Petroleum Engineers Annual Technical Conference and Exhibition,* Denver, CO, October 5–8.

The density of the sediments around the dome increases with depth, whereas the density of the salt remains constant at approximately 135 lb/ft^3. This difference in density gradients results in disparate forces between the salt stock and the surrounding sediments. The sediments around the dome become more dense than the salt below a particular depth, and buoyancy forces would likely cause the salt to rise. The stress distribution between the undisturbed far-field sediments and the salt-dome boundary is complex and depends on the mode of emplacement and formation. A diapiric structure that has pierced the overlying sediments imprints the region around the dome with compressive radial and low tangential stresses[3]. Stresses outside the salt dome can become perturbed for radial distances that are several times the dome diameter in all directions[3]. Figure 3 illustrates the hypothetical anisotropic stress state in the sediments adjacent to a salt dome.

The geologic complexity of salt diapirs and the phenomena associated with their formation can make the accurate determination of the dome boundary very difficult to define with high confidence. Furthermore, the techniques typically employed to define the boundary of a salt diapir are not generally well suited for determining the extent of "good quality salt" for the construction and operation of storage caverns[4]. The exterior salt contact of a diapir may be considered to be a shear or fault zone that may include a zone where the salt and country rock have been intermixed. This region near the dome flank is often referred to as an edge anomalous zone and can be expected to occur along the periphery of salt diapirs in the Gulf Coast[4]. The presence of impurities or nonsalt inclusions in the edge anomalous zone can potentially degrade the creep behavior and strength of the salt near the dome flank. The rock within an edge anomalous zone could potentially exhibit higher shear stresses and be weaker (i.e., lower salt dilation strength) than the salt stock further away from the dome flank. The complex stress distribution in the sediments next to a salt dome may impact the stresses immediately inside the salt dome along the dome flank. Additionally, the potential heterogeneity of the salt along the dome flank may affect the creep behavior such that the stress state could be anisotropic within the edge anomalous zone.

SUMMARY

Backfilling a salt cavern with solids material is one potential remediation approach to mitigate the risk of excessive salt dilation and spalling that may lead to roof falls or web collapse. The increased pressure within the backfilled interval inside the cavern will provide additional support to the surrounding rock compared to brine-filled conditions in the cavern. The solids-filled volume of the cavern is expected to impede the outflow of the brine from the cavern, potentially providing favorable conditions for managing the backpressure on the brine-side of the well. The higher density of the backfilled volume may also reduce the severity and extent of catastrophic failure of the salt web by generally reducing the void space available for rock to fall into the cavern. Ideally, the slurry design and injection control are successful in achieving maximum distribution and filling of the cavern void space with solids material; however, material type availability and logistical factors may significantly constrain the efficacy of the backfill to completely fill the void space in the cavern. Potential brine-filled areas of the cavern (i.e., not filled with solids) are not expected to present significant increased risk of salt dilation, but the potentially unique pressure conditions in a back-filled cavern have not been thoroughly evaluated or modeled in other caverns. The estimated pressure differential between sand-filled portions of the

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[3] **Dusseault, M. B., V. Maury, F. Sanfilippo, and F. J. Santarelli, 2004.** "Drilling Around Salt: Stresses, Risks, Uncertainties," ARMA-04-647, *Proceedings, 6th North America Rock Mechanics Symposium,* Houston, TX, June 5–9, American Rock Mechanics Association, Overland Park, KS.

[4] **Looff, K., J. Duffield, and K. Looff, 2003.** "Edge of Salt Definition for Salt Domes and Other Deformed Salt Structures – Geologic and Geophysical Considerations," *Solution Mining Research Institute Spring Meeting*, Houston, Texas, April 27–30.

cavern and brine-filled portions of the neighboring PPG 6 cavern are not expected to present significant risk for web instability. The pressure differential between the two caverns should be managed to maintain a nominal pressure difference to limit the risk of inducing web instability.

In general, the potential for exceeding the in situ stress in the salt with solids backfill, which may lead to hydraulic fracturing, is low if the stress state around the cavern is isotropic and lithostatic. Close proximity of a cavern to the dome flank may impact the stress state surrounding the cavern, potentially increasing the risk of hydraulic fracturing with increased cavern pressure. The complex stress distribution along the flank of the dome and the potentially complex lithology and rock properties within a possible dome edge anomalous zone may significantly impact the risks associated with backfilling a cavern. In general, the various unknown specifics regarding the stress conditions, material properties, backfill material and resulting cavern pressures during and after backfill emplacement may impact the risks discussed herein.

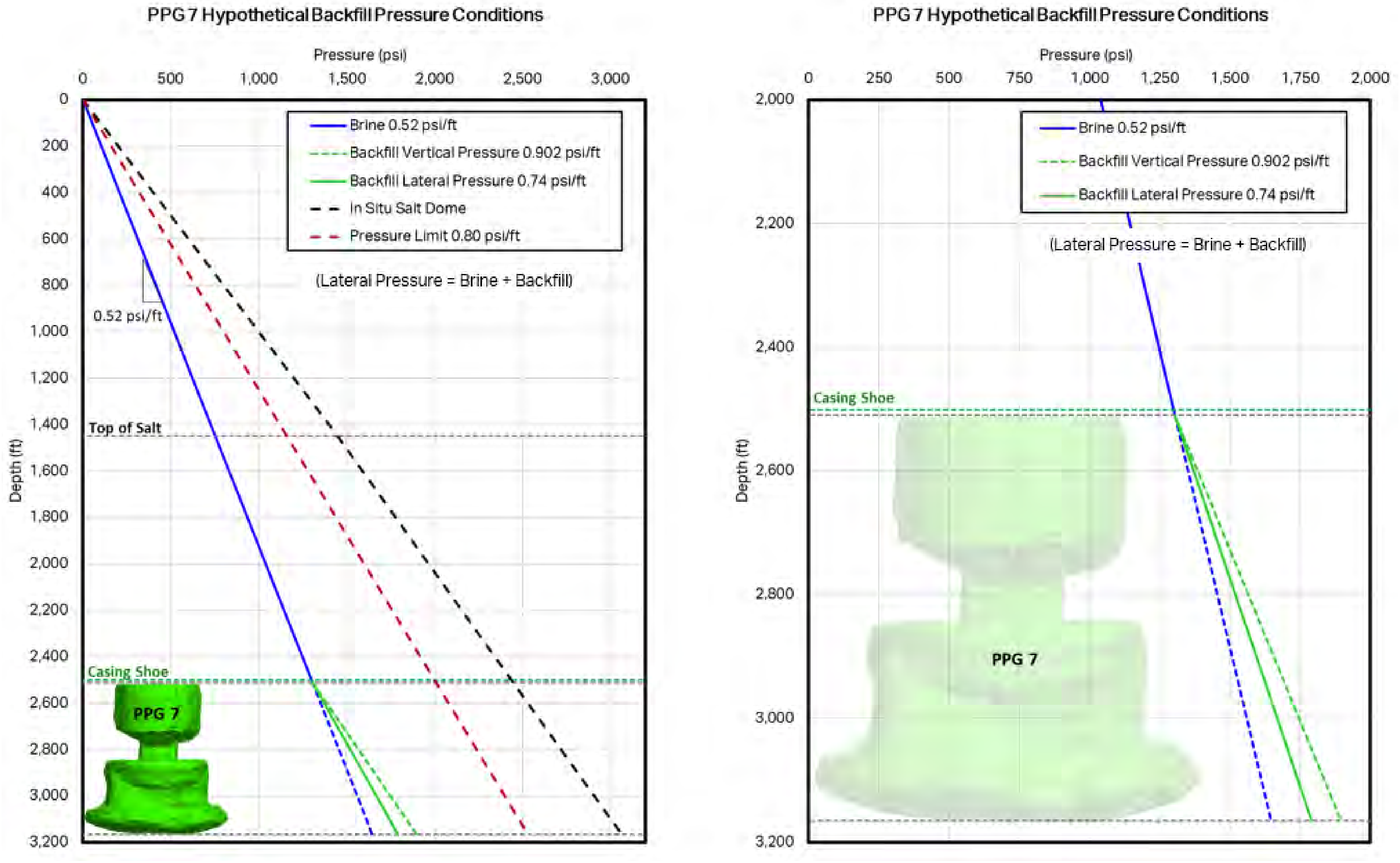


Figure 1. Hypothetical Cavern Pressures With Saturated Brine and Consolidated Sand Backfill.

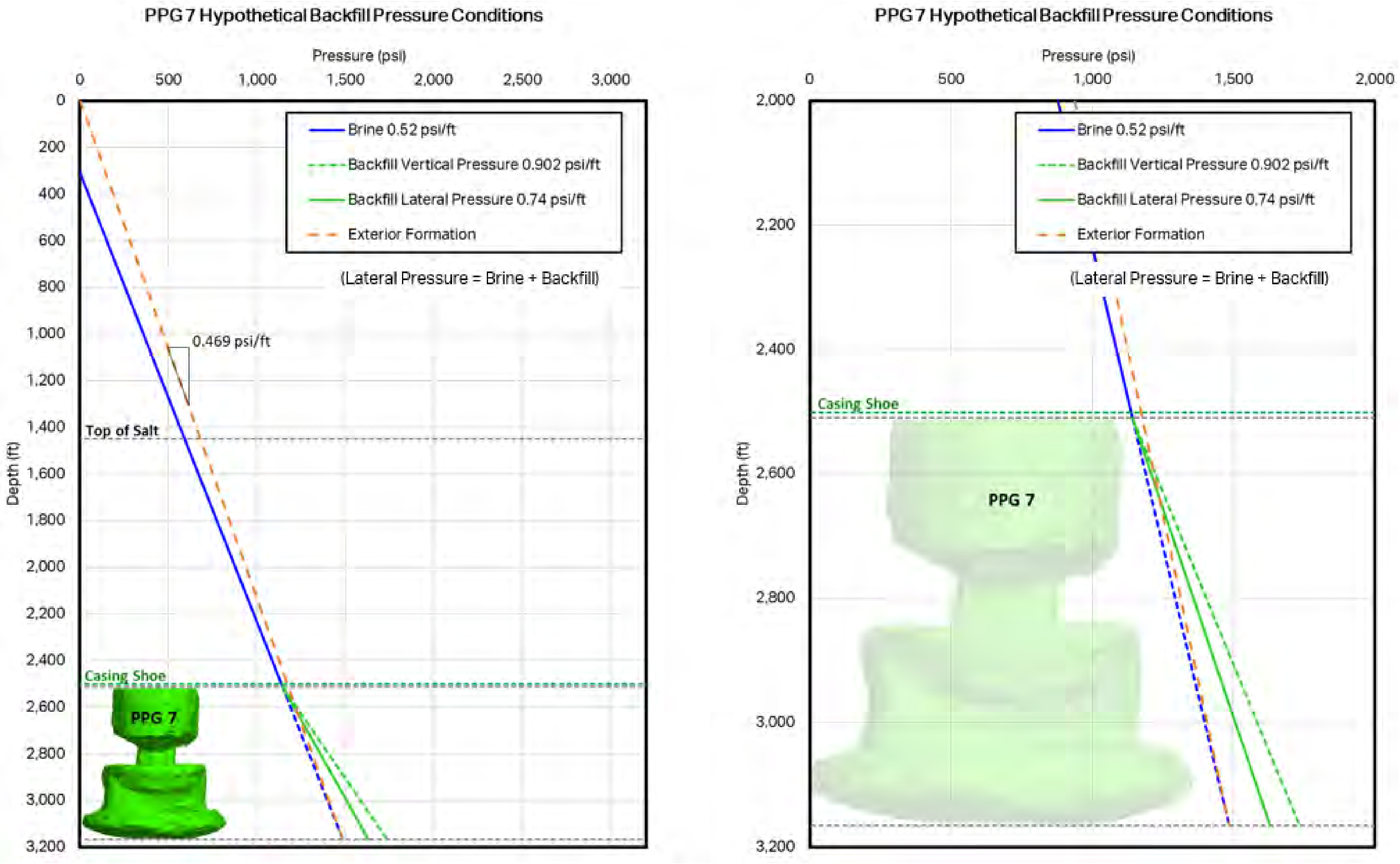


Figure 2. Hypothetical Cavern Pressures With Saturated Brine and Consolidated Sand Backfill After Equilibrating with an Exterior Formation Pressure at the Floor Depth of Cavern PPG 7.

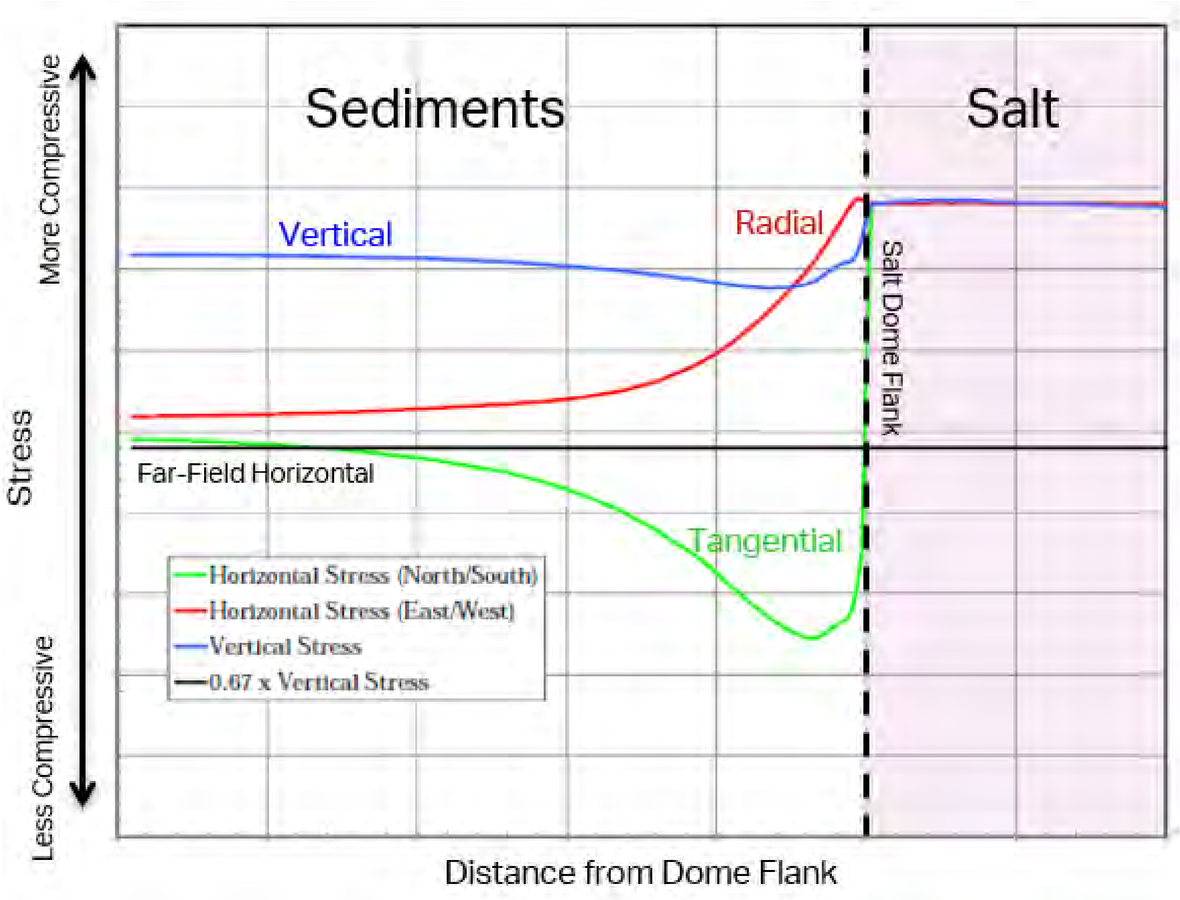


Figure 3. Illustration of the Hypothetical Anisotropic Stress State in the Sediments Adjacent to a Salt Dome in the Gulf Coast.

ATTACHMENT D

Proposed New InSAR Reflectors Map

Location of Planned Reflectors

Sulphur Mines Salt Dome

Westlake US 2, LLC

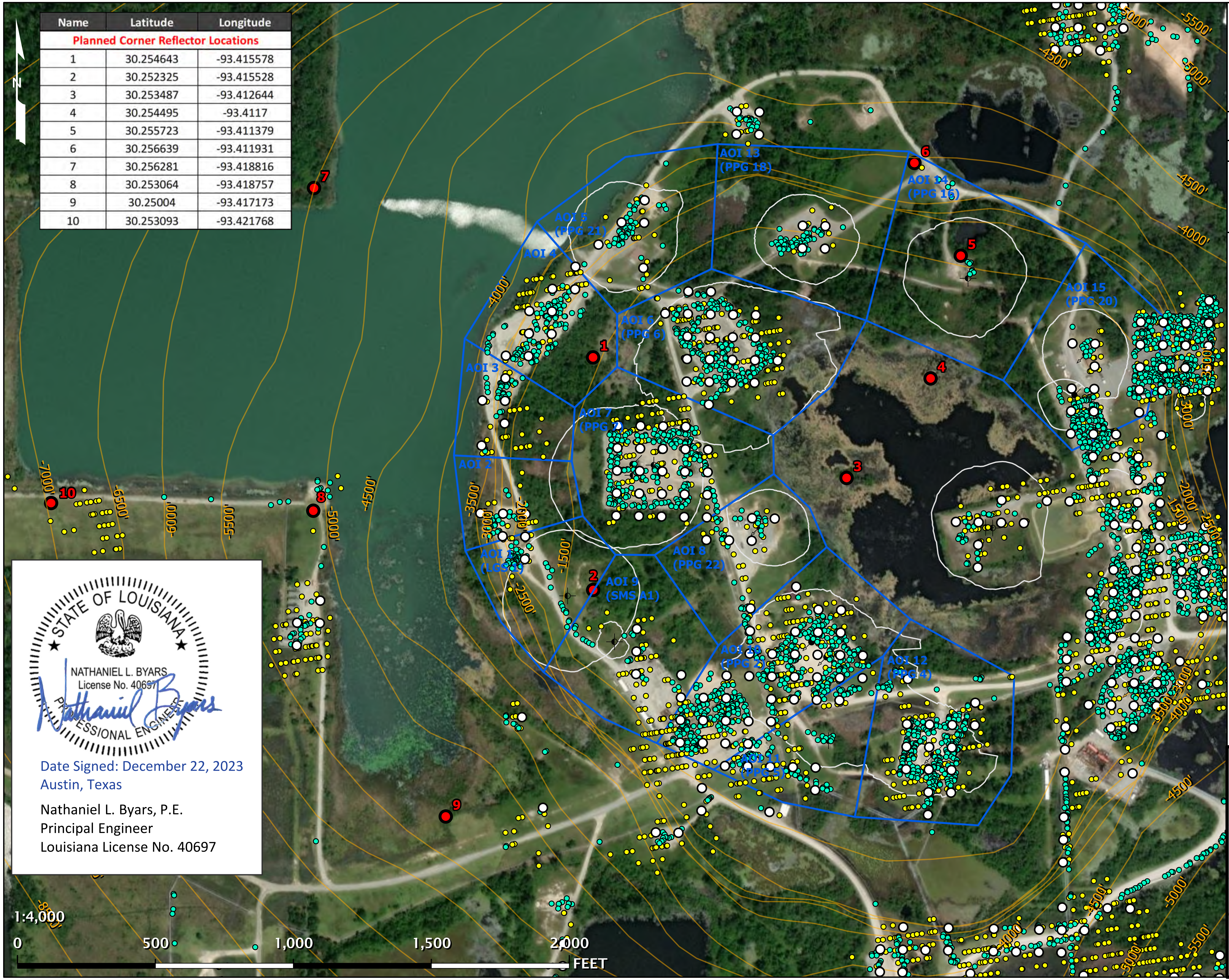
Calcasieu Parish, LA

Drawn by: Steven Larcom	Date: 12/22/2023	Approved by: Nathaniel Byars

PCS: NAD 1983 State Plane LA-S FIPS 1702 (US Ft.)

LONQUIST & CO. LLC

PETROLEUM ENGINEERS | ENERGY ADVISORS



Name	Latitude	Longitude
Planned Corner Reflector Locations		
1	30.254643	-93.415578
2	30.252325	-93.415528
3	30.253487	-93.412644
4	30.254495	-93.4117
5	30.255723	-93.411379
6	30.256639	-93.411931
7	30.256281	-93.418816
8	30.253064	-93.418757
9	30.25004	-93.417173
10	30.253093	-93.421768

NATHANIEL L. BYARS
License No. 40697

Nathaniel Byars

Date Signed: December 22, 2023
Austin, Texas

Nathaniel L. Byars, P.E.
Principal Engineer
Louisiana License No. 40697

●	Planned Corner Reflector Locations
○	2D (Vertical & East-West) InSAR Measurement Points
●	SNT Line-of-Sight InSAR Measurement Points
●	TSX/PAZ Line-of-Sight InSAR Measurement Points
☐	Historical Cavern Extents
☐	AOI Boundaries
—	Top of Salt Contours (CI = 500')

Cavern Wellhead Locations

↙	09 - ACTIVE INJECTION
⌖	29 - DRY AND PLUGGED
↙	30 - PLUGGED AND ABANDONED