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Stephen Lee, Director
Louisiana Department of Natural Resources
Office of Conservation - Injection & Mining Division
617 North Third Street, LaSalle Building
Baton Rouge, Louisiana 70802-5431

DATE
January 23, 2024

SUBJECT
Response to 3rd Supplement to Compliance Order No. IMD 2022-027, 6b

REFERENCE
0712237

Dear Mr. Lee:

On behalf of Westlake US 2 LLC, Environmental Resources Management, Southwest (ERM) is pleased to provide this plan in response to the LDNR's Third Supplement to Compliance Order No. IMD 2022-027, item 6b, which requires Westlake to:

> *"Submit to IMD a plan to protect and/or remediate the public freshwater supplied by the Chicot Aquifer in the event of the introduction of constituents of concern into the aquifer."*

ERM believes that there is no current risk to the public drinking water supply at this time. Per LDNR's request, this report summarizes potential impacts to the public freshwater supplied by the Chicot Aquifer, as well as a plan to address potential impacts.

1. OVERVIEW OF SITE AND GEOLOGY

Based on the geologic and geochemical information generated to date, there is no apparent risk to the Chicot aquifer sands from the loss of brine at Cavern 7. The top of the cavern is approximately 2,500 feet below ground surface (bgs), extending to a depth of 3,100 feet bgs. In the Lake Charles area, the Chicot Aquifer is comprised of 3 main sands – the "200-foot", "500-foot", and "700-foot" sands (Figure 1). The majority of water production, including public supply wells, are installed in the "500-foot" sand. At the Sulphur Dome, the base of the Chicot Aquifer has been encountered at approximately 700 feet bgs. There are no data currently available that indicates there is communication between the brine cavern or the cavern well and the Chicot Aquifer.

2. POTENTIAL IMPACT SCENARIOS

Three general scenarios were evaluated that could represent introduction of brine into the Chicot sands:

1. Potential Cavern failure,
2. Passive brine leakage, and
3. Active brine injection

2.1 POTENTIAL CAVERN FAILURE

During the summer of 2012, a brine cavern failed in the Napoleonville Oil and Gas field. The result of the cavern failure was a large sinkhole within the cypress tupelo swamps. Initially the sinkhole was measured at approximately 500 feet across (4.2-acre area), with a depth of approximately 440 feet. Over time, the sinkhole expanded, and shallowed as the sides sloughed into and filled the hole. Eventually the sinkhole stabilized being approximately 1,700 feet in diameter, encompassing approximately 55 acres, and a final depth of approximately 150 ft. The Napoleonville cavern was approximately twice as large as Cavern 7 at the Sulphur Dome (19.2 MMbbls vs 10 MMbbls).

Cavern failure at the Sulphur Dome would likely form a very similar, but smaller, sinkhole at the surface, where the adjacent subsurface material flows into the cavern and the liquids migrate to the surface. The fluids currently within the cavern include brine, crude oil, and natural gas. As seen at Napoleonville, the liquid hydrocarbons would likely come to the surface where they would be captured and removed. The gas would likely come to the surface and not remain trapped in the subsurface. Based on the observations made at the Napoleonville sinkhole, the brine will likely not migrate to the surface, but remain in the deeper formations, and mix with the surrounding waters in the adjacent formations. The Napoleonville sinkhole contains saltwater at the bottom and freshwater at the top. The saltwater at the bottom has freshened over time from about 70,000 mg/L chloride to approximately 11,000 mg/L chloride. Monitoring wells installed at approximately 150, 240, and 340-feet depths within the adjacent Mississippi River Alluvial Aquifer and within 500 - 1,500 feet of the sinkhole, never showed any indications of impact from brine over several years of monitoring. Minor hydrocarbons were reported, but nothing that would indicate impacts from crude oil.

If Cavern 7 were to fail, there is a possibility that brine would be introduced into the Chicot Aquifer. The impact would likely be low based on the fact that the brine would be moving upward at a relatively fast speed compared to the saturated sands of the Chicot with a slow horizontal flow regime. Some groundwater would likely be displaced by and/or mixed with the Chicot groundwater at the "neck" where fluids are flowing to the surface, but very little horizontal migration into the Chicot is likely to occur initially. The potential source of brine, or other constituents (i.e. hydrocarbons) that could migrate into the Chicot sands would be at the "neck" or within the sinkhole. Over time there is the possibility that water from the sinkhole could enter and mix with the groundwater in the Chicot sands and migrate downgradient.

Because the depth to water within the Chicot is approximately 55 feet below ground surface, equilibration with a surface water body would likely result in downward movement of the surface water into the Chicot aquifer. Under the worst-case scenario, approximately 10 MMbbls or brine could be released into the Chicot sands in the event of a cavern failure. Assuming all the brine enters the Chicot, with 400 feet of sand and 30% porosity, this would result in a maximum area approximately 10.7 acres that would have brine impacts. This would be a non-continuous source of brine potentially entering into and migrating through the Chicot.

2.2 PASSIVE BRINE LEAKAGE

Passive brine leakage represents situations where the brine may have migrated through the subsurface, whether it be from the caprock, along the edge of the salt dome, through a fault, or via a historical borehole and into the Chicot sands, or other migratory pathway. The expectation is that the brine would be travelling upward through the subsurface and into the basal portion of the Chicot at approximately the same pressure or slightly higher pressure than the surrounding geology. The brine is not being forced into the formations through injection.

2.3 ACTIVE BRINE INJECTION

Active brine injection represents situations where the injection of the brine may be in direct communication with the Chicot, through leaking casing, historical boreholes, etc. and where the brine is being forced into those formations. It is assumed that brine would enter the base of Chicot, within the "700-foot" sand. For the purposes of this report the average rate of injection is assumed to be 350 gallons per minute of brine into Cavern 7.

Brine is much denser than the freshwaters of the Chicot Aquifer. If brine were to make it into the Chicot sands, it would likely move along the basal portions of the sands.

3. MODELING

Using MODFLOW, a simple 3D groundwater flow model was developed to simulate the three scenarios discussed above. The model was constructed using five homogeneous layers to represent the three Chicot sands, and two clay units between the sands. The values for the hydraulic conductivity of the Chicot sands were obtained from published values (Harder, 1960) at 171, 157, and 165 ft/day for the "200-foot", "500-foot", and "700-foot" sands, respectively. The confining layers were assigned hydraulic conductivity values of 0.3 ft/day. It was assumed that there was no recharge, with general head boundaries surrounding the model grid.

The model assumes a freshwater flow regime. Although brine is a dense liquid, no density corrections were applied, and it is conservatively assumed that the brine will migrate through the aquifers as freshwater.

3.1 GROUNDWATER FLOW DIRECTION

Based on available data from regional water wells, the predominant groundwater flow direction appears to be from northwest to southeast across the site (Figure 2). There is some uncertainty about the local groundwater flow direction due to the heavy industrial pumping occurring near the dome.

The model was developed using the known regional water level data and adjusted to match those wells, while still including pumping. Figure 2 shows the comparison between the observed groundwater levels of the "500-foot" sand and the modeled groundwater levels. Generalized pumping data were used based on households served, known water production, and/or estimates based on well type. There are no data available for industrial water well withdrawals in the Lake Charles area, so the model data near Lake Charles are less representative of the measured values. However, the model data in the vicinity of the salt dome and the City of Sulphur match the known water elevations quite well and appears to be generally representative of regional groundwater flow conditions.

3.2 POTENTIAL IMPACT TO DRINKING WATER SUPPLY

Using the MT3DMS package withing MODFLOW, the development and migration of potential plumes were modeled for the three different scenarios. It was assumed that the concentration of brine is 200,000 mg/L and that advection and dispersion are the primary drivers of plume migration. For comparison, the chloride in the Chicot is generally between 25 and 120 mg/L. The model was set to simulate 100-years of groundwater movement.

3.2.1 POTENTIAL CAVERN FAILURE

The potential cavern failure scenario was modeled by assigning a constant concentration of 200,000 mg/L in all cells within a 10.7-acre circle around Cavern 7. As a non-continuous source, the concentration was set to be constant for 1 year and then the cells were allowed to change concentration over time. Based on the model, it is expected that a plume would migrate as a slug of high concentration water that would slowly attenuate over time. Without pumping, the slug of water is predicted to reach the City of Sulphur water wells in approximately 75 years from the time of failure (Figure 3).

To assess capture of the plume six pumping wells were added to the model, 3 in the "500-foot" sand and 3 in the "700-foot" sand. With six wells pumping at 250 gpm each (total 1,500 gpm) and turned on 4 years after the failure event. The plume appears to be effectively captured within approximately 35 years of the failure event (Figure 3).

3.2.2 PASSIVE BRINE LEAKAGE

To model passive brine leakage, a model cell at Cavern 7 was assigned a constant concentration of 200,000 mg/L. A plume develops at the constant concentration cell and continues to expand over time. The general trend of the plume is to the southeast, toward the City of Sulphur water wells and Lake Charles areas of pumping. The plume moves slowly, reaching the edge of the dome after about 10 years. The plume does not encounter any water wells for approximately 100-years, at which time it would be projected to reach the City of Sulphur public supply wells (Figure 4).

Following the initial model run and hypothetical pumping well was inserted into the model downgradient of Cavern 7. Different pumping rates were tested to identify the lowest pumping rate to provide capture within the "700-foot" sand at the theoretical pumping well. Pumping at 330 gallons per minute (gpm) or greater appears to be sufficient to capture passive brine flow within the "700-foot" sand under passive flow conditions. The results of the passive brine leakage model are shown on Figure 4, showing both the results when there is no pumping well, and when a theoretical downgradient well pumps at 330 gpm.

Because the pumping well is modeled in the "700-foot" sand, there is the possibility that migration into the "500-foot" sand might occur. Based on the model, pumping in the "700-foot" sand alone would capture the majority of migrating constituents in the "500-foot" sand, but not all. However, migration in the "500-foot" sand is not expected to reach the City of Sulphur public water supply wells in 100 years. An additional pumping well in the 500-foot sand would completely capture the brine.

3.2.3 ACTIVE BRINE INJECTION

To model active brine injection, an injection well was inserted into the model at the Cavern 7 well. Again, a constant concentration of 200,000 mg/L, was assigned at the same cell where the injection well was inserted. As expected, a much larger plume develops due to the injection as compared to the passive model. The general trend of the plume is to the southeast, similar to the passive leakage model; however, the concentrations are much greater, and the plume shape is broader. The plume still moves rather slowly, reaching the edge of the dome after about 10 years. The plume would not encounter any water wells for approximately 85-years, at which time it would be projected to reach the City of Sulphur public supply wells.

With active injection, the pumping rate at the recovery well(s) would need to exceed the brine injection rate at 700 gpm or greater to capture brine within the "700-foot" sand. The results of the active brine injection model are shown on Figure 4, showing both the results when there is no pumping well, and when a theoretical downgradient well pumps at 700 gpm. This pumping rate in the "700-foot" sand would not capture potential migration into the "500-foot" sand. To achieve full capture of the "700-foot" sand and the "500-foot" sand, an additional well would be required in the "500-foot" sand pumping at approximately 370 gpm. A total of 1,070 gpm with about 65% of the total pumped volume coming from the “700-foot” sand appears to capture all brine that is being injected.

4. PLAN TO PROTECT AND/OR REMEDIATE FRESHWATER SUPPLY

At this point in time there is no evidence that the Chicot Aquifer has been impacted by brine. Several monitoring wells are currently being installed, and two of the three clusters fall along the model plume flow path. Based on the model results, these sets of monitoring wells will function as an early detection system, far in advance of any brine entering the public supply.

In the most extreme case, brine being injected directly into the Chicot aquifer at 350 gpm, it is estimated that the brine plume would arrive at MW-2 within about 4 years, and at MW-3 about 7 years from the start of injection. While active pumping downgradient would draw the plume toward the pumping well, pumping would not be necessary until the plume is closer in proximity. Based on the location of the theoretical pumping well, the travel time of the plume to the well would be approximately 12 years from the start of pumping. However, pumping prior to the plume arrival would narrow to plume and increase the likelihood of complete capture.

The monitoring wells are positioned in ideal locations to function as an early detection system for migrating brine within the Chicot, either due to passive leakage or active injection. In the event that brine migration is suspected in the Chicot, the plan to protect and/or remediate the freshwater supply would follow a step-wise approach:

1. **Frequent monitoring of the monitoring wells**. Given the slow travel time, the monitoring wells will provide the first indication that concentrations are increasing before reaching any public supply well. The frequency of monitoring could be variable but recommended at no less than one year between sampling. Concentrations are likely to naturally fluctuate within the aquifer, so increasing concentrations over three consecutive sampling events and resulting in a concentration 10-times the original baseline conditions would be deemed a cause for concern and would trigger the next step. After 10 years of monitoring without confirmed increasing concentrations that pose a risk to the public supply the plan will be reevaluated.
2. **Increase monitoring frequency to determine if the increasing concentrations are continuing to show the same trend**. This second phase of monitoring will be no less frequent than monthly and will not extend beyond 6 months. One additional monitoring well will be installed in downgradient direction for additional data. If concentrations are indeed continuing to increase after 6 months the next step will be triggered. Otherwise, the sampling will return to step 1.
3. **Evaluate ideal location(s), depth(s), and number of additional wells to provide additional data and or maximum capture of the plume**. The

properties of the plume will determined during this step. Specific details about additional wells will be determined during this step. Likely, additional wells will be installed downgradient first as monitoring wells, which could be easily converted into pumping wells as needed. Wells would be installed on Westlake's property, with a goal of keeping the plume from migrating beyond the property boundary. The well would be installed no later than 2-years after confirmed brine migration. After additional monitoring, and if there appears to be a need for active remediation, the next step will be triggered.

4. **Active pumping of the Chicot**. The wells installed during step 3 will be converted into pumping wells. The flow rates would be evaluated at this time to maximize capture of the plume. Ideally the water generated from pumping would be returned to the plant to make brine. Additional monitoring wells will likely need to be installed further downgradient to ensure capture has been achieved. The plume would continue to be monitored.

A brief diagram of the plan, with hypothetical well locations, is included as Figure 5. There is no plume of brine within the Chicot, thus many of the details cannot be known or modeled at this time and could not be evaluated until a plume is detected. For now, frequent sampling of the monitoring wells is recommended, per step 1 above. ERM proposes to sample the monitoring wells quarterly during 2024, then move to semi-annually in subsequent years.

Should you have any questions or wish to discuss this plan, please contact us.

Sincerely,

Environmental Resources Management Southwest, Inc.

Scott A. Himes, P.G.
Senior Hydrogeologist

David C. Upthegrove, P.G.
Partner

FIGURES

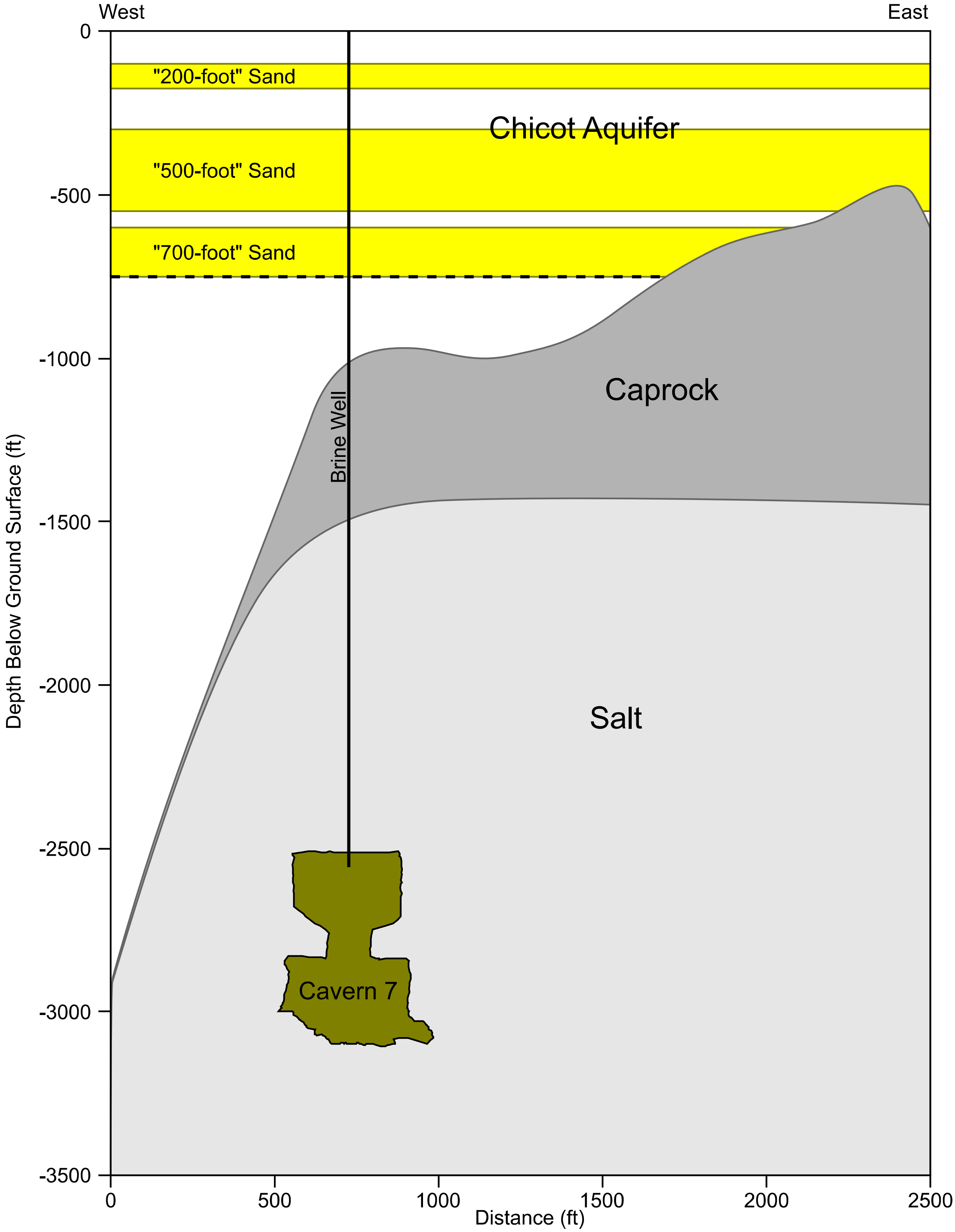

Figure 1
Generalized Cross-Section through Cavern 7
Sulphur Dome
Westlake US 2, LLC
Calcasieu Parish, Louisiana

Notes:
Same horizontal and vertical scales
Data for salt and caprock depths provided by Lonquist.
Cavern outline obtained from 2023 SONAR data.

ERM

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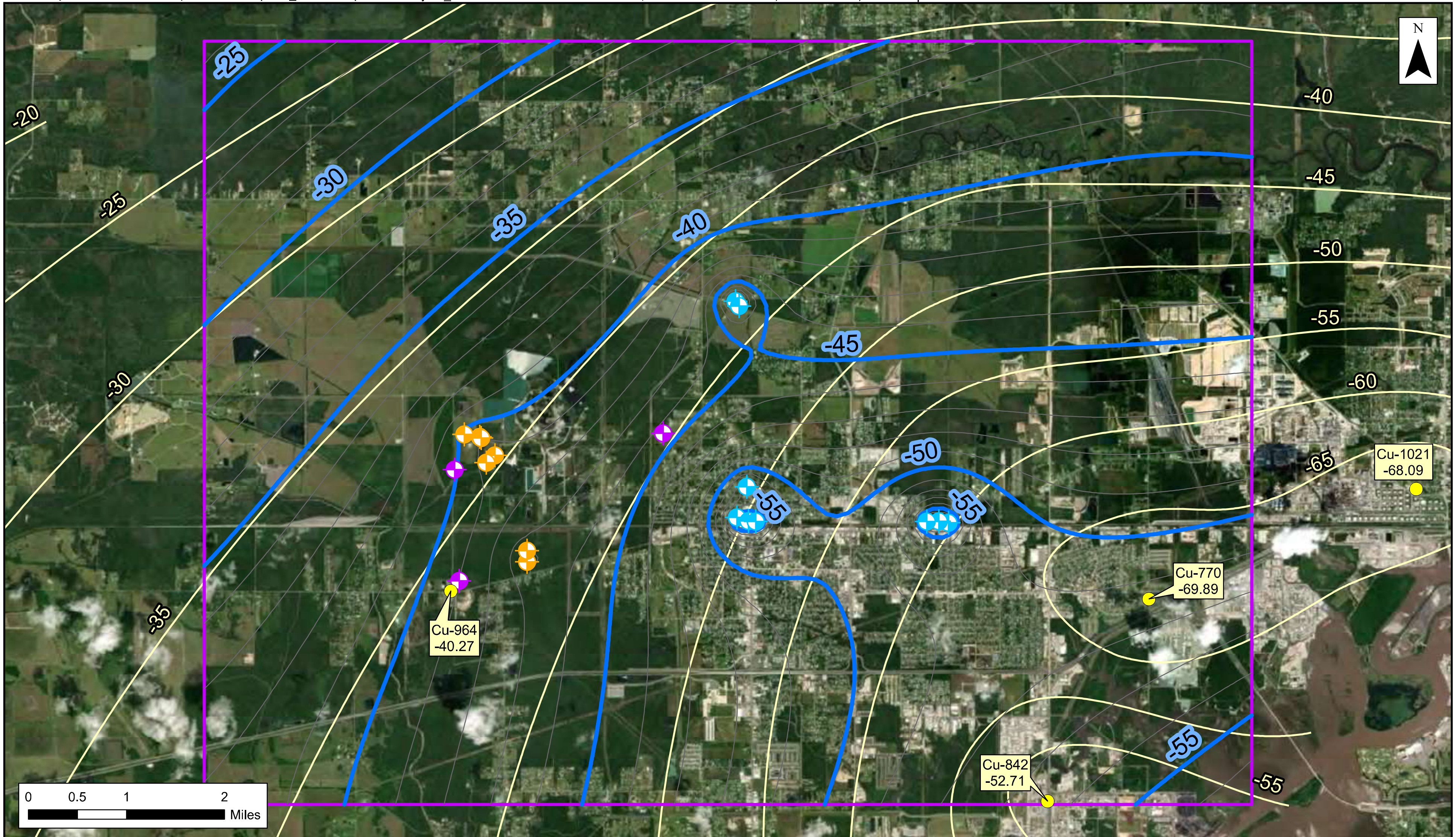

Legend

- 1-foot Model Contour
- 5-feet Model Contour
- Contour based on limited USGS data
- Model Grid Frame
- Industrial Well
- Public Supply Well
- Domestic Well
- USGS Groundwater Monitoring Point

Notes:
Basemap imagery via ArcGIS Online.

Figure 2
Modeled Groundwater Surface
Sulphur Dome
Westlake US 2, LLC
Calcasieu Parish, Louisiana

ERM

Source: Esri - ArcGIS Online; NAD 1983 UTM Zone 15N

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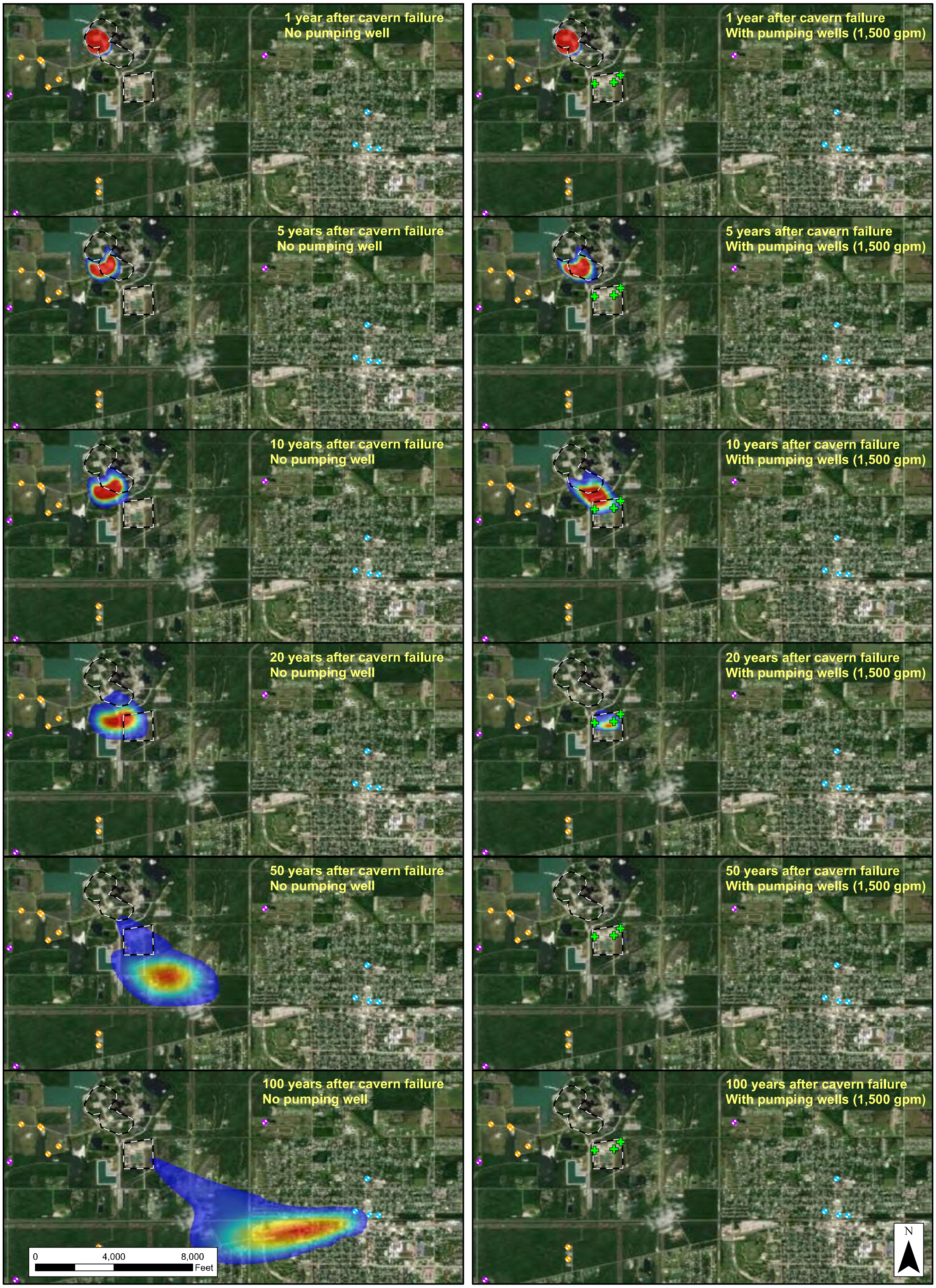

Legend

- Industrial Well
- Municipal Well
- Domestic Well
- Theoretical Pumping Well
- Westlake Property

Chloride Conc. (mg/L)
250
200,000

Figure 3
Potential Cavern Failure - "500-foot" Sand
Sulphur Dome
Westlake US 2, LLC
Calcasieu Parish, Louisiana

Notes:
Basemap imagery via ArcGIS Online.

ERM

Source: Esri - World Imagery; GCS North American 1983

Legend

- Industrial Well
- Municipal Well
- Domestic Well
- Theoretical Pumping Well
- Westlake Property

Chloride
Conc. (mg/L)

250

200,000

Notes:
Basemap imagery via ArcGIS Online.

Figure 4
Passive Brine Leakage - "700-foot" Sand
Sulphur Dome
Westlake US 2, LLC
Calcasieu Parish, Louisiana

ERM

DRAWN BY: SAH

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Legend

- Industrial Well
- Municipal Well
- Domestic Well
- Theoretical Pumping Well
- Westlake Property

Chloride Conc. (mg/L)
250
200,000

Figure 5
Active Brine Injection - "700-foot" Sand
Sulphur Dome
Westlake US 2, LLC
Calcasieu Parish, Louisiana

Notes:
Basemap imagery via ArcGIS Online.

ERM

Source: Esri - World Imagery; GCS North American 1983

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