LDNR – Office of Conservation
Injection & Mining Division

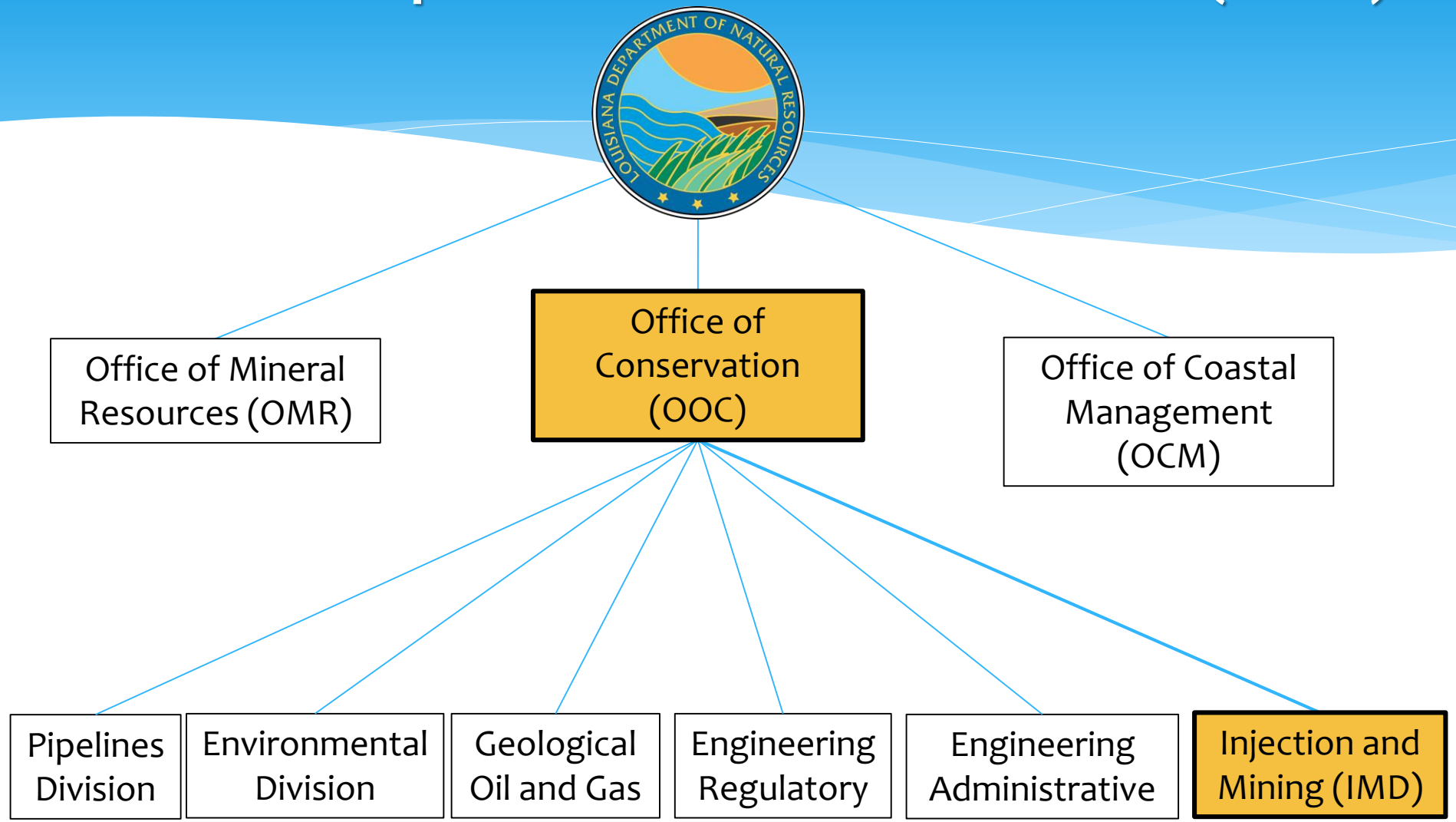
Briefing to

Calcasieu Parish Officials

Sulphur Mines Salt Dome
Calcasieu Parish, Louisiana

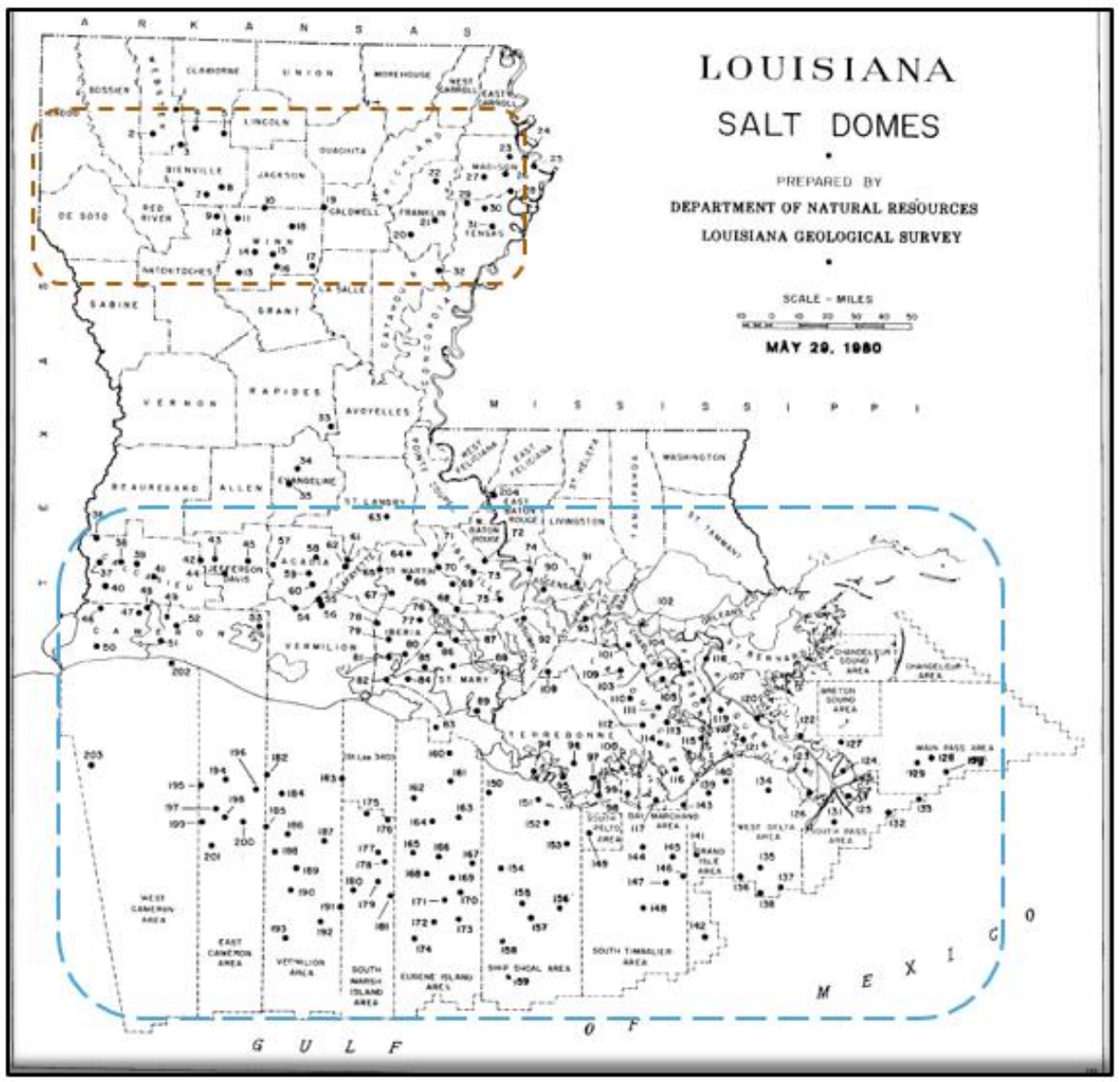
September 25, 2023

Louisiana Department of Natural Resources (LDNR)

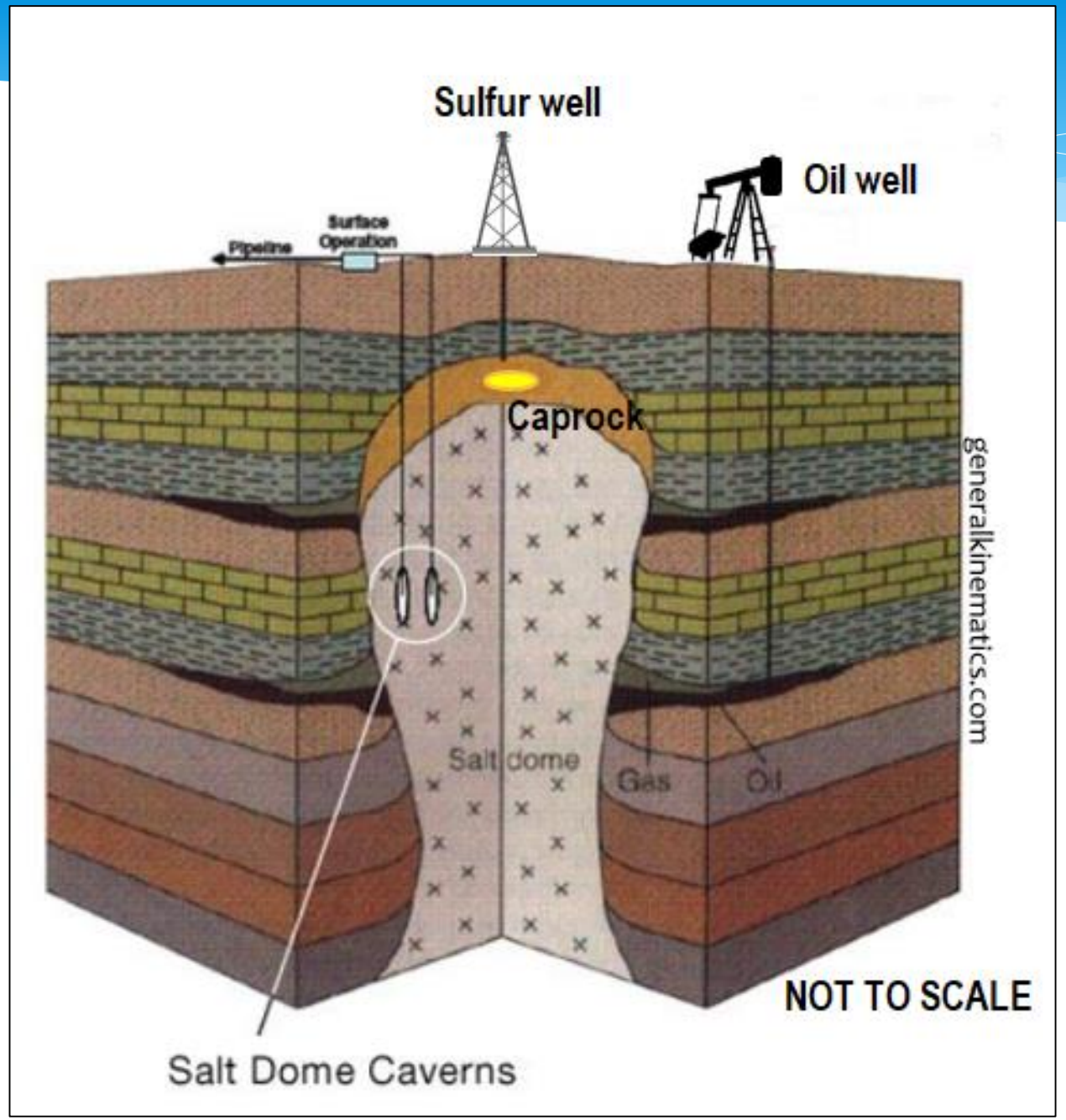


The Louisiana Office of Conservation was granted primacy of the Underground Injection Control (UIC) program in 1982

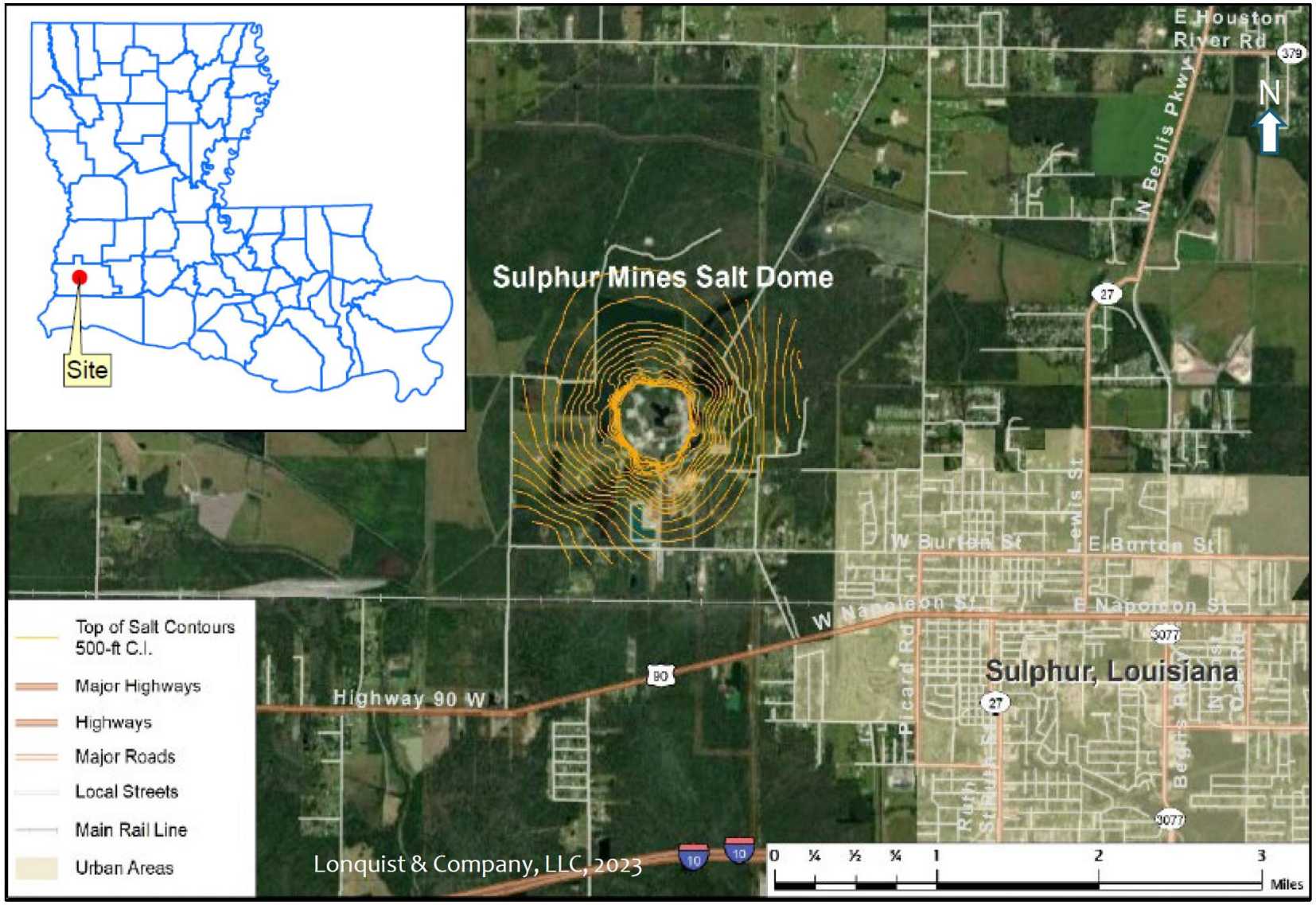
Louisiana Salt Domes



- In Louisiana, there are at least **200 known** or identified **salt domes**.
- Louisiana has **two salt basins**, the North Louisiana Salt Basin and the Gulf Coast Salt Basin.
- Louisiana currently has **20 "active" salt domes**, meaning there are salt caverns with active permits.
- **419 individual entries into caverns** with active permits in Louisiana.


Sulfur well
Oil well
Pipeline
Surface Operation
Caprock
Salt dome
Gas
Oil
generalkinematics.com
NOT TO SCALE
Salt Dome Caverns

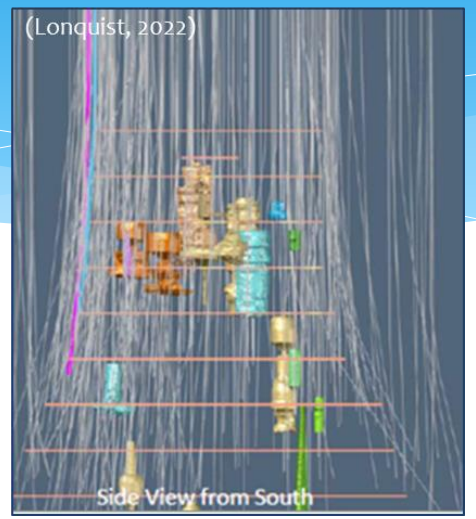
Site Location (surface)



Sulphur Mines Salt Dome, Calcasieu Parish, Louisiana

Sulphur Mines Salt Dome History: 1868 to 2023

Below: The white lines are historic traces of wellbore paths around the dome



- **155-years** of **hydrocarbon** exploration (1860's)
- **50-years** of **sulfur** extraction from caprock (1880's)
- **77-years** of **solution mining** of rock salt (1940's)
- **67-years** of **hydrocarbon storage** in salt caverns (1950's)
- **50-years** of **SWD Caprock Disposal** (1960's)

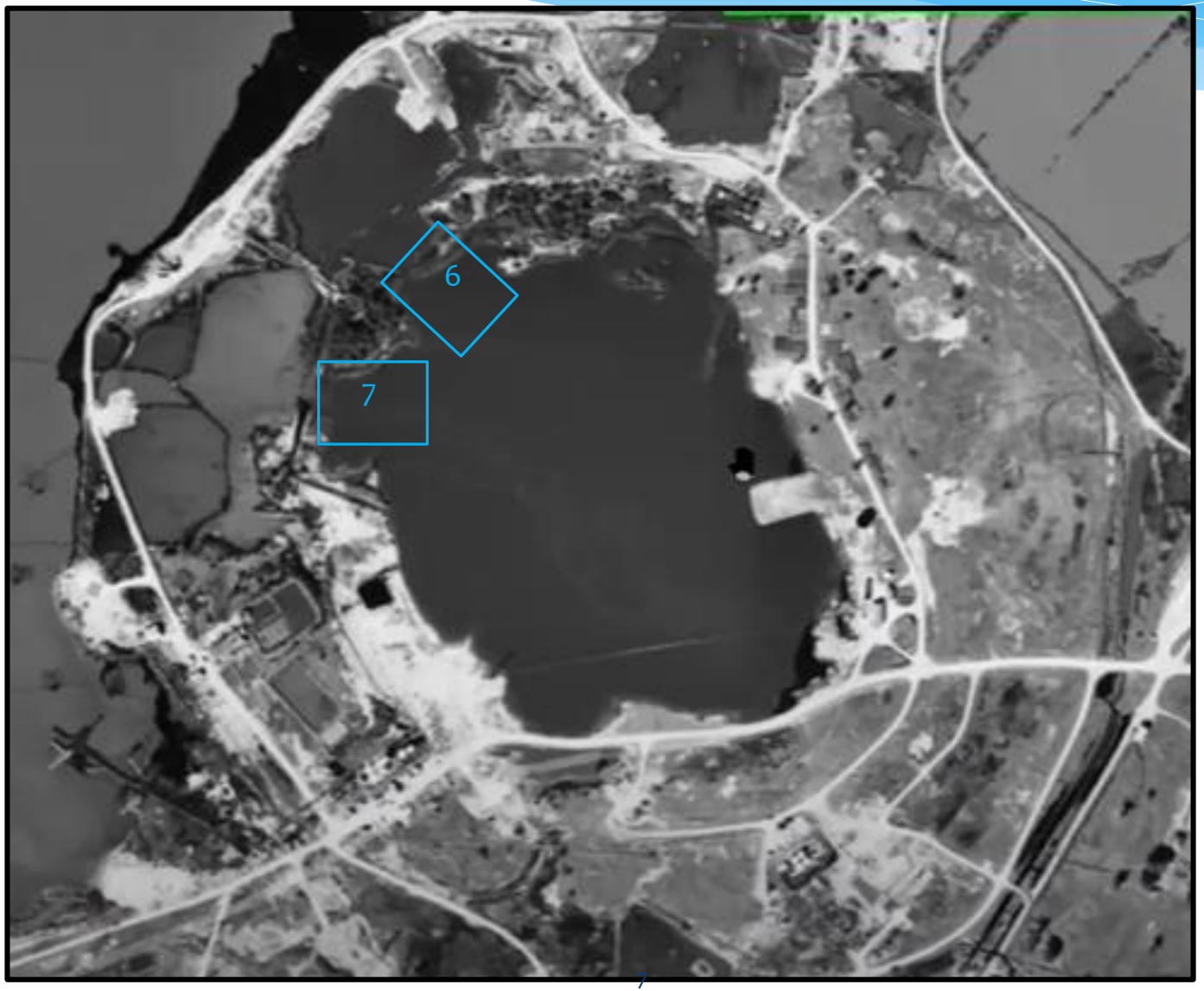
- **1978-1994: DOE-SPR** occupied **(5) caverns** for crude storage
- DOE-SPR left crude oil behind in the caverns, *but the total amount is unknown (possibly >115,000 bbls).*

Concerns:

- **Approx. 850+** known wells drilled into caprock and most were used for **sulfur mining**
- Many wells ***not* properly plugged** creating **vertical conduit(s) to surface**
- **Unknown amount of produced fluids** (likely under-saturated) injected into caprock for disposal
- **Historic drilling practices** have compromised the salt stock and caprock

Above: 1-million ton block of sulfur (40' tall)

Historical Site Location: 1954 Imagery of Sulphur Mines Salt Dome (USGS)



*Outlined in blue are the approximate current locations of PPG 6 & 7 well pads

Site Location (surface)

Approximate Distances:

Distance From:	6X/7B	Salt Dome
1. Camps	0.18 mi	0.09 mi
2. SW Residence	0.83 mi	
3. SW Residence	0.71 mi	
4. Railroad		0.76 mi
5. US 90		1.17 mi
6. SE Residence	0.73 mi	0.36 mi
7. Sulphur City Limits	1.24 mi	0.87 mi
8. Leblanc Middle School	2.0 mi	1.1 mi
9. Church	1.83 mi	1.46 mi

- Approx. 2.3 miles north of I-10
- Approx. 9.5 miles west of Lake Charles, LA.
- Approx. 18 miles from dome to LA/TX state line

Site Location (subsurface)

Cavern Operator: Westlake US 2, LLC

Cavern No. 6 Inactive in 2014 (no longer mining); Drilled **= 08/26/1955**
Cavern No. 7 Inactive in 2014 (no longer mining); Drilled= **10/22/1957**

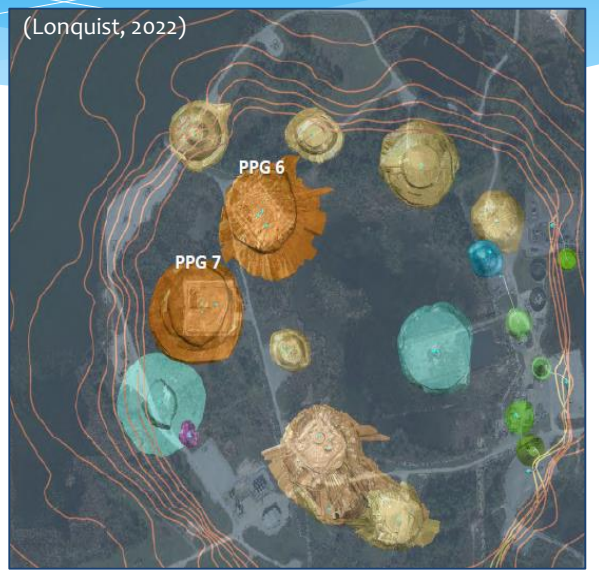
January 2023: 24/7 injection began into **Cavern 7** (rate ~315 gallons per minute) after loss of mechanical integrity. **Pressure rapidly declines** if injection rate decreases or stops

- **Volume of Brine Injected into Cavern 7:** ~2.2 mmbbls (as of 9/6/2023)
- **Volume of oil recovered out of Cavern 7:** ~54,600 bbls (as of 9/6/2023)

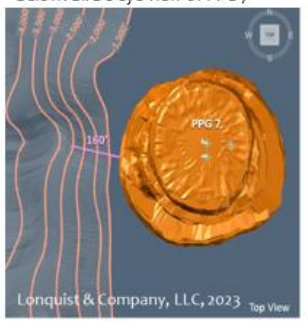
Cavern 6 has not been entered since March of 2022 and currently has an obstruction in the wellbore preventing tools from accessing cavern

Primary Concerns and Emergency Indicators

1) Loss of structural and mechanical integrity of Caverns 6 & 7
2) Seismicity
3) Potential threat to Chicot Aquifer
4) Gas bubbling and hydrocarbon sheen to surface
5) Increased subsidence rate

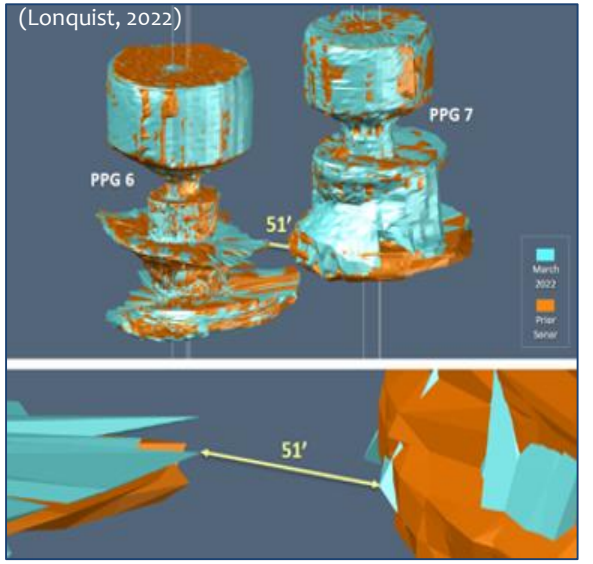


Below: Bird's eye view of PPG 7

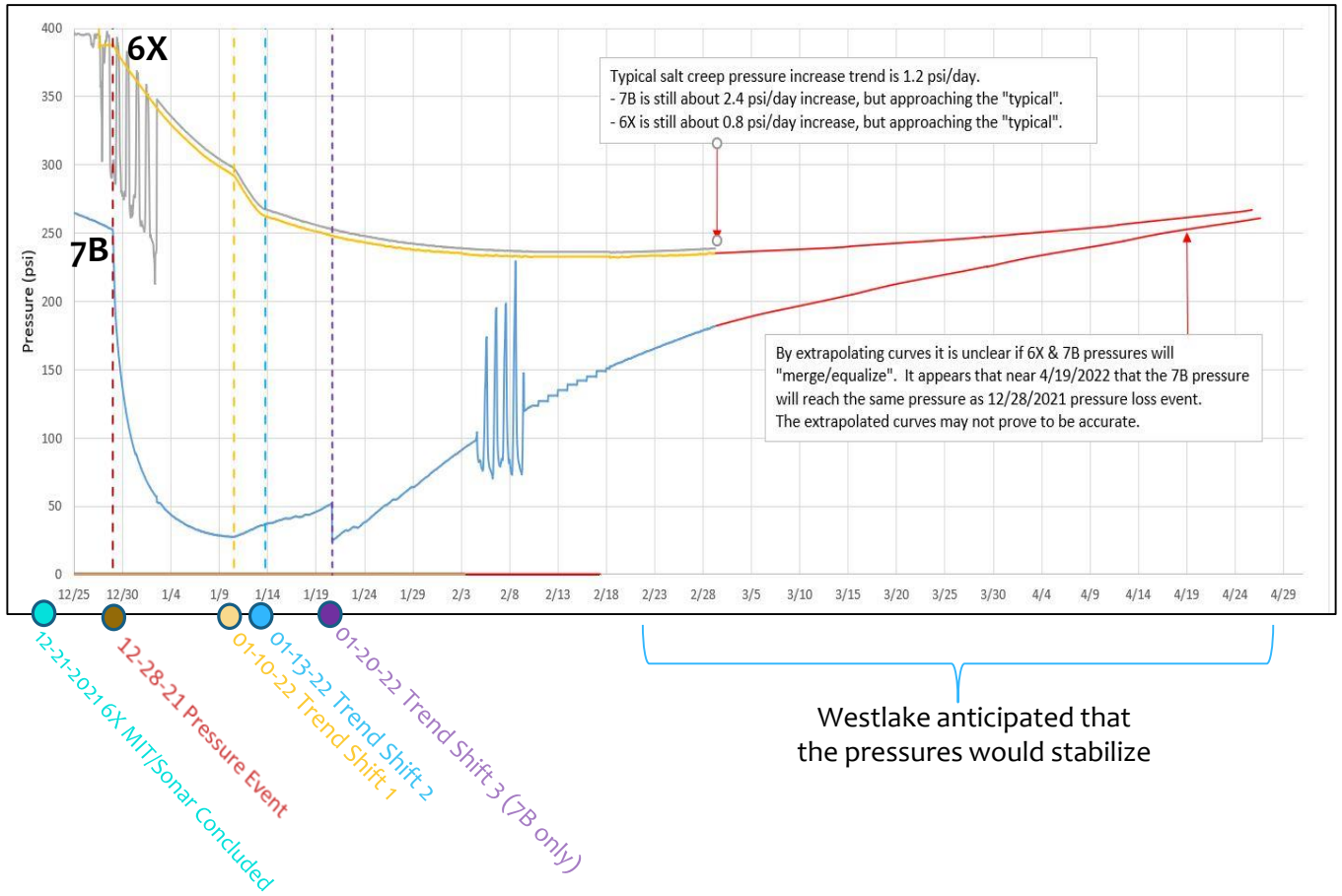


Below: Cross-section of PPG 7

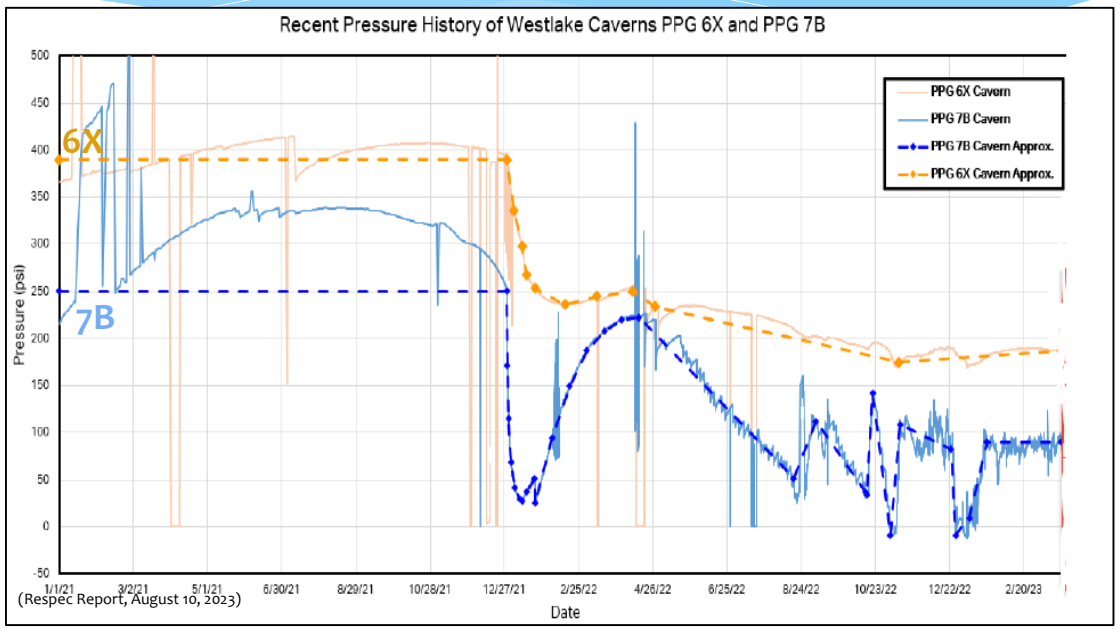
Area of potential breach



Impacted Areas: The Event – December 28, 2021



Westlake anticipated that the pressures would stabilize



Pressures have not stabilized

**This event occurred within a week of concluding a mechanical integrity test (MIT) on PPG 6X

Observed Impacts: Deployment of Passive Seismic Monitoring Array

Micro-Earthquake (MEQ) Semi-Permanent Array

- **12/28/2021:** "The Event" is suspected to have been a MEQ event
- **3/18/2023:** MEQ event registering 0-1 (origin inconclusive likely due to depth); deep MEQ's cannot be accurately located using a surface array
- **1st Quarter of 2024:** Anticipated installation of a downhole seismic array; instant notification

"Energy Equivalents"

Magnitude	Potential Energy
0	minivan dropping 3 feet
-1	bbl oil dropping 3 feet
-2	jug of milk 3 feet

Magnitude	Kinetic Energy
0	Rifle
-1	Pistol
-2	Air rifle

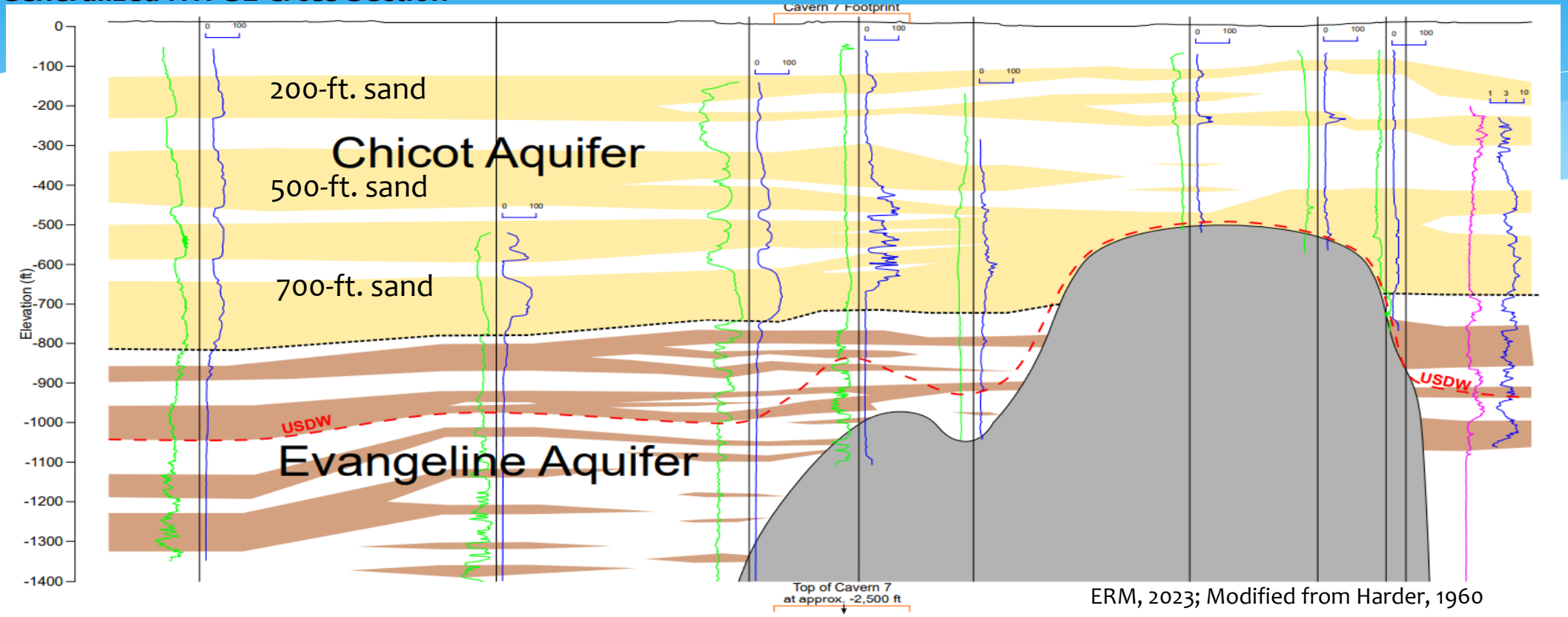
Source for Energy table: Microseismic Imaging of Hydraulic Fracturing: Improved Engineering of Unconventional Shale Reservoirs (Distinguished Instructor Series No. 17), SEG, 2014.

Magnitude range	Class	Length scale	Displacement scale	Frequency Scale
2 to 4	Small	0.1–1 km	4–40 mm	1–100 Hz
0 to 2	Micro	10–100 m	0.4–4 mm	10–1,000 Hz
–2 to –0	Nano	1–10 m	40–400 µm	0.1–10 kHz
–4 to –2	Pico	0.1–1 m	4–40 µm	1–100 kHz

*Magnitude is Logarithmic

Potentially Impacted Areas: USDW & Aquifers

Generalized NW-SE Cross-Section



ERM, 2023; Modified from Harder, 1960

- The **USDW** mainly consists of the **200-ft. and 500-ft**. sands of the **Chicot** aquifer. In this area, the 700-ft. sand is typically not considered "fresh" due to dissolution of the salt dome. The 700-ft sand is used for agricultural and industrial purposes. Over the dome, the **USDW ranges 500-1000-ft deep**. The Chicot Aquifer is a sole source aquifer in this part of the state.
- The **Evangeline aquifer** is **saline** near the dome, but not well delineated.

Observed Impacts: Bubbles and Sheen Over the Dome

1/13/2023: First report of **gas bubbling** at the wellhead cavern 7.

Since January 2023, oil has continued to seep to the surface

Laboratory Analyses:

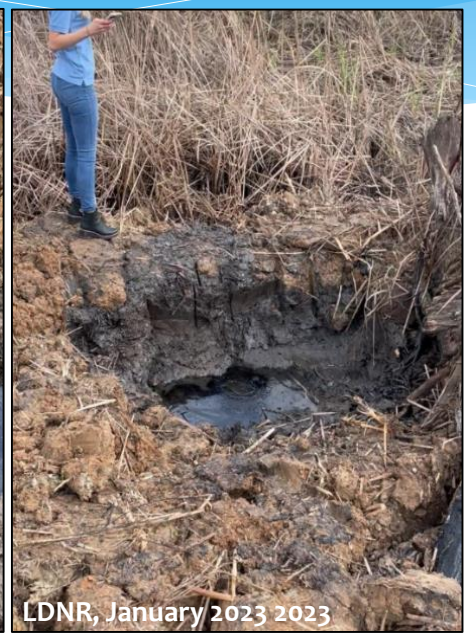
- Indicate that the samples of methane coming to surface is *mostly* thermogenic
- Indicate that oil sampled from the ground seep is closely related to the oil being locally produced by Yellow Rock
- Indicate that the oil recovered from Cavern 7 closely matches Middle Eastern oil profiles similar to the type of oil historically stored by the Dept. of Energy-Strategic petroleum Reserve at this site

***Note:** Drought conditions and lack of rain affect bubbling observation efforts

27 Gas Bubbling/Oil Sheen Locations

Observed Impacts

Sheen & Oil Seep

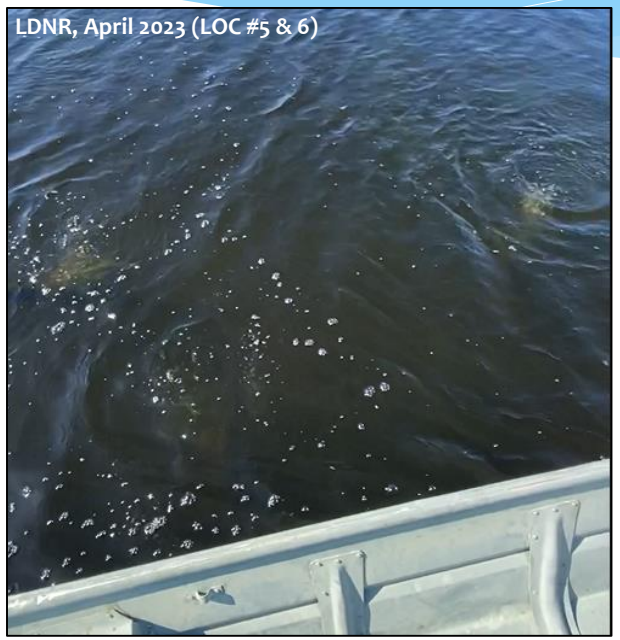


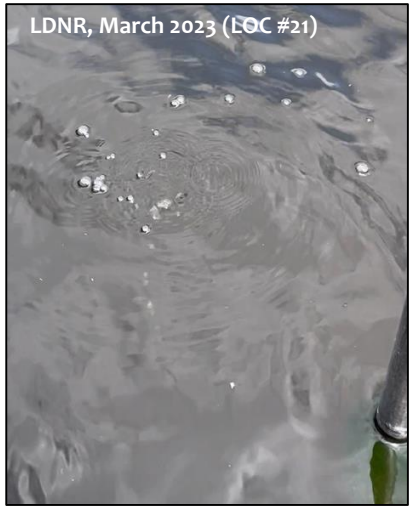
*All photos are from same location (near PPG 22 wellpad)

Observed Impacts

Methane Bubbling – January 2023 to present (various locations)


LDNR, May 2023 (LOC #10)


LDNR, April 2023 (LOC #5 & 6)

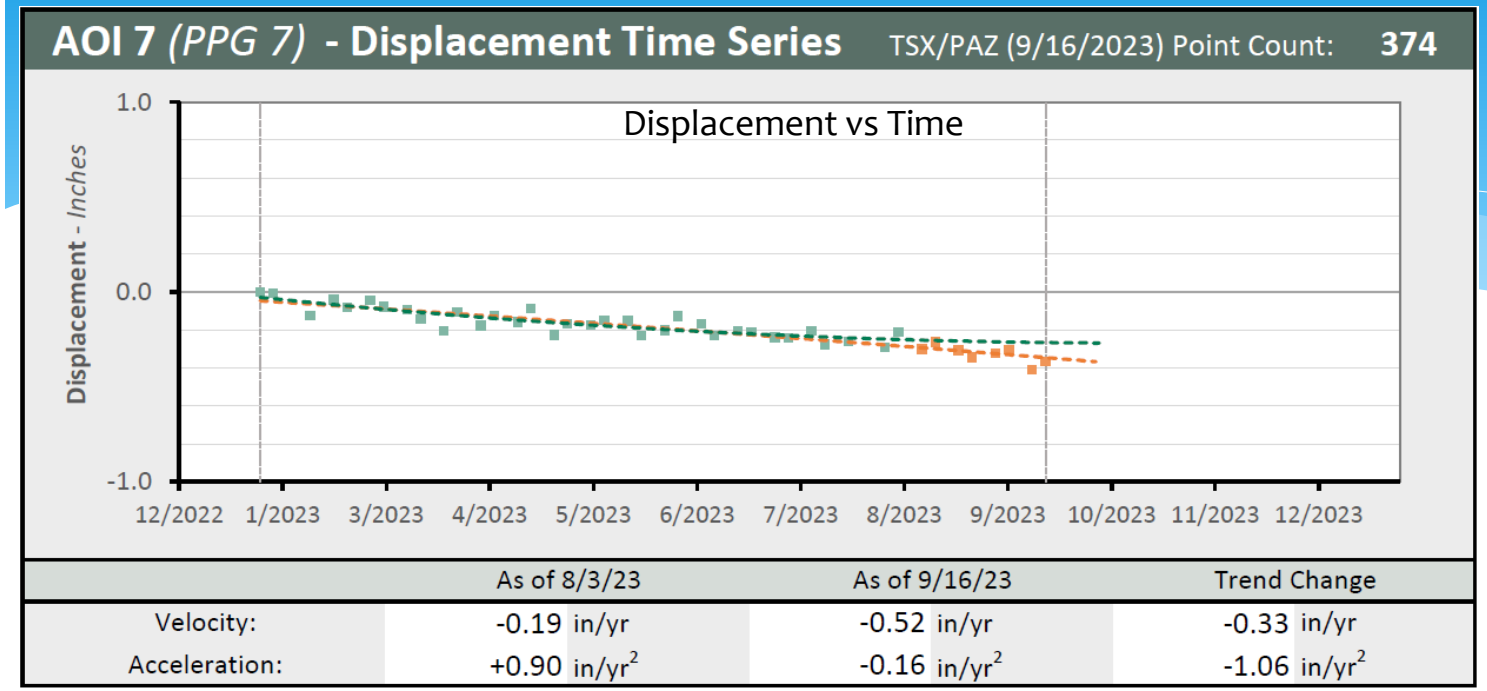

LDNR, March 2023 (LOC #21)

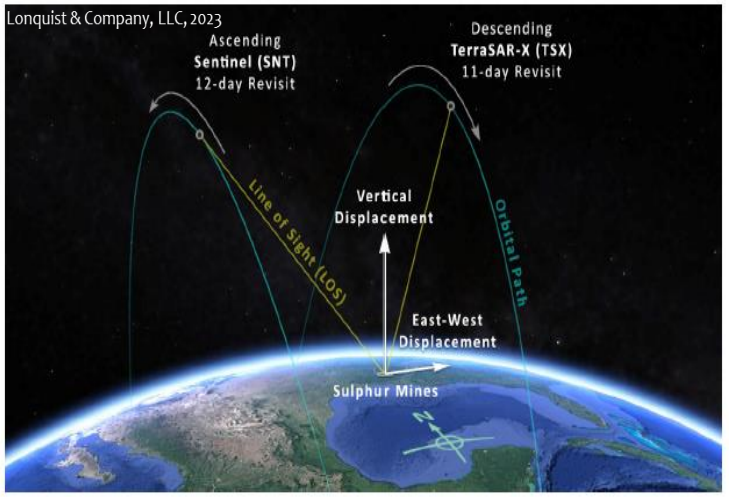

LDNR, May 2023 (LOC #24 – salt lake)

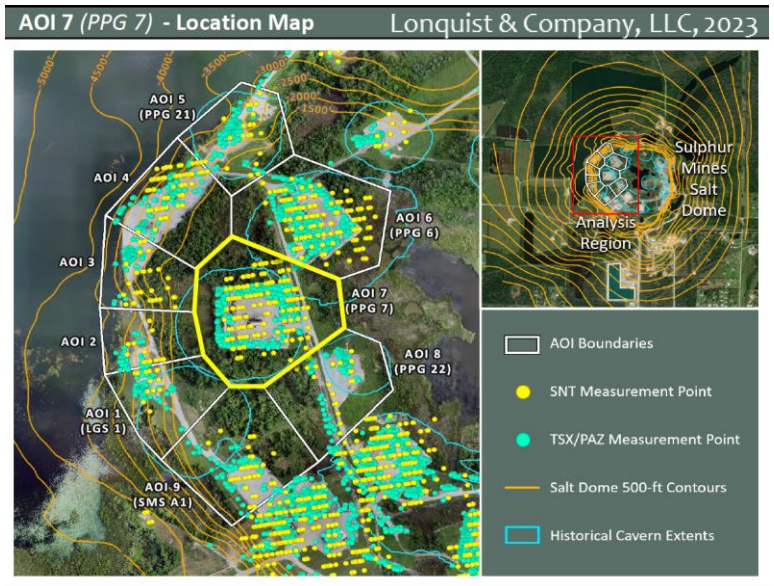

LDNR, July 2023 (LOC #26 – salt lake)


LDNR, Jan. 2023 (LOC #5 &6)

Observed Impacts: Subsidence







Note: Shaded AOI 7 covers the footprint of Cavern 7

- Satellite monitoring of surface movement (subsidence) can be a reliable predictor for subsurface movement prior to rapid collapse (documented after Bayou Corne sinkhole event in 2012)
- **8/25/2023** Westlake began reporting *possible variation from the historic trend line* for subsidence rates; this variation is still being investigated by Westlake

Comparison - Ground Subsidence & Sinkhole Formation

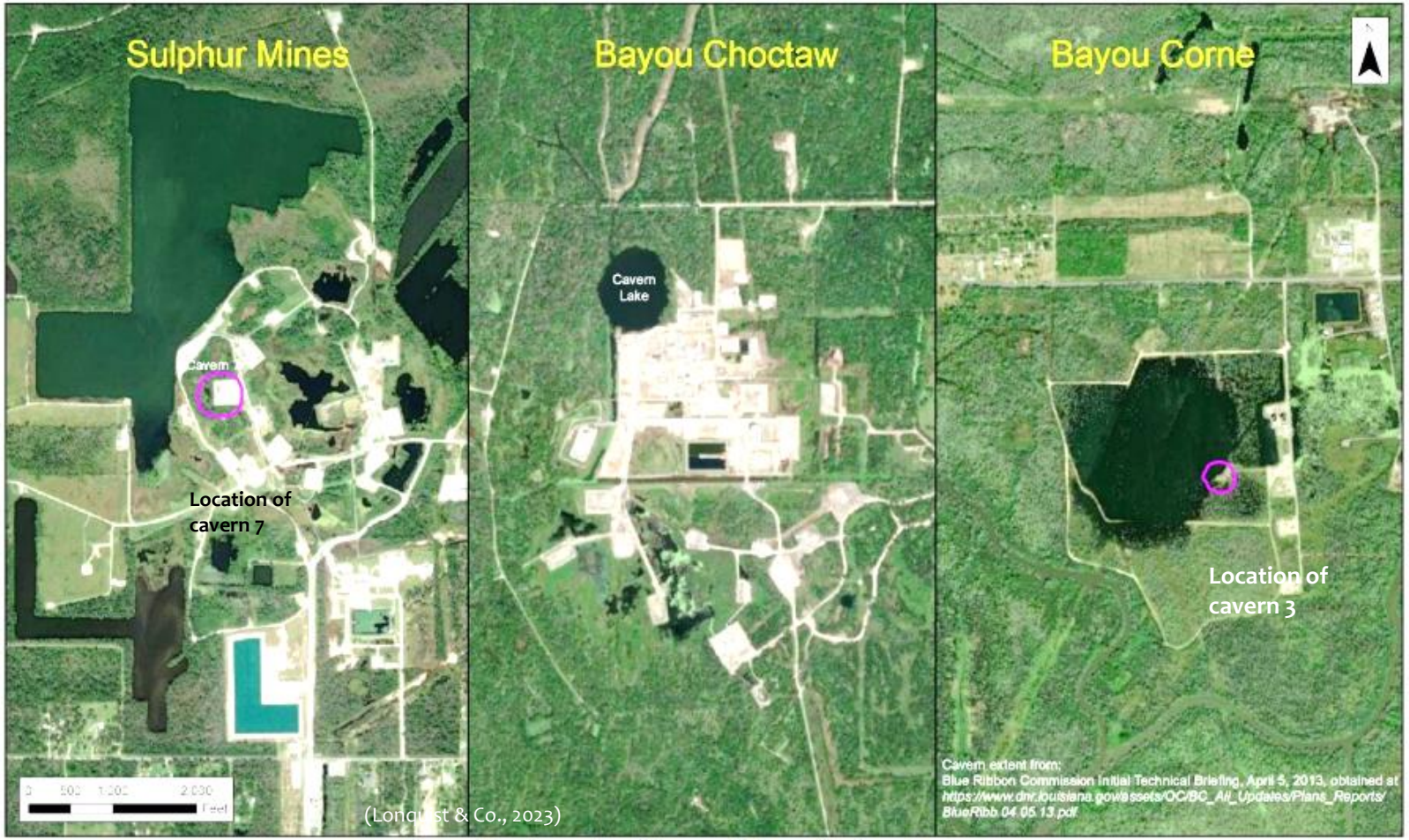
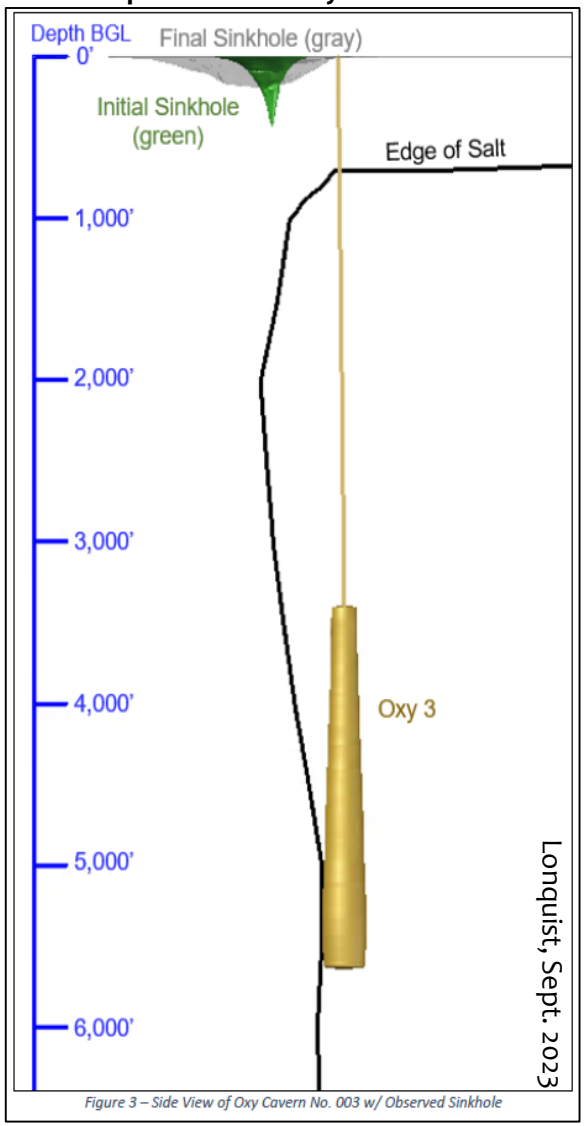


Figure 57 – Example of Cavern Collapse Surface Features

This is a unique and complex scenario, however, similar sinkhole events have occurred at Napoleonville dome and Bayou Choctaw dome.

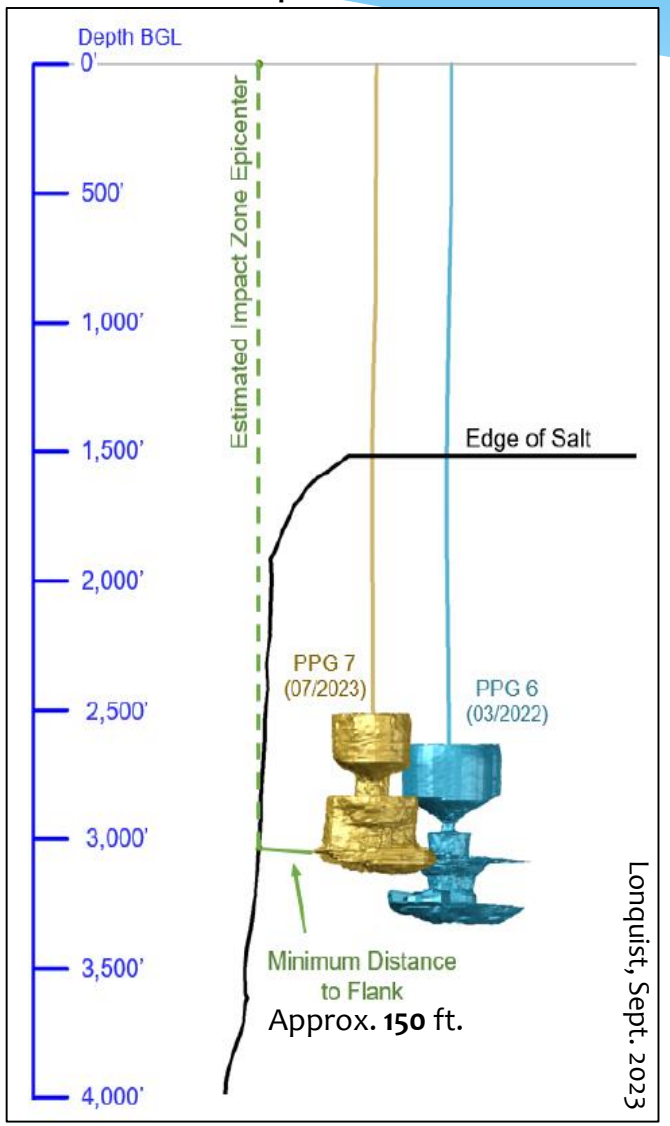
Comparison - Ground Subsidence & Sinkhole Formation

Napoleonville – Bayou Corne



Above: Oxy Geismar Well No. 3 at **Bayou Corne** is an example of side-wall failure (August 3, 2012)

Sulphur Mines



The estimated distance from **Cavern 7** to the edge of the salt dome is **150-feet.** 3D seismic is being processed to better determine this distance.

When **Cavern 3** at **Bayou Corne** happened, the estimated distance from the cavern to the edge of the salt dome was **140-feet.** It was later determined to be much closer.

Concern: Although there is uncertainty with the accuracy of the current models, it is important to note that more than one type of failure mechanism is possible. Additionally, more than one cavern could be impacted by rapid subsidence.

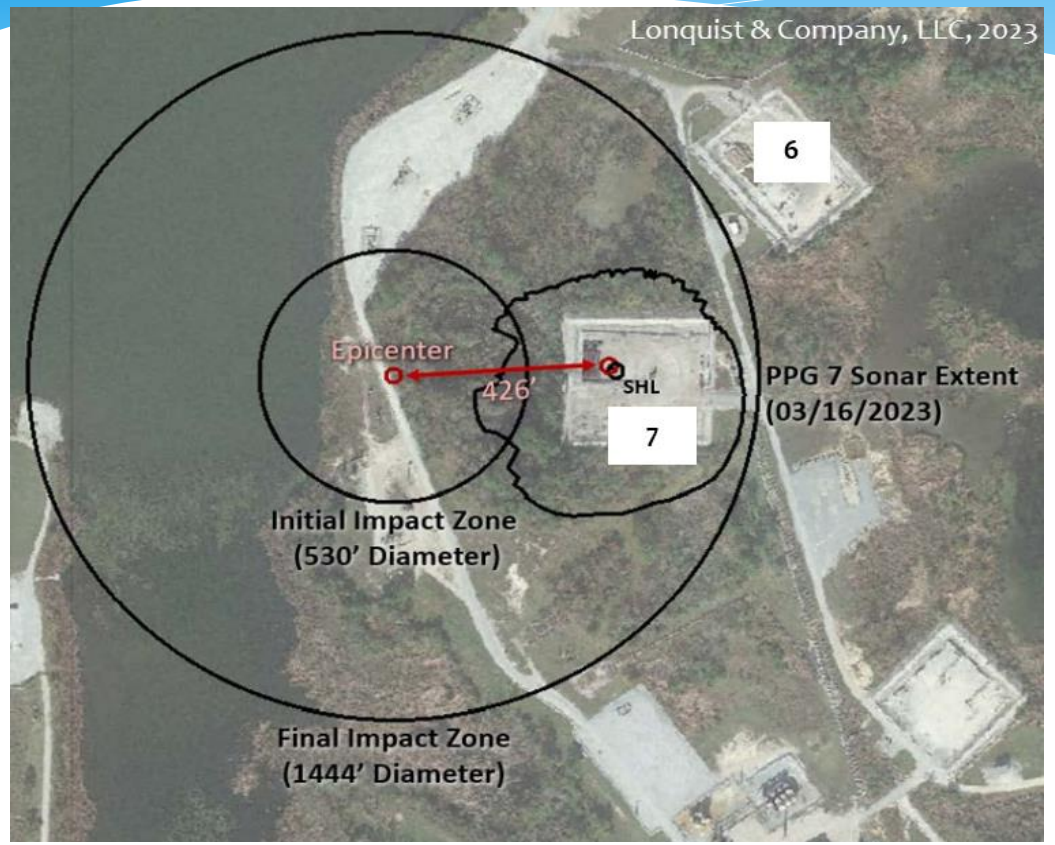
Comparison - Ground Subsidence & Sinkhole Formation

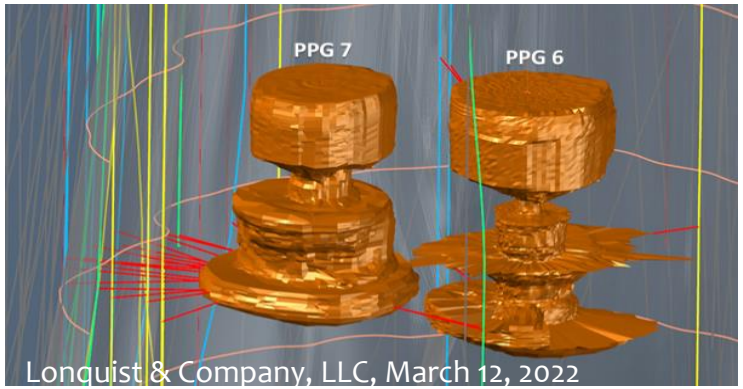
	Westlake's Cavern 7	Bayou Corne Cavern 3
Age of Cavern:	66 years	30 years (at the time of sinkhole)
Distance to edge or top of salt:	150 feet (estimated)	140 feet*
Distance to adjacent cavern(s):	51 feet (estimated)	345 feet (estimated)
Methane Bubbling or Oil Seep	27 locations (Jan-Sept 2023)	91 locations (May 2012- June 2013)
Reported Seismicity	Yes	Yes
Lack of Mechanical Integrity	Yes	Yes
Cavern Volume	Approx. 10 million barrels**	Approx. 20 million barrels
Cavern Depth	2510 to 3098 feet (588 feet in height)	3400 to 5600 feet (2200 feet in height)
Maximum Cavern Radius	327 feet (at 3083 feet deep)	192 feet (at 5450 feet deep)
Top of Salt Depth	1460 feet	700 feet

*In 1982 when the cavern was created, the distance from the cavern to edge of salt was estimated to be 1,000 feet. Prior to P&A of cavern in 2010, the distance was estimated to be 140 feet (to edge of salt dome)

**Both Caverns 6 and 7 are approx. 10 million barrels each, or 20 million barrels combined

Subsidence and Potential Sinkhole Formation





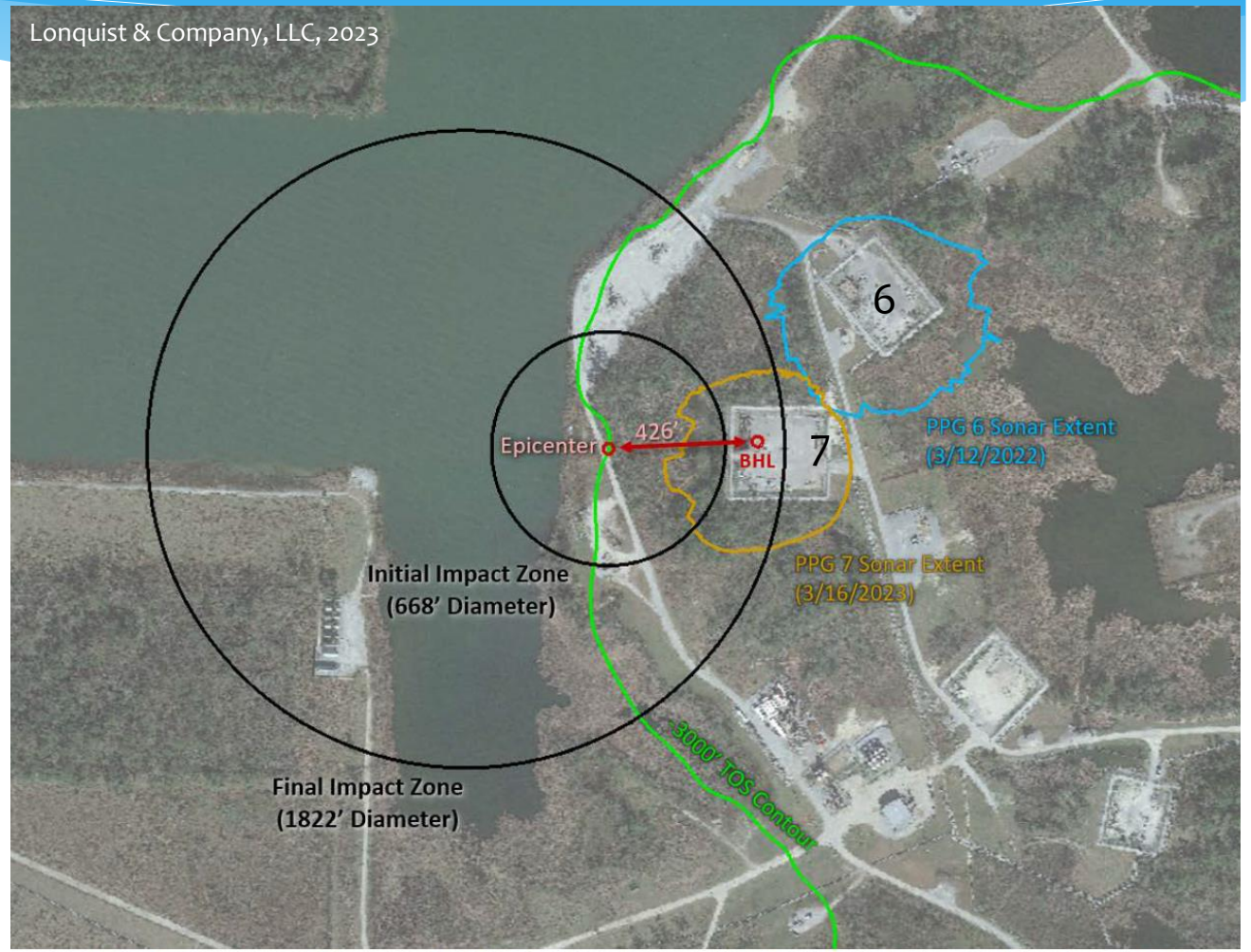


Figure 6 – Aerial View of Theoretical Sinkhole Projection Assuming Salt Dome Flank Collapse Involving Cavern 6 & 7.

Westlake's Preliminary Failure Analysis

Response Actions Taken by LDNR-OOC:

OOC-IMD Response to Date:

- Local, State, and Federal Agencies Notified by LDNR-OOC (January 2023):
  - GOHSEP
  - LOSCO
  - LDEQ
  - EPA-Region 6
  - DHH-OPH
- Issuance of **Compliance Order No. IMD 2022-027** (plus **two additional supplements**) to Westlake with a civil **penalty of $65,000**
- 1-2 times weekly site inspections of the Areas of Interest (AOI) by LDNR
- Continuous review of data and monitoring
- Regularly scheduled meetings and progress check-ins with Westlake, adjacent dome operators, and other stakeholders

OOC-IMD Order Requirements Received to Date (from Westlake):

1. Thermal Aerial Imagery of Salt Dome (day & night)
2. 4 & 7 Day Satellite Updates (SNT and TSX/PAZ)
3. Deployment of Surface Micro-Seismic Array (MEQ detection)
4. Daily Pressure Updates (operator reported)
5. Daily Observation Updates (operator reported)
6. Daily Volatile Organic Compound (VOCs) testing with PID (operator reported)
7. Monthly Water Sampling and Testing
8. Isotopic & Lab Analyses of Oil, Gas, and Water at Multiple Locations
9. Cavern 7 Recovered Oil Reporting (timing varies)
10. Geomechnical Plan and Phase 1 of Geomechanical Model
11. Failure Analyses Plan and Preliminary Failure Report
12. Plan to Conduct Underground Sources of Drinking Water (USDW) Evaluation
13. Plan to Install Groundwater Monitoring Wells
14. Cavern 7 Sonar Survey and Historical Comparisons
15. Plan to Acquire 3D Seismic Data for Mapping
16. Model of Depressurization Scenario (Caverns 6 & 7)
17. Weekly Boat & Airboat Inspections
18. Restriction of Access to Dome Facility
19. Westlake's Updated Emergency Response Plan
20. All Site Personnel Equipped with H_2S Sensors & PPE
21. Installation of Downhole Pressure and Temperature Gauge (Cavern 7)

Recent Priority Measures Taken by OOC

9/6/2023: IMD briefing to LDNR Secretary Harris and OOC Commissioner Edwards, Governor's Office, and AG's office

9/13/2023: LDNR-OOC briefing with Governor John Bel Edwards

9/14/2023: Informal emergency declaration notification to all dome operators

9/15/2023: LDNR briefing to EPA-Region 6

9/20/2023: Declaration of Emergency (No. 2023-1) by OOC Commissioner Edwards, and Proclamation of Emergency (No. 160 JBE 2023) by Governor John Bel Edwards

9/25/2023: OOC-IMD Briefing to Calcasieu Parish Officials

9/27/2023: IMD briefing to the Directors of the Office of Conservation, Louisiana Geological Survey and EPA Officials

Path Forward

Stakeholder Engagement
- Continued engagement with EPA-Region 6
- Engage with the United States Geological Survey (USGS) – Chicot Mapping
- Engage the Strategic Petroleum Reserve (DOE)
- Creation of dedicated webpage

Regulatory
- Decommissioning plans from all active operators
- Delineation of existing infrastructure & utilities

Technical
- Installation of tilt meters in all wells possible, would act as immediate alarm
- Subsidence & acceleration study
- Additional monitoring wells (on and off dome)
- Plan for cavern backfilling
- Fast track pending studies (3D seismic, geomechanical and failure analysis)
- Metering of expelled hydrocarbon at known surface locations
- Brine plume monitoring
- Obtain additional historical data
- Thermography camera(s) for hydrocarbon detection at the ground surface
- Obtain 3rd party experts – environmental, rock mechanics, geophysical