

**LDNR – Office of Conservation  
Injection & Mining Division**

Briefing for

**The Town of Sulphur**

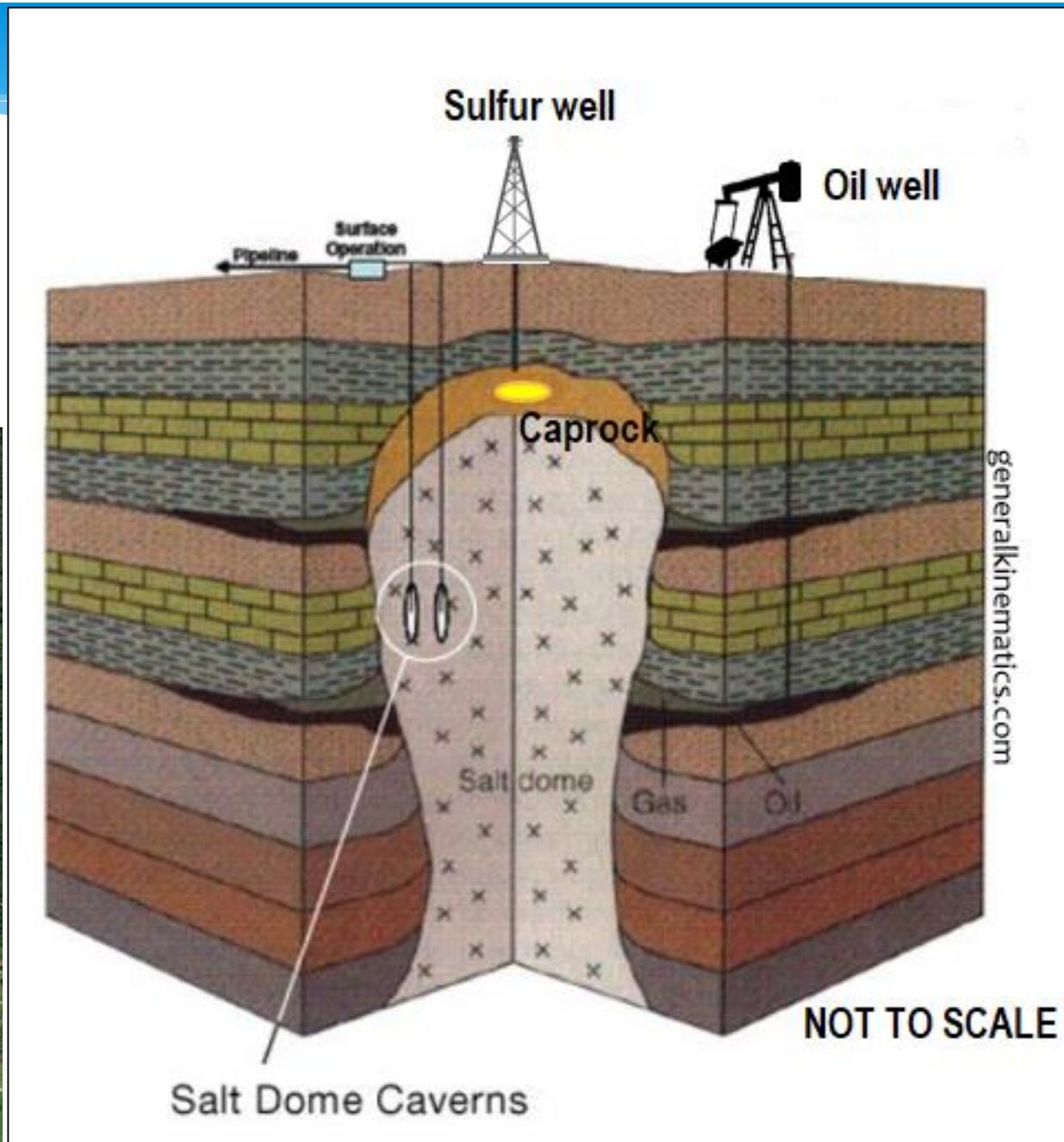
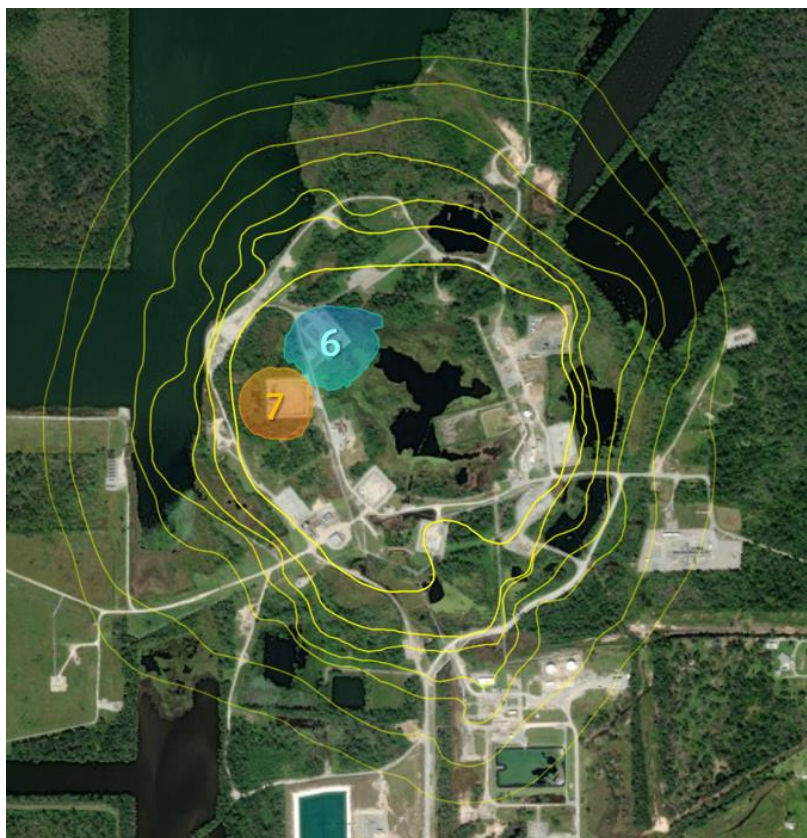
**Sulphur Mines Salt Dome  
Calcasieu Parish, Louisiana**

December 19, 2023



*State of Louisiana*

**DEPARTMENT OF  
NATURAL RESOURCES**



# Sulphur Mines Salt Dome History: 1868 to 2023

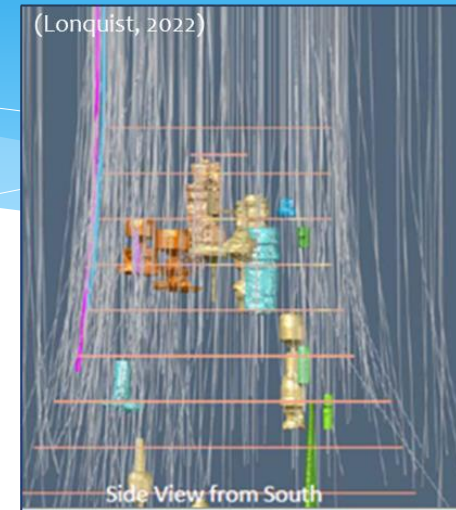


- **155-years of hydrocarbon** exploration (1860's)
- **50-years of sulfur** extraction from caprock (1880's)
- **77-years of solution-mining** of rock salt (1940's)
- **67-years of hydrocarbon storage** in salt caverns (1950's)
- **50-years of SWD Caprock Disposal** (1960's)
  
- **1978-1994: DOE-SPR** occupied (5) caverns for crude storage
- DOE-SPR left crude oil behind in the caverns, *the total amount is estimated to be about 112,000 bbls.*

## Concerns:

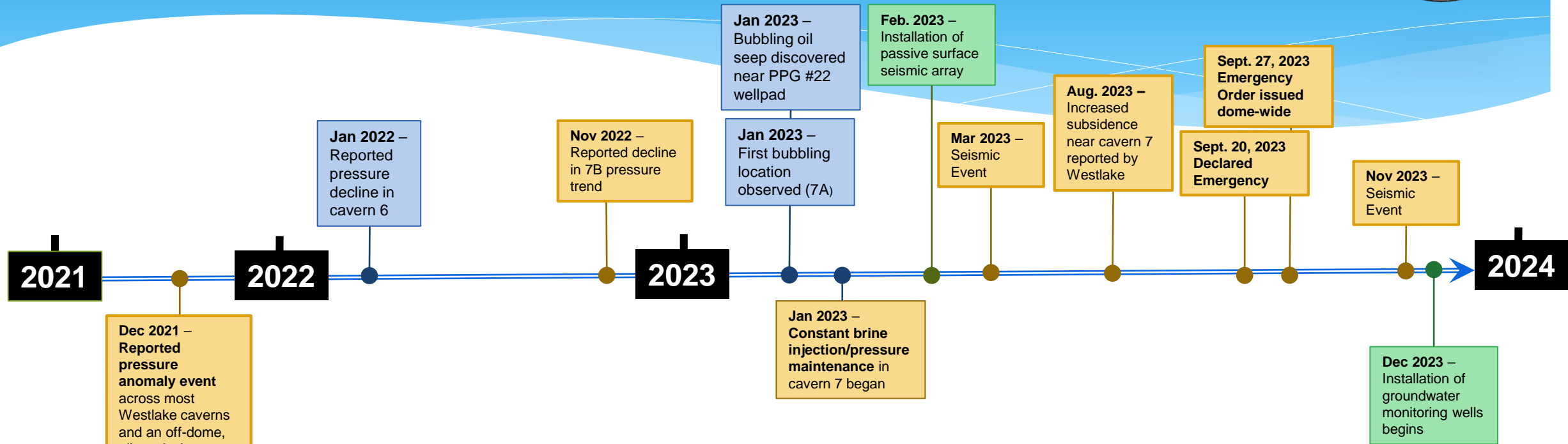
- **Approx. 850+** known wells drilled into caprock and most were used for **sulfur mining**
- Many wells **not properly plugged** creating potential **vertical conduit(s) to surface**
- **Unknown amount of produced fluids** (likely under-saturated) injected into caprock for disposal, likely contribute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

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



**Above:** 1-million ton block of sulfur (40' tall). About 10.5 million tons were produced from the Sulphur Mines dome

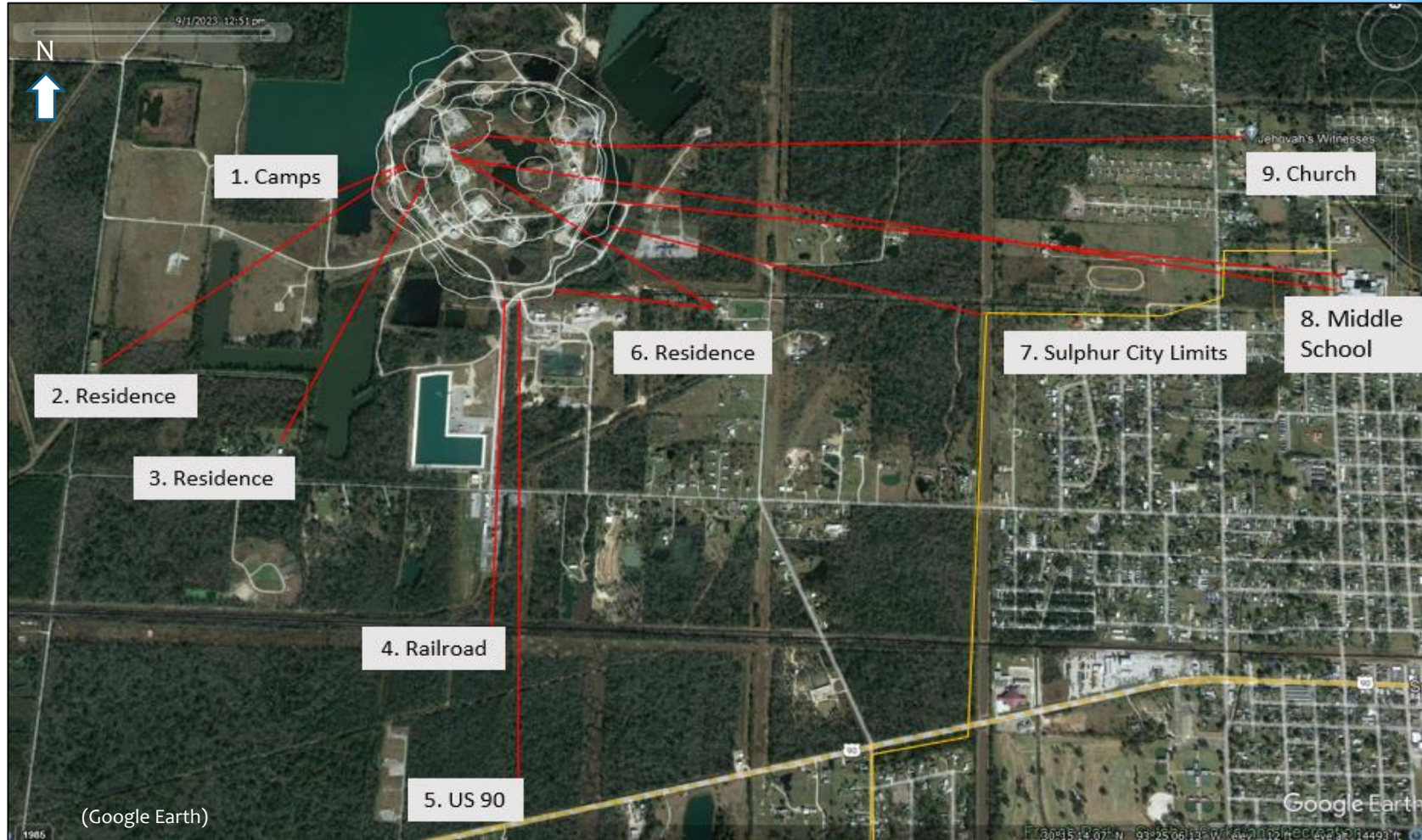
# Recent Timeline – 2021 to Present



Date of Issuance:	OOC-IMD Compliance Orders Issued to Westlake:
April 2022	• Issuance of Compliance Order (CO) No. IMD 2022-027 with <b>\$65K</b> civil penalty
January 2023	• Issuance of 1st Supplement to CO No. IMD 2022-027
April 2023	• Issuance of 2 <sup>nd</sup> Supplement to CO No. IMD 2022-027
October 2023	• Issuance of 3 <sup>rd</sup> Supplement to CO No. IMD 2022-027

# Site Location (surface)

## Approximate Distances:

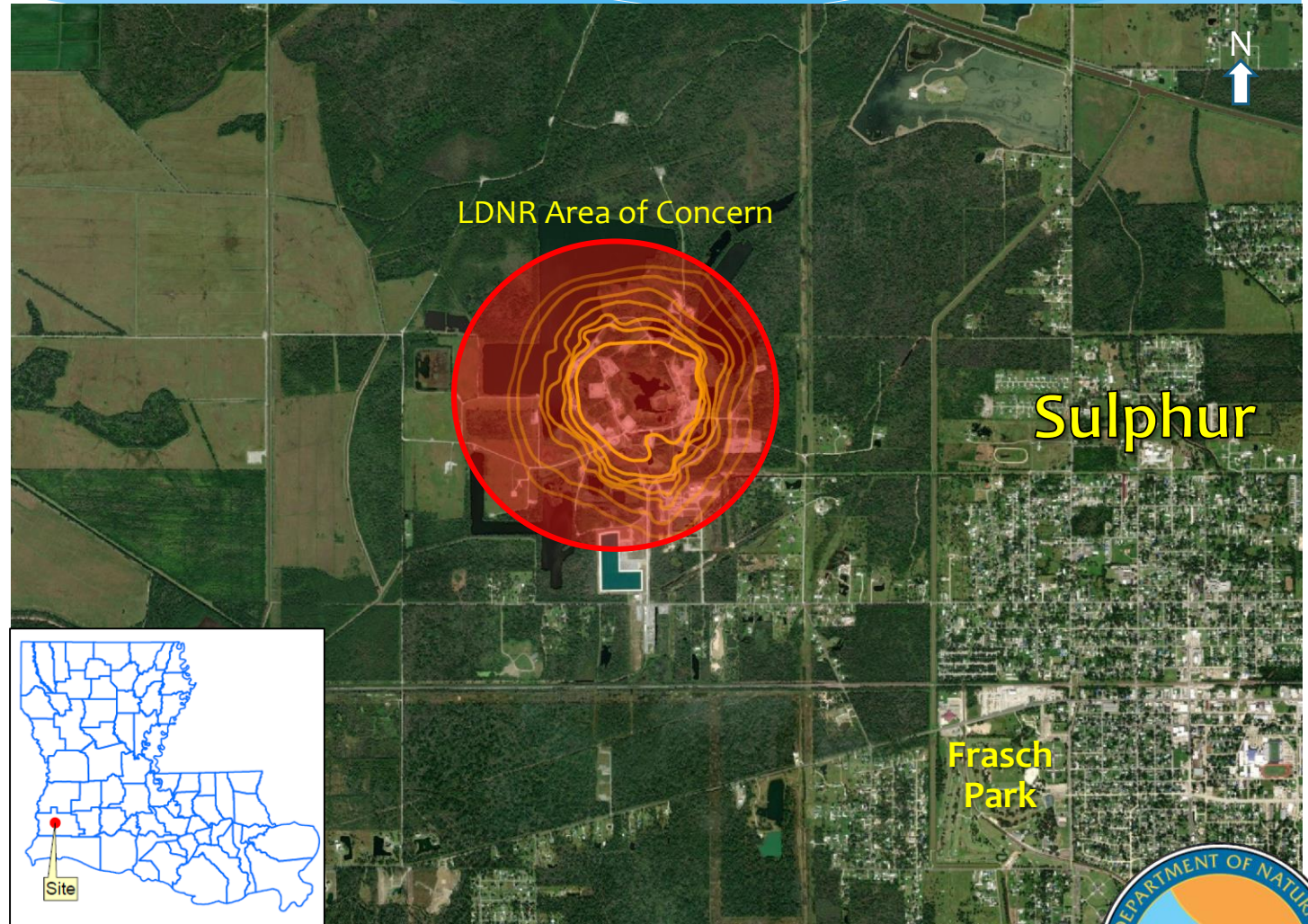
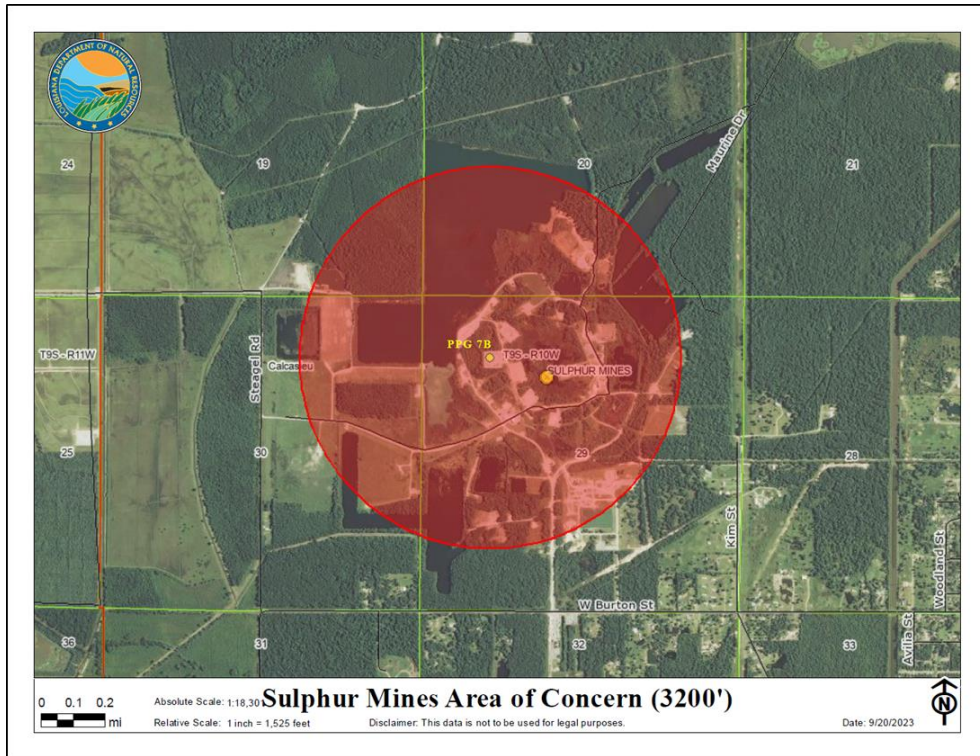


Distance From:	6X/7B	Salt Dome
1. Camps	0.18 mi	0.09 mi
2. SW Residence	0.83 mi	
3. SW Residence	0.71 mi	
4. Railroad		0.76 mi
5. US 90		1.17 mi
6. SE Residence	0.73 mi	0.36 mi
7. Sulphur City Limits	1.24 mi	0.87 mi
8. Leblanc Middle School	2.0 mi	1.1 mi
9. Church	1.83 mi	1.46 mi

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



# Surface Location: 3200-ft. Area of Concern



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



\*Outlined in blue are the approx. current locations of cavern 6 & 7 well pads



# Site Location (subsurface)

**Cavern Operator:** Westlake US 2, LLC

**Cavern No. 6:** Drill date = 08/26/1955; Inactive in 2014 (no longer mining)

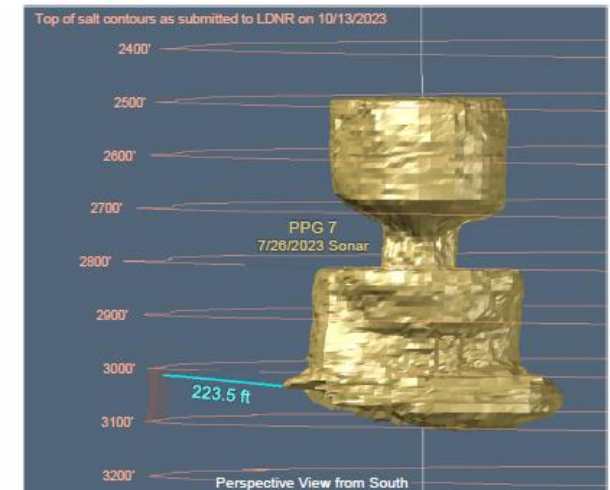
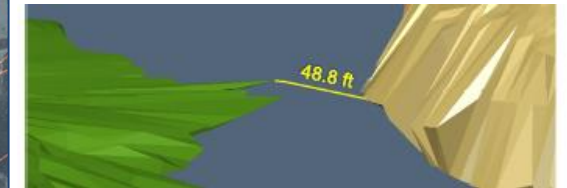
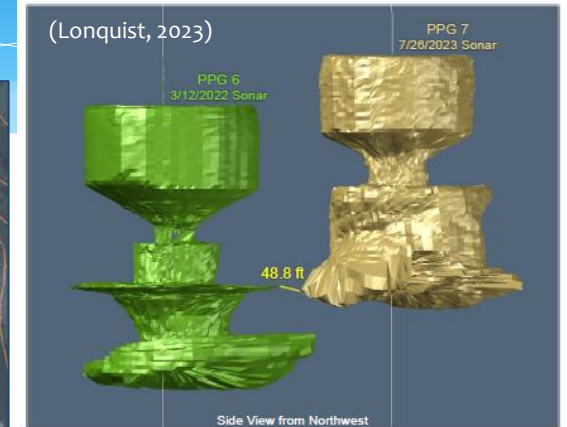
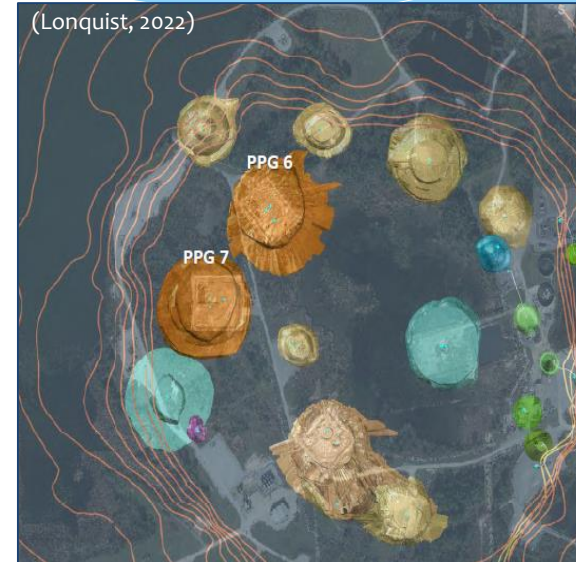
**Cavern No. 7:** Drill date = 10/22/1957; Inactive in 2014 (no longer mining)

→ **January 2023:** 24/7 injection began into **Cavern 7** (rate ~320 gallons per minute) after loss of mechanical integrity. **Pressure rapidly declines** if injection rate decreases or stops

- **Volume of Brine Injected into Cavern 7B:** ~3.2 mmbbls (as of 12/18/2023)
- **Volume of oil recovered out of PPG 7B:** ~54,975 bbls (as of 12/18/2023)

## Primary Concerns:

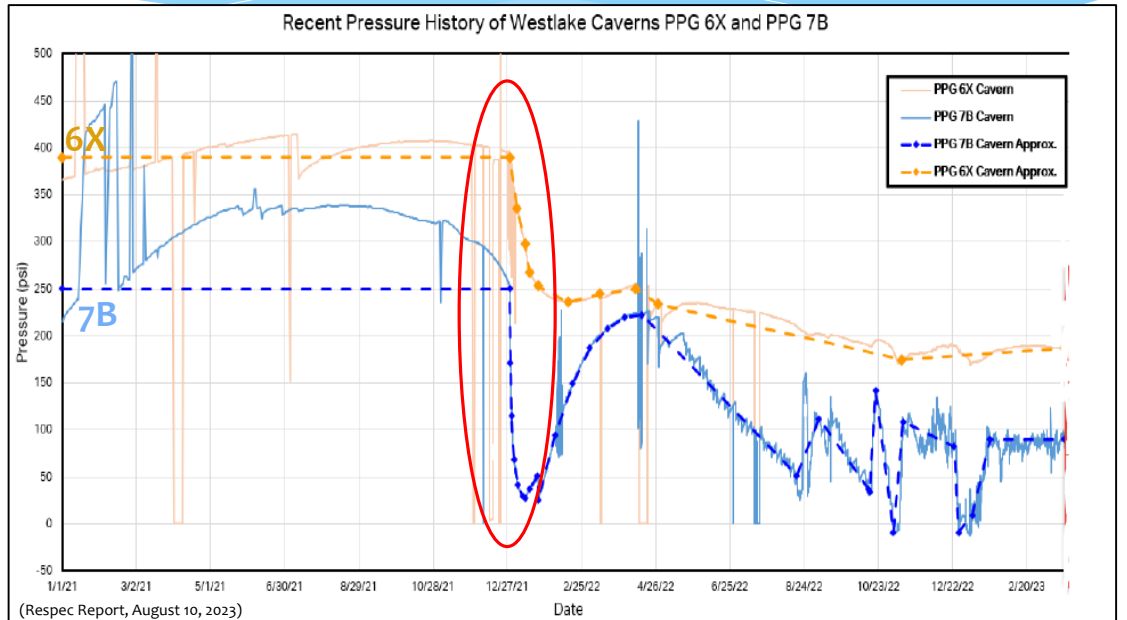
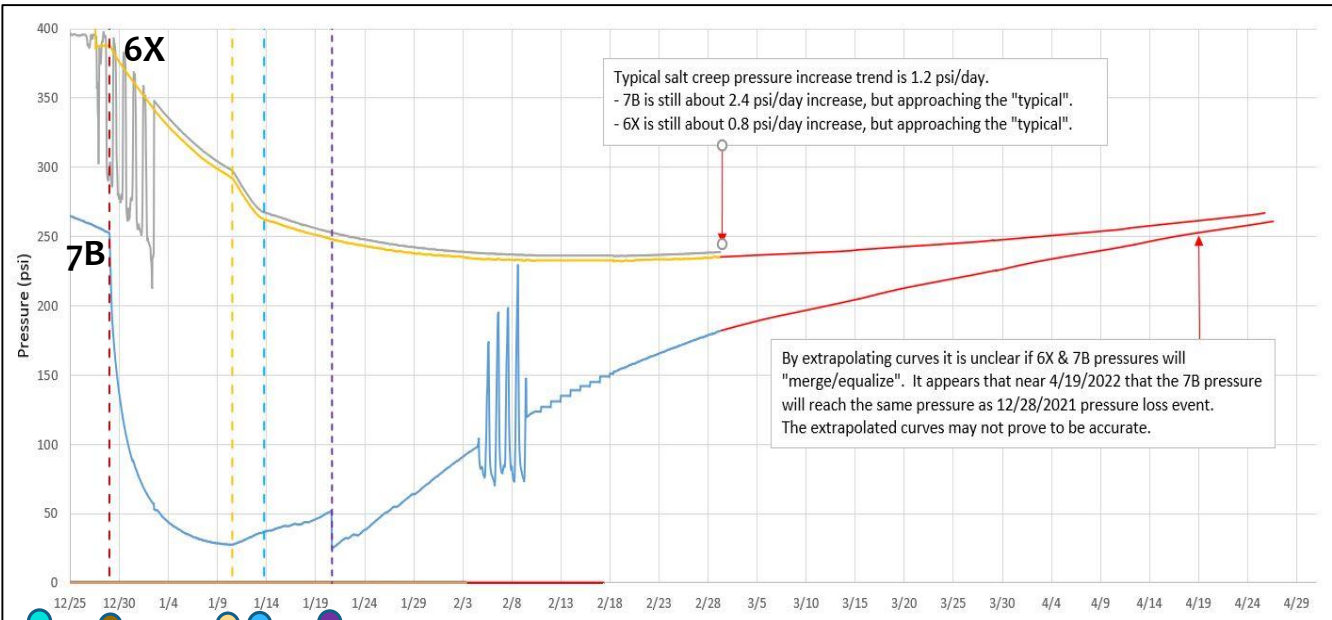
1. Structural and mechanical integrity of Caverns 6 and 7
2. Migration path of the fugitive brine from Cavern 7
3. Unknown source of hydrocarbons and release to surface
4. Potential threat to Chicot Aquifer (groundwater)





# Pressure Data: Caverns 6 and 7

## The Event – December 28, 2021



12-21-2021 6X MIT/Sonar Concluded  
 12-28-21 Pressure Event  
 01-10-22 Trend Shift 1  
 01-13-22 Trend Shift 2  
 01-20-22 Trend Shift 3 (7B only)

Westlake anticipated that the pressures would stabilize...

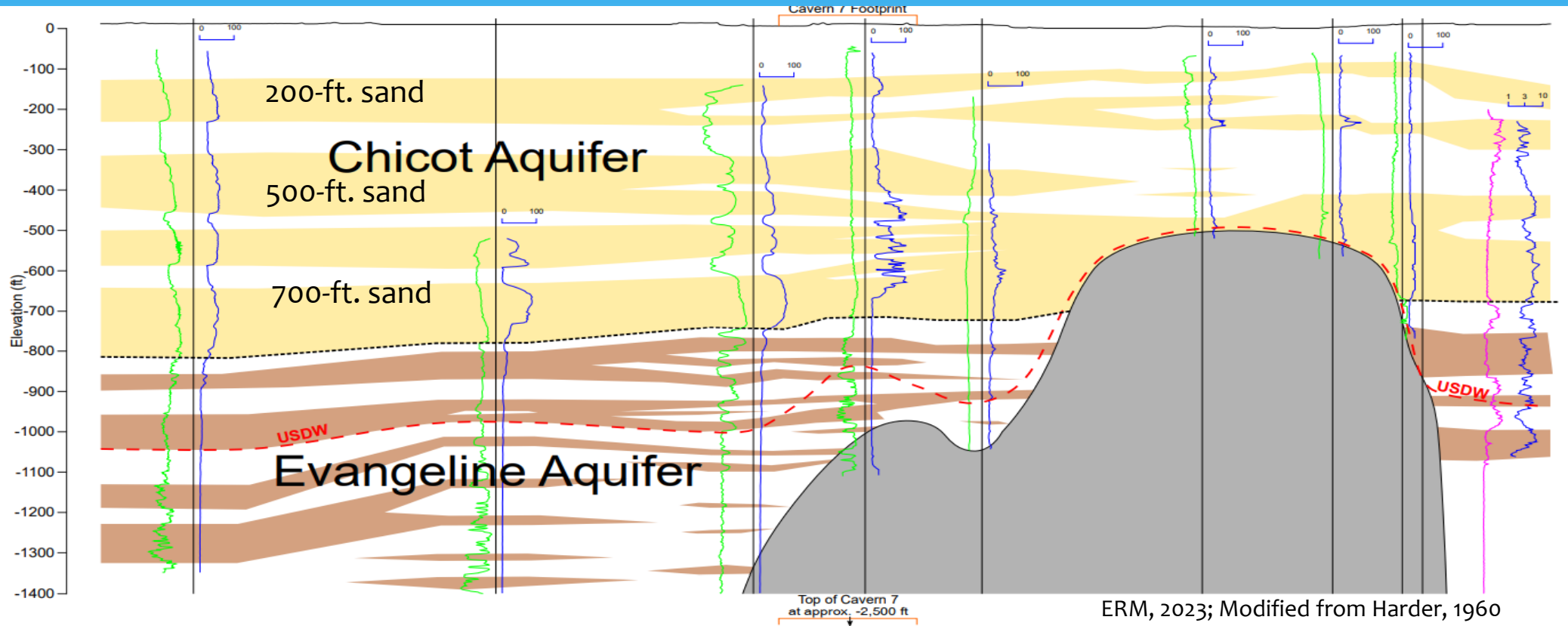
Pressures have not stabilized

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



# Potentially Impacted Areas: Groundwater

Generalized NW-SE Cross-Section



- There are 2 water bearing formations or aquifers in this area of the State, the **Chicot** and **Evangeline aquifers**.
- The **Evangeline aquifer** is **saline** near the dome and is not utilized.
- The **Chicot aquifer** is the sole source aquifer in this area and consists of the **200-ft.**, **500-ft.**, and **700-ft.** sands all of which are utilized regionally.



# Chicot Aquifer Investigation

- Identified all water wells within a 5-mile radius. Inspections have found a large number of domestic wells in the area no longer exist.
- Gathering available data on existing wells related to drawdown, static water levels, and water quality from USGS, OPH, etc. to establish background/baseline.
- Directed the operator to install (9) monitoring wells to evaluate the Chicot Aquifer around the caverns and dome.
- Pursuing assistance with aquifer modeling and evaluation through LSU and 3<sup>rd</sup> party contractor (procurement pending).



# Seismicity

## Micro-Earthquake (MEQ) – Passive Seismic Array



Figure 1. Google map image showing the location of the broadband seismic (Trillium Compact Sensors, yellow symbols and labels) stations near and at the Sulphur Mines Salt Dome.

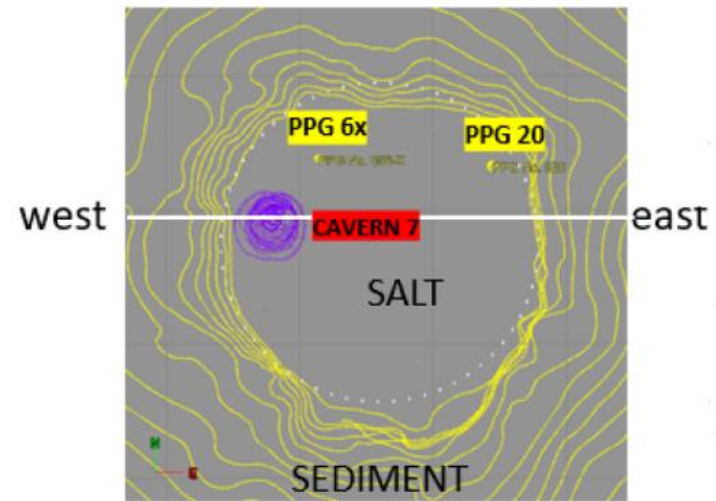
- **12/28/2021:** “The Event” is suspected to have been a MEQ event
- **3/18/2023:** MEQ event registering 0-1 (origin inconclusive likely due to depth); deep MEQ’s cannot be accurately located using a surface array
- **11/1/2023:** MEQ event (size and origin inconclusive)
- **1<sup>st</sup> Quarter of 2024:** Anticipated installation of a downhole seismic array. This will provide **instant notification** and will have less “noise” and more accuracy than that of the surface array.

“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
<b>0 to 2</b>	<b>Micro</b>	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



Cross section location

Downhole array locations



# Observed Impacts: Bubbles and Sheen Over the Dome

## 27 Gas Bubbling/Oil Sheen Locations

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

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

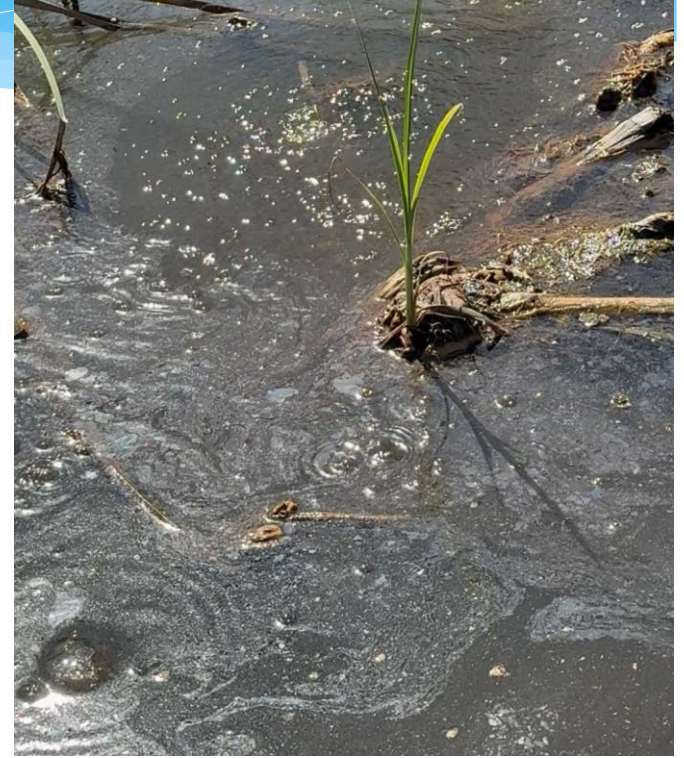
### Laboratory Analyses:

- Indicate that the samples of **methane** coming to surface is *mostly* thermogenic
- Indicate that **oil** sampled from the ground surface is **closely related to the oil being locally** produced by Yellow Rock (oil & gas operator)
- Indicate that the **oil recovered from Cavern 7** closely matches Middle Eastern oil profiles similar to the type of oil stored by the **Dept. of Energy-Strategic Petroleum Reserve** at this site from 1978-1994

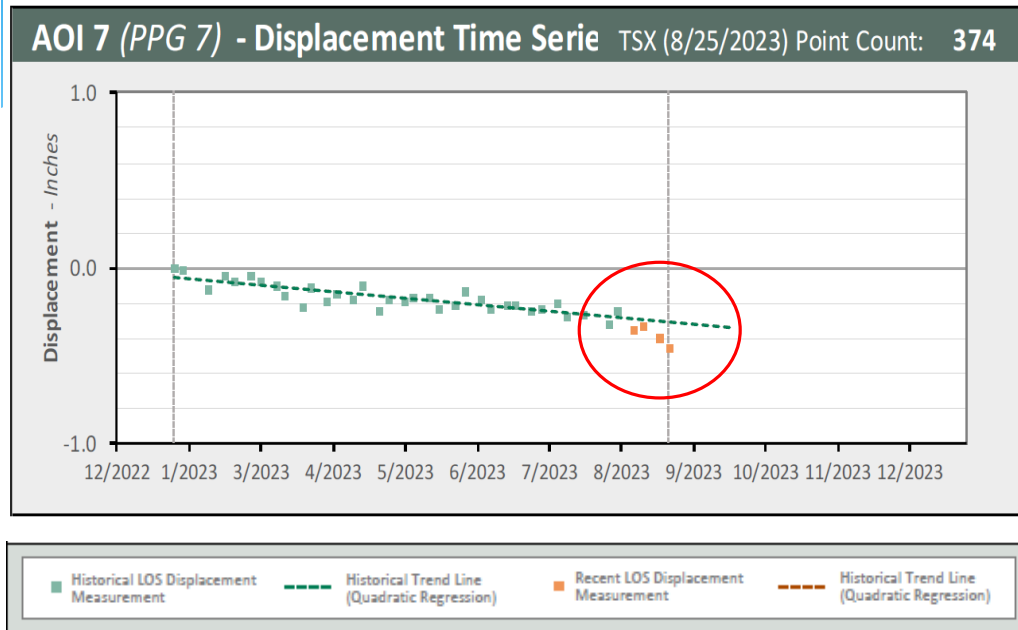
**\*Note:** Drought conditions and lack of rain affect bubbling observation efforts



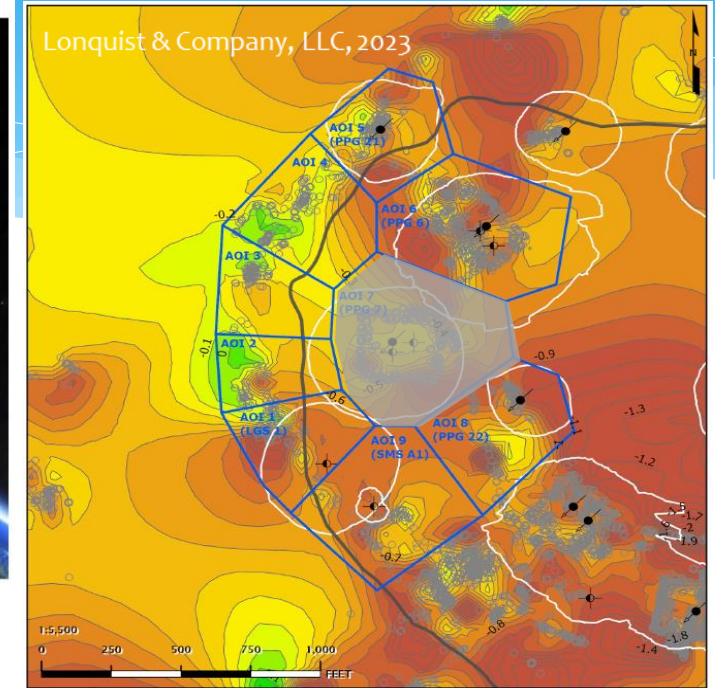
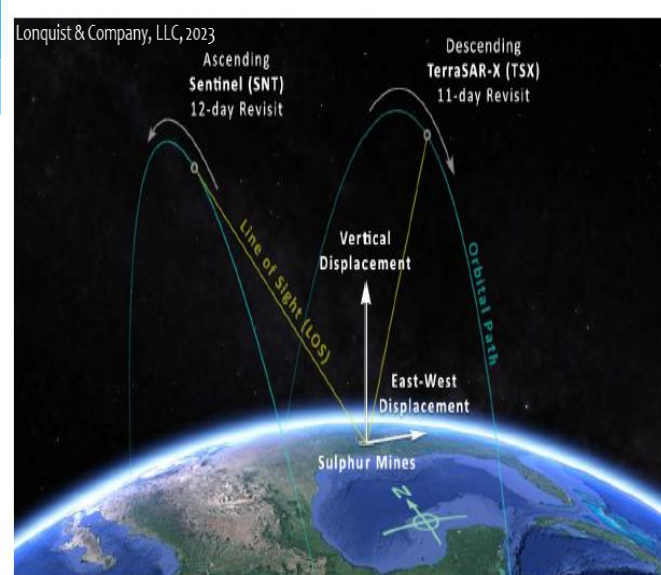
# Observed Impacts: Sheen & Oil Seep



# Observed Impacts: Subsidence



Displacement vs Time



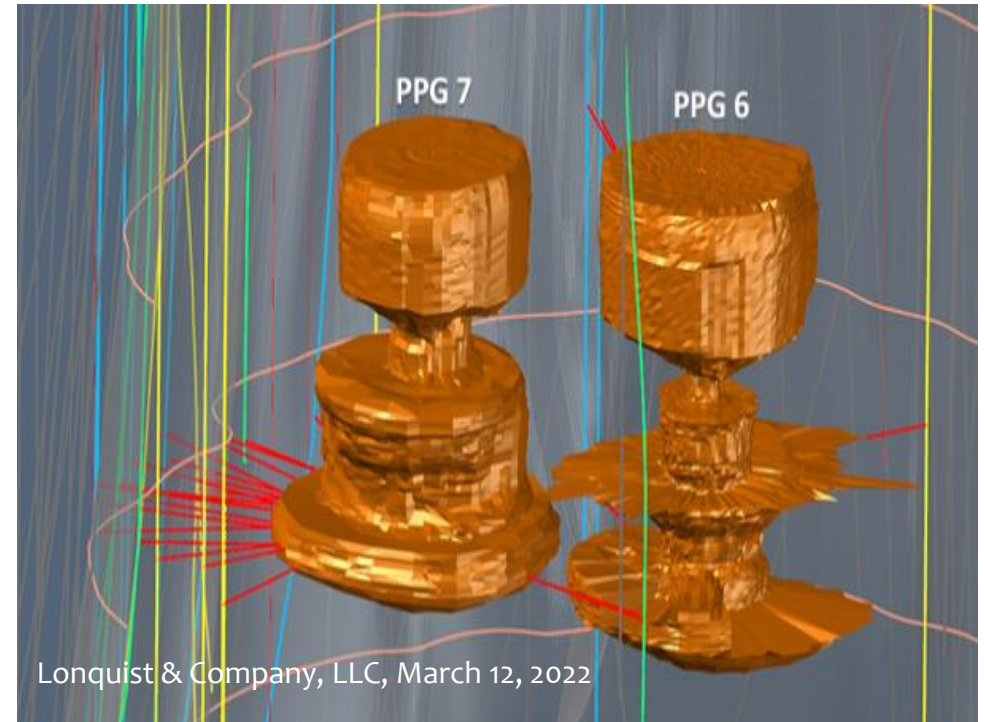
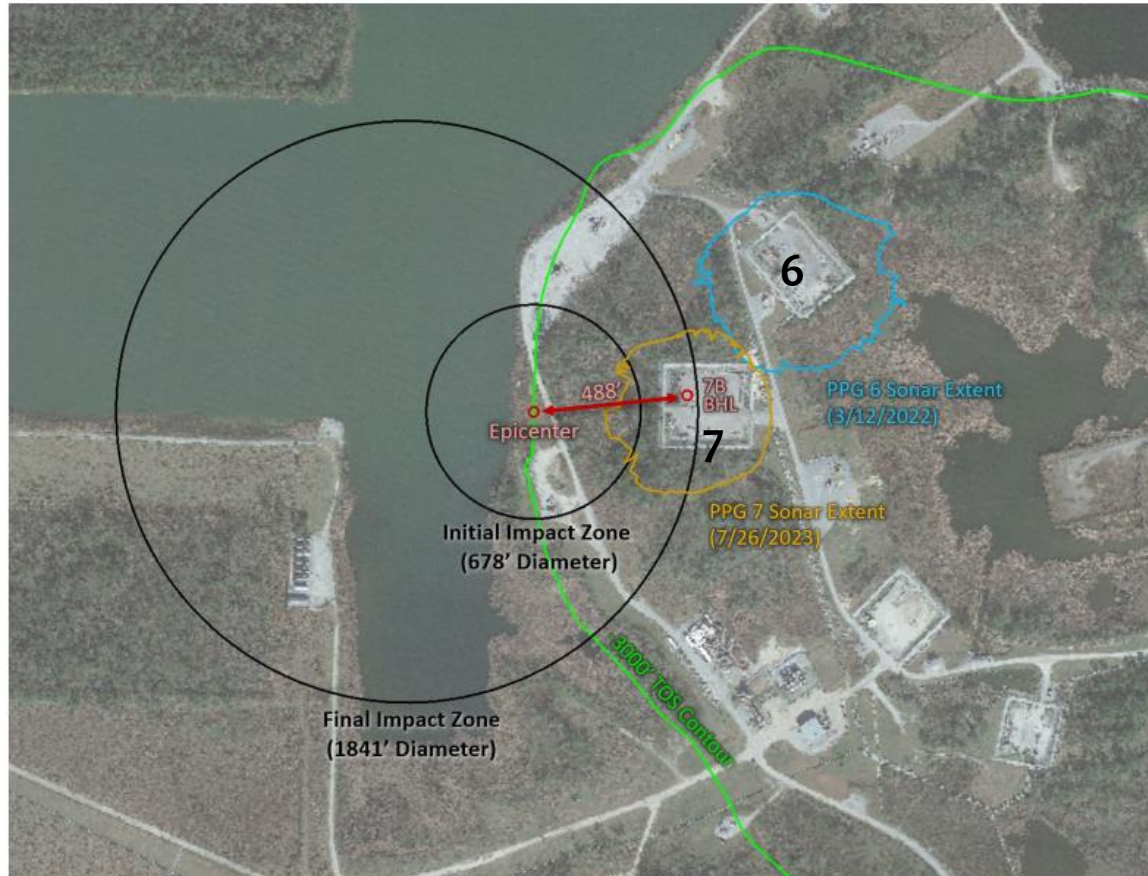
Note: Shaded AOI 7 covers the footprint of Cavern 7

- **Satellite (InSAR) 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



# Subsidence and Potential Sinkhole Formation

## Westlake's Impact Zone Analysis – November 2023

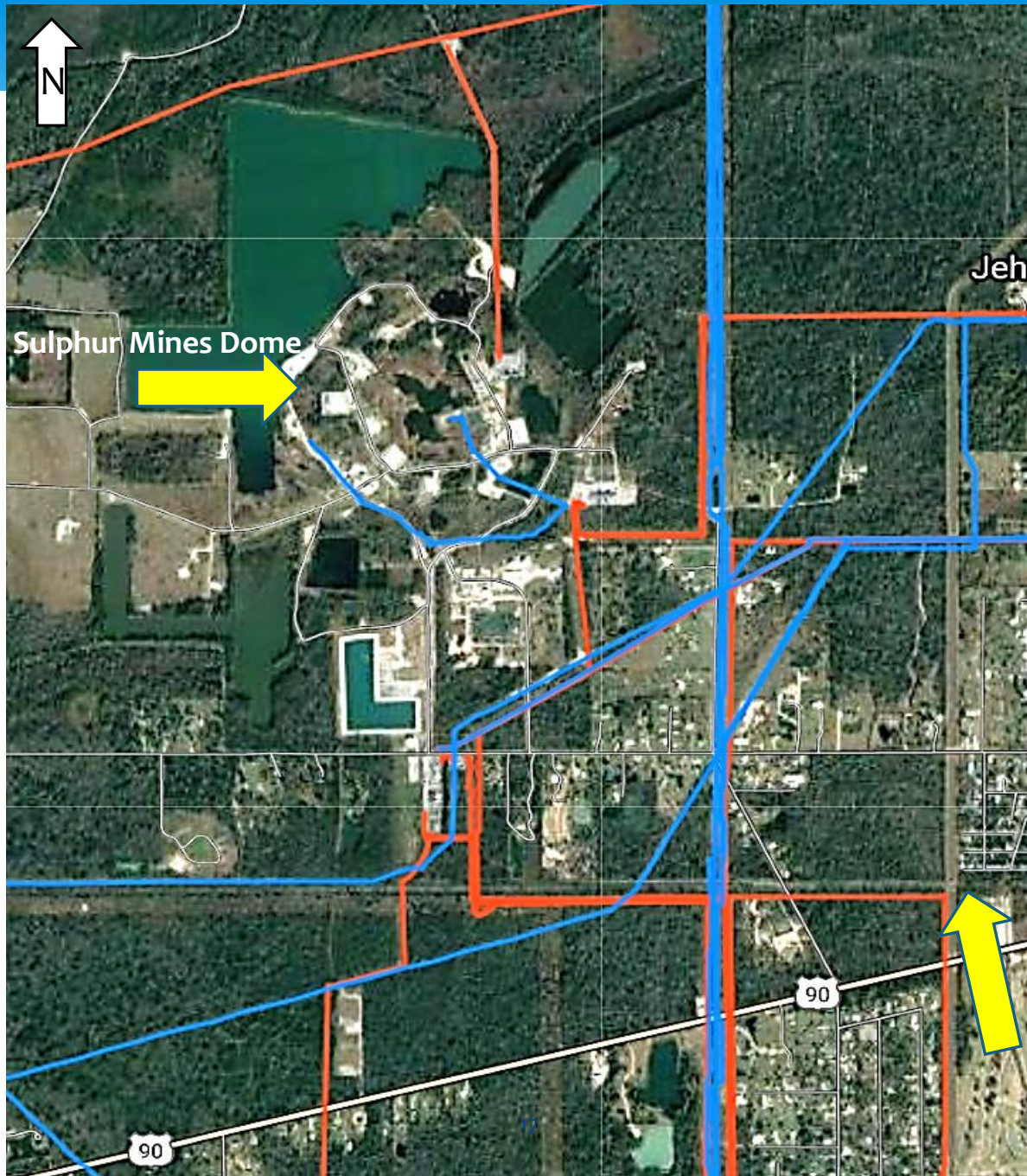


Lonquist & Company, LLC, March 12, 2022

LDNR has retained Agapito Associates, Inc. and they are working to validate the potential impact zone







## Existing Pipelines

**Red Lines** = liquid hydrocarbon pipelines

**Blue Lines** = gas pipelines

# Response Actions Taken by LDNR-OOC

## OOC's Response to Date:

- Issuance of **Compliance Order No. IMD 2022-027** (plus **three additional supplements**) to Westlake with a **civil penalty of \$65,000**
- 1-2 times weekly site inspections of the AOI/AOC by LDNR
- Subpoenas Issued and documents received
- Continuous review of data and monitoring
- Regularly scheduled meetings and progress check-ins with Westlake, adjacent dome operators, and other stakeholders
- Dedicated Sulphur Mines informational website (updated daily)

## OOC's Resources deployed to Sulphur Mines:

- In-house geologists and engineers continuously reviewing data as submitted
- Weekly site visits by OOC field inspectors
- Third party contractors
  - Agapito
  - TetraTech
  - LSU



## Ongoing Monitoring Required by OOC

Report Type	Reporting Frequency
Pressure and Operational Reports	<i>Daily</i>
Satellite (InSAR) Subsidence Reports	<i>Every 4, 7, and 12 days</i>
Microseismic Reports	<i>Biweekly</i>
Water Well Sampling	<i>Monthly</i>
Bubble Site Gas and Water Sampling	<i>Quarterly</i>

## Ongoing & Planned Projects Required by OOC

Project Type	Date Expected
Geomechanical Model (Phases 2-5)	<i>Mid January 2024</i>
Monitoring Well Installation, Logging and Sampling	<i>End of January 2024</i>
Borehole seismic installation in cavern nos. 6 & 20	<i>Early 1<sup>st</sup> Quarter 2024</i>
Containment Structure	<i>TBD</i>



# Community Questions



1. *What type of experts and resources have been sent to the area to study what's going on?*
2. *Who picks up the bill for that type of work?*
3. *When referring to these caverns, how many are we talking about that are being studied? Or, is there a "problem" with a certain number of caverns and underground are many caverns?*
4. *Could you help us "picture" what it looks like beneath the surface?*
  - a. *How far down is the cavern?*
  - b. *Do individual caverns hold petroleum products?*
  - c. *How long has the oil been in these caverns? If that is what holds the oil, are these caverns compromised, weakened, unable to hold pressure, etc.?*
5. *Did Westlake Corp. alert you to a potential problem based on something happening at the surface, inability of cavern to maintain pressure, or other problem?*
  - a. *Or, does your department or some other department check on these sites periodically? (How was the potential for problem discovered?)*
6. *What is under the Dept. of Natural Resources purview/umbrella? Which department is overseeing this issue?*
7. *I have contacted GOHSEP, and the local head of that program said that they have not taken any action? Why were they authorized? What kind of action do you see them taking?*

# Community Questions Continued



***8. What is the potential problem that led to the Declaration? What is your primary concern? Contaminating the water with salt, petroleum, other? An explosion? Are you trying to "get at" the reserves? Is there the danger of a sinkhole?***

***9. Will the first collapse cause any other dome to collapse?***

***10. How would it affect all of these underground pipelines?***

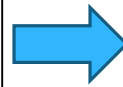
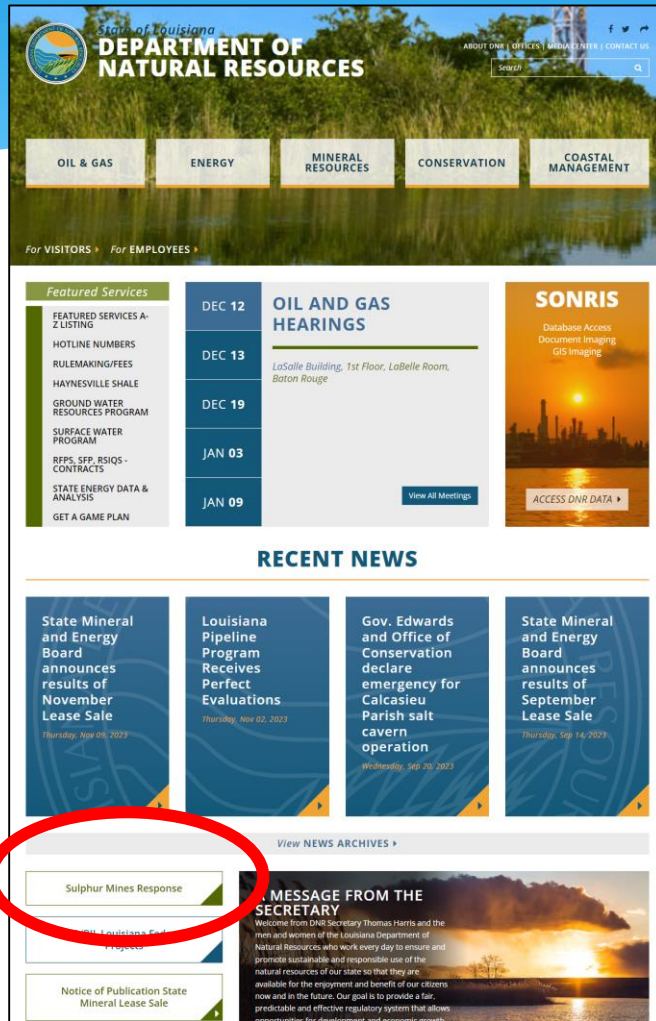
***11. What would be the effect on the houses according to the distance from the collapse of the dome?***

***12. Any warning signs?***

***13. Any flooding?***

***14. Any methane gas released?***

# LDNR-OOC Website Access



or

<https://dnr.louisiana.gov/SulphurMines>



# Coordinating Agencies and Consulting Experts

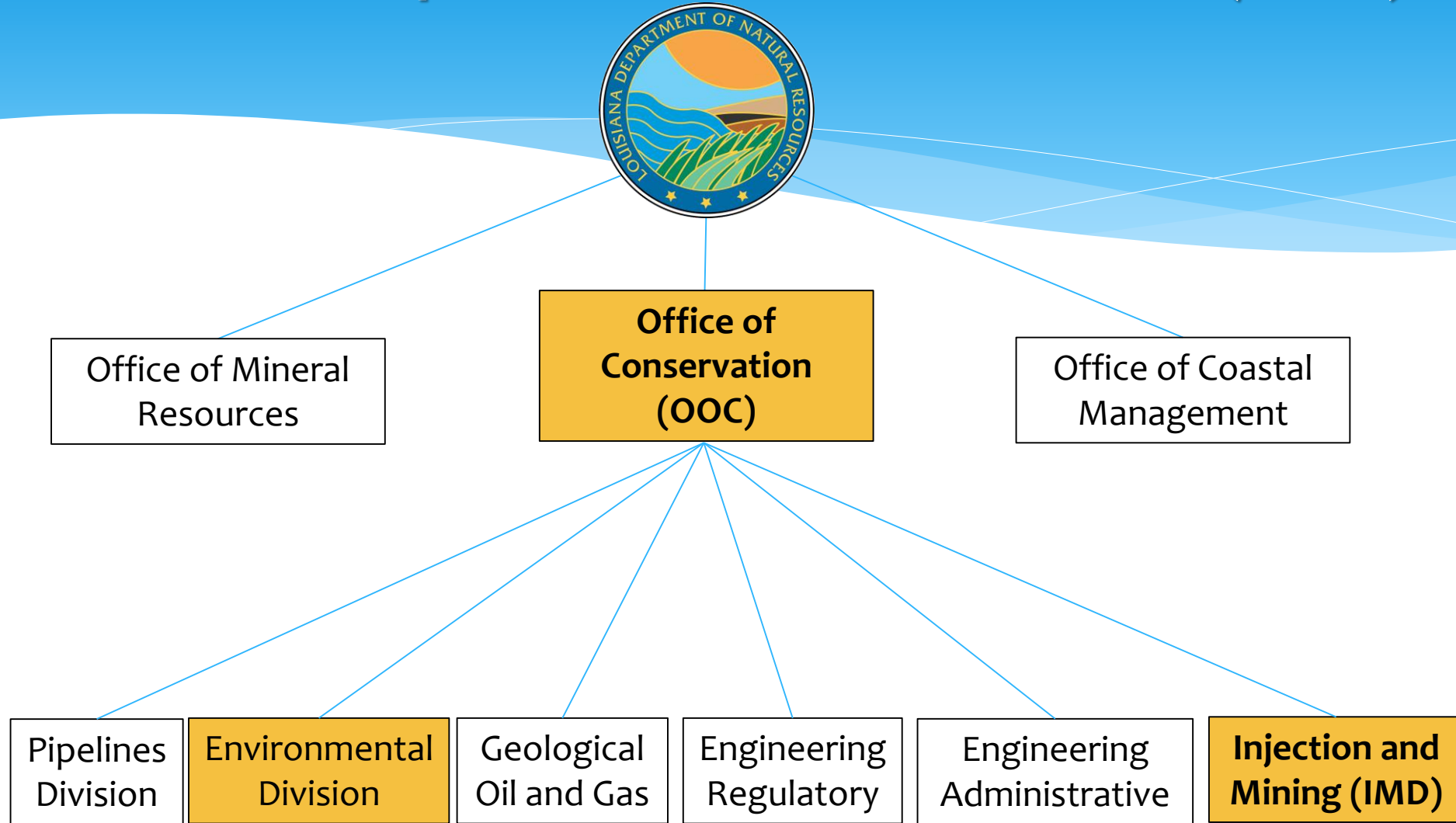




## Reference Slides

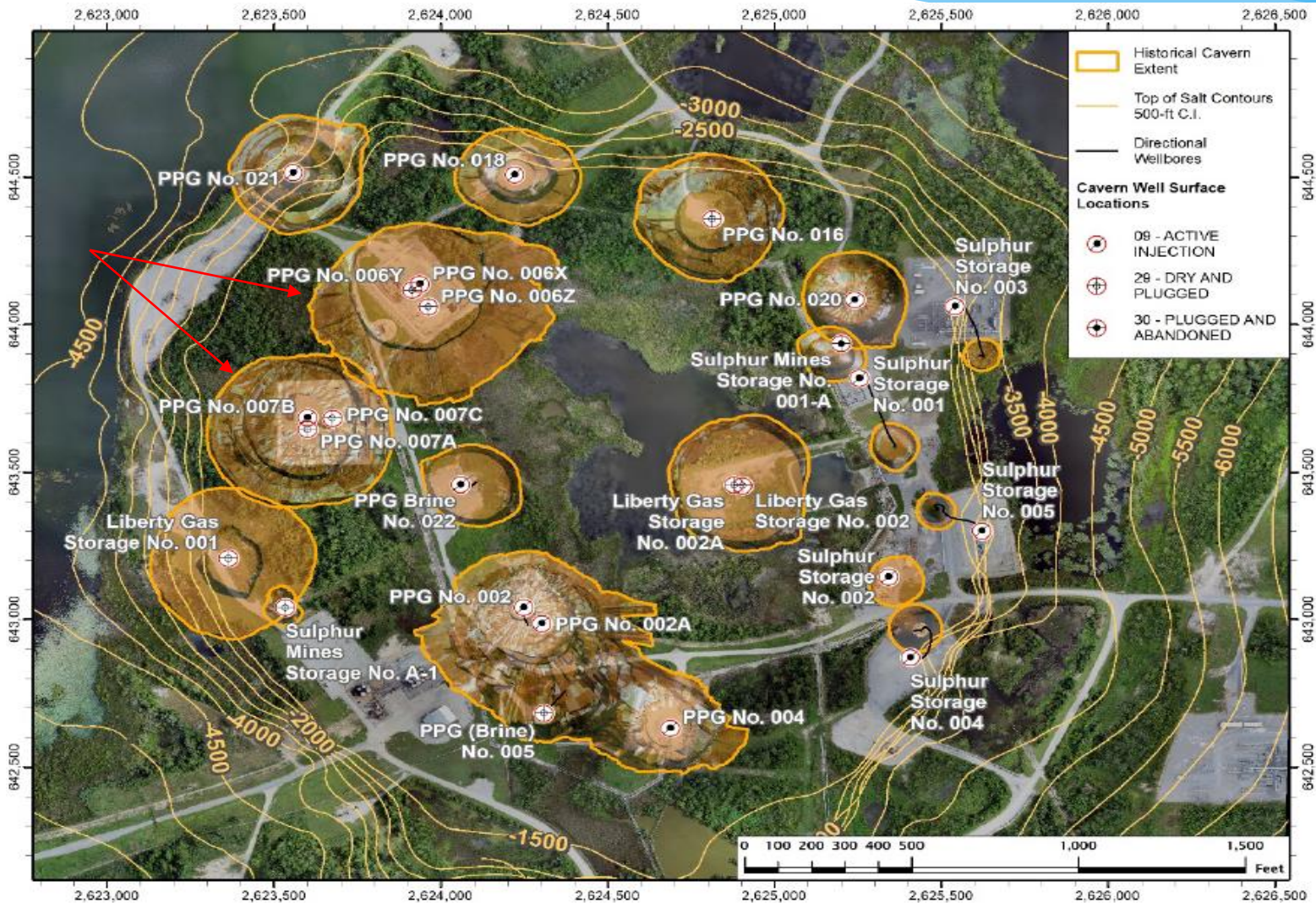


# Louisiana Department of Natural Resources (LDNR)



The Louisiana Office of Conservation was granted primacy  
of the UIC program in 1982

# Current Operations/Operators



- 19 Total Caverns
- 5 Caverns in active LPG storage (eastside)
- 3 Caverns actively brine mining
- 4 Caverns inactive
- 10 Caverns P&A
- 2 Active Cavern Operators: **Westlake and Boardwalk**
- 1 Inactive Operator with 2 P&A caverns: **Liberty Gas Storage**



## Additional OOC-Ordered Data Submitted by Westlake to Date:

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 VOC testing with PID (operator reported)
7. Quarterly Water Sampling and Testing
8. Isotopic & Lab Analyses of Oil, Gas, and Water at Multiple Locations
9. PPG 7B - Recovered Oil Reporting (timing varies)
10. Plan and Phase 1 of Geomechanical Model
11. Plan and Preliminary Risk Failure Report
12. Plan to Conduct USDW Evaluation
13. Plan to Install Groundwater Monitoring Wells
14. 6X and 7B Sonar Survey and Historical Comparisons
15. Plan to Acquire 3D Seismic Data for Mapping
16. Model of Depressurization Scenario (6X/7B)
17. Boat & Airboat Inspections and Path Clearing
18. Restriction of Access to Dome Facility
19. Westlake's Updated Emergency Response Plan
20. All Site Personnel Equipped with H<sub>2</sub>S Sensors & PPE
21. Installation of Downhole Pressure and Temperature Gauge (7B)
22. Top of Salt, Top of Caprock, Faulting, and Cavern Distances maps
23. Containment structure plans
24. Thermography Plan
25. Decommissioning Plan
26. Groundwater Metering Plan
27. Impact Zone Estimate
28. Delineation of Potential Impacts to Infrastructure (Surface & Subsurface)
29. Bathymetric survey plans for Central Lake and Salt Lake



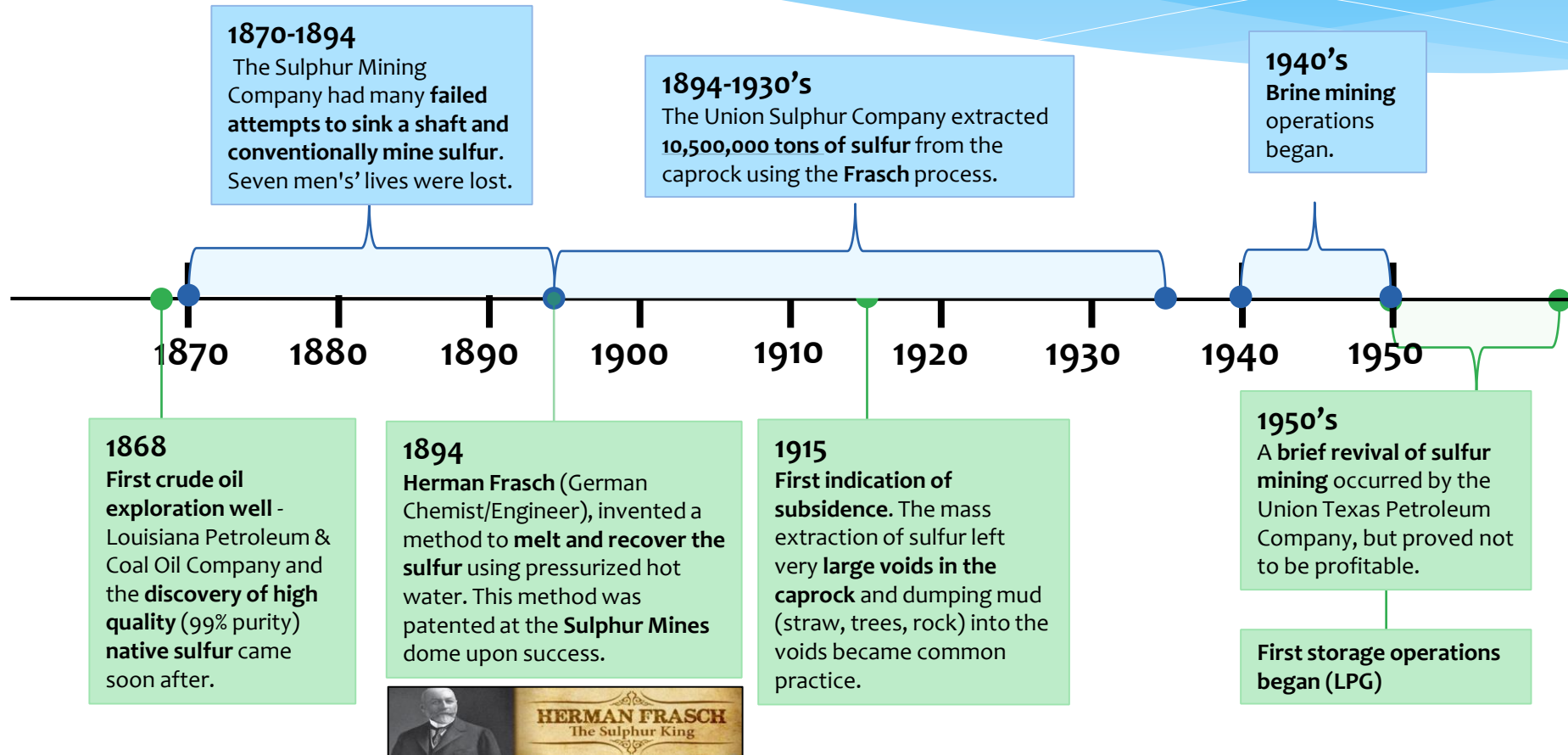
# Additional OOC-Ordered Data (not yet submitted):

## Technical

- Installation of tilt meters in all wells possible, would act as immediate alarm
- Continued satellite monitoring and future installment of artificial reflectors
- Additional monitoring wells (on and off dome)
- Plan for cavern backfilling
- Metering of expelled hydrocarbon at known surface locations
- Brine plume monitoring and identification of leak path
- Thermography camera(s) for instant hydrocarbon detection at the ground surface
- Collaborate with 3<sup>rd</sup> party experts – environmental remediation, rock mechanics, geophysical
- All dome operators to coordinate a dome-wide salt and caprock mapping effort



# Timeline: Pre-1950s



# Timeline: 1950 to 2022

