Blue Ribbon Commission on Bayou Corne and Grand Bayou Public Safety

SUMMARY OF CURRENT GROUND STABILITY UNDERSTANDING AND RECOMMENDATIONS

1. Background

The Blue Ribbon Commission (BRC) on Bayou Corne/Grand Bayou Public Safety is tasked with recommending the stability conditions necessary to lift the mandatory evacuation order for Bayou Corne, which will ensure that the ground stability in the area surrounding the sinkhole along the western edge of the Napoleonville Salt Dome in Assumption Parish, Louisiana remains safe for residents and visitors.

This document contains an assessment of the current surface and sub-surface conditions on the western side of the Napoleonville Salt Dome as impacted by the failure of the Oxy-Geismar No. 3 (Oxy 3) cavern. This assessment is based on current understanding and available data at the time this whitepaper was drafted and it should be noted that those conditions are subject to change. Following from this assessment is a set of recommendations for appropriate actions to be taken at the site and a framework for monitoring of the stability moving forward.

All of this information has been reviewed and considered by the BRC Stability Subgroup, in coordination with the full commission, and the BRC offers the following guidance regarding stability monitoring and reporting.

2. Current Stability Monitoring and Reporting

The following excerpts provide information on the intent of the Charter specifically related to the stability issues for the BRC.

> The Commission is to determine the conditions necessary to ensure that appropriate benchmarks are met regarding the mandatory evacuation order and the conditions in the area surrounding the sinkhole along the western edge of the Napoleonville Salt Dome in Assumption Parish, Louisiana. It is expected that the data necessary for the Commission to determine these conditions has either been collected, is in the process of being collected, or is scheduled to be collected. If said data is inadequate, the Commission will identify the additional data needs. Additionally the Commission will provide recommendations to the Unified Command Group (UCG). The Commission will prepare a report with recommendations that include the following:
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> - Determine the current and future structural stability of the western edge of the Napoleonville Salt Dome with consideration of salt cavern operations and public safety.
> - Determine the stability and management of the sinkhole and underlying Disturbed Rock Zone (DRZ) to protect public safety.

Although there have been previous examples of cavern collapses throughout the world, in these cases the roof of the cavern has collapsed causing a cylinder of rock and sediment above to fall in. The Oxy 3 cavern collapse is historically unprecedented in that a salt cavern wall failure allowed material adjacent to the salt dome to collapse into the cavern thousands of feet deep. The unexpected and rapid collapse of sediments along the flank of the dome disrupted geologically trapped hydrocarbons allowing liquids and gas to migrate upward to surface, posing potential risks to residents of the community.

In order to provide recommendations the Commission was tasked with addressing at least two key factors:

- Establish appropriate remediation/monitoring benchmarks or conditions to ensure sustained public safety.
- Define additional data needed to assess current conditions and define remediation/monitoring benchmarks.

Texas Brine Company, LLC (TBC) is currently performing a number of monitoring initiatives at Bayou Corne (Table 1). Furthermore, the BRC has provided a number of Recommended Requirements Documents (RRDs) to the Louisiana Department of Natural Resources (LDNR), the Office of Conservation (OC), the Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP), and Assumption Parish Office of Emergency Preparedness (OEP). TBC data-collection efforts, per the technical requirements recommended by the BRC, are ongoing.

The cavern is currently being monitored by an extensive surface and borehole seismic network operated by TBC. Cavern wellhead-brine pressures are being recorded on a 10-second interval and currently cavern-floor wireline tags and simultaneous pressure-density logs are conducted once every two weeks. A high-resolution 3D seismic investigation in the vicinity of the cavern to assess geologic conditions down to over 8,000 feet deep was performed and numerous 3D geomechanical models were developed to aid in the analysis of subsurface conditions and interpretation of the data being collected. Interpretation of the 3D seismic and development of the 3D geomechanical models was contracted by LDNR.

Within the Charter of the BRC, the Stability Subgroup has, to the best of its ability within the limitations of available data, assessed the current and future structural stability of the western edge of the Napoleonville Salt Dome with consideration of salt cavern operations close to that edge and public safety, including the effect the collapse of the Oxy 3 cavern has had on the current and future stability of nearby caverns (Oxy-Geismar No. 1, 2, 9 and 10) or adjacent portions of the Napoleonville Salt Dome. Following from these conditions is a set of recommendations for appropriate actions to be taken at the site including a framework for monitoring of the stability moving forward. Data acquired within existing monitoring initiatives, the RRDs and this monitoring framework should be available for use by LDNR/OC, with the support of other agencies as appropriate, and LDNR/OC should be the regulatory agency responsible to establish final safety benchmarks. The assessment of the BRC is summarized here.

3. Bayou Corne Stability Monitoring Framework

BRC Charge:
- Determine the short and long-term measures that should be undertaken to monitor the stability of the western edge of the Napoleonville Salt Dome, existing caverns, and surrounding sedimentary layers.

As a requirement for the continued mining of any caverns on the western edge of the Napoleonville Salt Dome the BRC recommends that a specific monitoring framework be implemented (this includes any continuation, initiation or restarting of mining in Oxy caverns 1, 2, 3, 9 and 10, or any portions of the dome immediately adjacent to these caverns defined by the State).

The framework should include a ***Mining Operations Plan*** provided by the site operator(s), and an assessment of the *long-term site stability* performed using geomechanical assessment tools including 3D geomechanical models constructed to effectively consider the uncertainties in subsurface conditions. The geomechanical assessment should be validated against robust site measurements performed by the operator(s), regularly reviewed as part of a quality and safety management system, and with additional site characterization considered to reduce uncertainties in the assessment as appropriate.

The BRC recommends continued and ongoing monitoring described in Table 1 and Table 2. The monitoring and stability assessment needs within the framework are recommended in the sections below. These recommendations aim to assess the site stability including plans for the safe decommissioning of the caverns and are thus recommended even if all brine extraction *per se* is ceased. In order to provide robust information, all site measurements should have sufficient instrument coverage and long-term redundancy, data sampling and quality fit for purpose through industry standards, and be thoroughly reviewed for completeness and quality by experts independent of the operator(s). All data should be analyzed by the operator(s) and interpreted in terms of site stability. The initial and subsequent annual reports on the site stability should be prepared and submitted by the operator(s) to the LDNR/OC.

Due to current uncertainties and continued mining operations, the monitoring framework should be implemented by the operator(s) in its entirety as soon as reasonably possible and a deadline should be set for this implementation. It is reasonable to expect such a framework be developed and implemented within 12 months. In the event such a monitoring framework is not established and implemented, the BRC recommends that mining operations be stopped on that deadline. As such, the BRC recommends that a full monitoring framework proposal be submitted by the operator(s) for review and approval by LDNR/OC within 3 months of the date of this document.

It is clear to the BRC that there are ongoing stability dynamics in the pillars between Oxy caverns 1, 2, 3 and 9, inducing stress changes and salt disturbance that generate micro-earthquakes (MEQs) in that salt volume and pressure changes connected between caverns. The significance and urgency of these challenges are not clear and thus an expedient but reasoned approach must be taken. The BRC therefore recommends that the initial geomechanical assessment be performed within 6 months of the date of this document with initial focus on the barrier pillar between Oxy 1, 2 and 3 with explanations for the observed MEQs and pressure changes. The assessment should include analyses for possible mechanisms (particularly structural and geological related) of accelerating failure of the caverns and provide recommendations for additional monitoring needs that might provide a warning before a future collapse if it were to occur. The geomechanical assessment should be regularly reviewed and updated on a 3 month basis, and include analysis of changing MEQ data as such changes are detected.

In addition to these efforts by the operator(s), the BRC also recommends that the State continue its ongoing review of *operational site stability* (daily review of site conditions and interaction with site operators through dedicated personnel). This work should include ongoing review of recorded data, independent analysis and provision of advice and recommendations to the State for the site stability, and ongoing review of site operations that may have an impact on the stability.

Collection of data following implementation of the monitoring framework may assist in the development and further refinement of stability safety benchmarks State wide by the appropriate regulatory agencies.

The BRC further recommends that the State of Louisiana continue to advance the knowledge of the sub-surface behavior occurring in and around the Napoleonville Salt Dome by soliciting rigorous and open scientific analyses of the data collected and using these analyses within the general permitting regulations used across the dome. The BRC recommends that all stability data be made easily accessible to the public including in an electronic format on the Internet through a single web portal.

3.1 Condition of Caverns and Salt Dome

BRC Charge:

- Determine the current and future structural stability of the western edge of the Napoleonville Salt Dome with consideration of salt cavern operations and public safety.
- Determine the effect the collapse of the Oxy-Geismar No. 3 cavern has had on the current and future stability of nearby caverns or adjacent portions of the Napoleonville Salt Dome.

It is now believed that a portion of the OXY 3 western cavern wall breached inward into the cavern partly due to the thin salt wall (pillar) between the cavern and the sedimentary formations outside of the dome. The timing of the breach is uncertain, however, in 2010 the cavern failed an integrity test (i.e., pressure tightness) and the cavern well was plugged and abandoned following the failed test. The breach started the filling of the cavern from the bottom upwards – it is likely the breach was above the bottom so the filling of the cavern was initially downward as sedimentary material (broken rock and/or unconsolidated sediments) flowed inwards.

The sedimentary material and broken salt initially flowed into the cavern as a highly viscous flow. The driving force for this movement was the weight of the bounding sedimentary material. There is no evidence of substantial damage in the roof of the cavern; however stress-induced fractures may exist in this volume as evidenced by data, including observations in Oxy 3A relief well, MEQs and geomechanical model results. The size of the breach in the western wall is unknown and could be a "puncture" of the order 10s to 100s of feet through to the majority of the entire wall having collapsed.

The history of brine pressure and sediment compaction in the cavern is complex. We believe that the bottom portion of the cavern fill has compacted to a point at which it may impact the cavern pressure evolution by providing a stiffer plug of material beneath the stratifying sludge above. The compacting fill has direct hydraulic and/or mechanical connection to surrounding sedimentary formations and the associated DRZ. The cavern pressure responds essentially instantly to sinkhole sloughing and Very Long Period seismic events (VLPs) and therefore appears to be coupled and interdependent - although the causal effects are highly uncertain (whether behavior of material in the cavern drives sloughing and VLP activity outside or vice versa).

It is our belief that the cavern will continue to fill with sedimentary material while the material within the cavern compacts for many years to come. The filling rate will slow relative to the initial period after cavern failure as the stratifying sludge has reached the cavern top. Gas accumulation has periodically appeared in the roof of the cavern and/or the Oxy 3A relief well, affecting pressure measurements at the wellhead. The observed VLPs are believed to be associated with the movement of sedimentary material and fluids through constricted pathways in the DRZ. MEQs originate in the salt and caprock and are believed to be associated with mechanical deformation and/or elevated pore pressures, and likely relate to disturbance on fractures of the scale feet to 10s of feet. Some MEQs have been located in the sedimentary material below the sinkhole; however the locations are highly uncertain due to the seismic characteristics of the sedimentary materials and the salt-sediment interface.

The BRC's current assessment of stability conditions of the OXY 3 cavern, surrounding western edge of the salt dome, and neighboring Oxy caverns is summarized as follows.

a) The Oxy 3 cavern is experiencing fill movements, pressure evolution and MEQs. These ongoing events are currently not of an increasing scale that might warrant immediate concern of further catastrophic collapse of Oxy 3.

b) The Oxy 3 cavern itself should continue to stabilize with time as it fills with compacting sediment, however this will take many years, and an as-yet-unknown salt instability immediately around or above the cavern could impact this stabilization progress.

c) At this time, there is high uncertainty regarding how the Oxy 3 wall collapse has affected the western flank of the salt dome and how the stability conditions of the flank will progress in the future.

d) There is evidence for stress changes and salt disturbance in the pillars between Oxy caverns 1, 2, 3 and 9, that manifests as MEQs in that salt volume and pressure changes connected between caverns. The significance and urgency of these stability challenges are not clear and thus no conclusion can be yet drawn on the integrity of those caverns neighboring Oxy 3. As such, the stability conditions at the site warrant a continuous review through the monitoring framework introduced here including site-wide stability monitoring combined with 3D geomechanical assessment.

e) MEQ locations suggest that fracturing is occurring around the Oxy 3 cavern and between the Oxy 1, 2, and 3 caverns. The MEQ magnitudes suggest the scale of this fracturing is on the order of feet to 10s of feet in dimension. The normal, or expected, background level of MEQs for mining and storage operations in this cavern field has not been established and therefore the significance of this activity cannot yet be concluded.

f) The MEQ activity needs to be monitored, analyzed and better understood, so that the significance of the rock/salt breakage can be better considered in the overall site stability assessment and mining plans.

g) A cautious approach is warranted for continued mining in the Oxy caverns, meaning that mining should only continue if a long term operations plan is implemented that includes site monitoring combined with 3D geomechanical assessment to predict the long-term sub-surface behavior and site stability. The plan needs to consider: (i) If collapse of the western wall of the Oxy 3 cavern is over a significant area (the size of the breach is unknown) then the effective western edge of the salt dome becomes the eastern wall of the Oxy 3 cavern for the purposes of activities in the neighboring Oxy caverns; (ii) Brining operations continue in some of the adjacent caverns, and it is unknown how the active brining is changing cavern Pillar Thickness/Cavern Diameter ("P/D" ratios) and/or how the changing cavern shapes are impacting the stability of these caverns.

h) Subsidence measurements show that the western portion of the dome continues to subside at a faster rate than before 2010. MEQs occur within the caprock above the OXY 3 cavern, as well as other locations. The MEQ activity indicates there is ongoing salt movement, some of which is likely normal around any salt cavern or mine. The effect of dissolution in the caprock is unknown.

i) The 2013 3D seismic interpretation by Don Marlin suggests that faults exist in the caprock adjacent to the sinkhole. It is not known at this time when faulting or fracturing occurred or whether hydrologic flow around the caprock or salt has changed post collapse.

3.2 Recommendations: Caverns and Salt Dome

The BRC recommends that the monitoring framework consists of the following items related to the stability of the caverns and salt dome. (In conjunction with the monitoring initiatives currently underway, as outlined in Table 1, the BRC has developed Table 2 with specific recommendations to be implemented for monitoring the caverns.) The BRC

believes the operator(s) should be responsible for designing particular techniques and equipment specifications to fit within the recommended framework.

- Continued pressure monitoring of Oxy 3A:
  - Improvement through the installation and monitoring of a downhole pressure transducer to more accurately record pressure in the cavern compared with existing pressure monitoring;
  - Improve using higher frequency downhole monitoring (greater time resolution) and clock synchronization with other measurements.
- Develop a cavern well-specific monitoring procedure to monitor cavern pressure, inspect well casing and casing seat integrity.
- Continued subsidence surveys across the dome and caverns (annual reports for Napoleonville Cavern Operators currently provided by the consultant Joe Ratigan). Consider additionally performing semi-annual level-line subsidence surveys of the same markers used the in the Joe Ratigan report but just for the western portion of the dome.
- Use soil or sediment mechanics expertise to understand the rheology of the Oxy 3 cavern fill and assess the likely behavior of this fill with time as it compacts. This requires that samples of the fill material be collected for analysis.
- Continue to improve understanding of whether the MEQs are to be expected using principals of rock and fracture mechanics, and define which MEQs, in terms of changes in position and other seismic parameters, may be hints of changing dome or cavern stability.
- Continue to monitor and report on Oxy 1, 2, 9, and 10 well pressures.
- Continue to maintain Oxy 1 shut-in pressure with no additional brining.
- Perform regular and frequent Mechanical Integrity Tests (MITs) on Oxy 2 and 9. The testing procedures and schedule should be proposed by the operator, however, due to the stability uncertainties at Bayou Corne the BRC expects 6 to 12 months to be reasonable.
- For Oxy 2, 9 and 10, develop operational protocols for site-specific P/D ratio and stable cavern shape using 3D geomechanical models with validation using appropriate site measurements. Use the combination of geomechanical models and site measurements to assess the ongoing stability of the Oxy cavern field, the salt pillars, the western section of the Napoleonville Salt Dome, the overlying cap rock and surrounding sedimentary layers.
- Continue to perform sonar surveys regularly on the caverns 2, 9 and 10.
- Any structures, utilities and pipelines within a reasonable distance of the collapse should be evaluated for stress analysis, special monitoring, and possible relocation (the distance

criteria should be determined by the operator based on what is reasonable for the sensitivity of the infrastructure to the effects of the collapse).

- Conduct an assessment, including using 3D geomechanical modeling, of how the Oxy 1, 2, 3, 9, and 10 cavern wells should be abandoned, the stability conditions when this is safe to do so, the requirements needed to ensure stability continues to be monitored after abandonment and the corrective actions needed if instability is observed.

As part of the State's improvements to the regulatory framework, the BRC also offers the suggestion that the LDNR consider the feasibility of expanding the requirement for operational protocols for site-specific P/D ratio and stable cavern shape to all Napoleonville caverns, and then in some form consider implementing state wide, to better understand similarities and differences with other domes and caverns, possibly combined with a requirement of MEQ data for 'highest risk' sites.

3.3 Sinkhole and Underlying Disturbed Rock Zone (DRZ)

BRC Charge:
- Determine the stability and management of the sinkhole and underlying DRZ to protect public safety

The BRC believes that the DRZ partially developed in the year prior to the first sinkhole observation at the surface, although its exact initiation time is uncertain. It is believed that the initial Oxy 3 cavern breach triggered the formation of the DRZ, which progressively moved upwards as mass moved into the cavern. This is suggested by the seismic events and changes in subsidence prior to the sinkhole formation.

In contrast to the DRZ, it is believed that the sinkhole formed by sedimentary material dropping and flowing downwards replacing the DRZ volume flowing into the Oxy 3 cavern. Observations of plant material in the cavern indicate that some materials originating from very near the surface have flowed into the cavern. The size and shape of the DRZ is highly uncertain and could extend from 50 to 600 ft. from the salt dome wall into the sedimentary layers. The DRZ is likely a mixture of broken rock, sedimentary material, and fluids, with a zone of more intact rock and less disturbed sediments at greater depth and distance from the salt. The DRZ growth may have been guided by a weaker 'sheath' zone (where salt is in contact with sedimentary material) along the salt dome edge.

The specific structure and mechanics of the connection between the sinkhole and the DRZ, and how this has evolved with time, is uncertain. The structure of this connection could include sedimentary material disturbance and movement below and around the sinkhole (potential evidence includes 3D seismic and MEQs) as well as subsurface pathways through which some materials flow out of the bottom of the sinkhole (potential evidence for an induced pipe and/or piping network formed by the collapse includes VLPs and sinkhole depth tags).

It is believed that as the DRZ formed, and its structure propagated up towards the surface, it liberated gas, oil and other fluids from sedimentary layers bounding the salt dome, either by directly disturbing these layers or by creating new subsurface pathways through the sedimentary material comprising rock and unconsolidated sediments. It is believed that these less dense fluids are then able to migrate to shallower sediments and through the ground surface and sinkhole. Analysis of computer models for this fluid behavior in the DRZ and near surface compared with recorded site data may assist in determining the current and future behavior of the natural gas emissions continuing to be observed at the surface.

Current sub-surface ground conditions are affected by complex interactions between the sedimentary layers and the salt dome in an area of substantial ground disturbance surrounding the failed Oxy 3 cavern. The character, position and extent of the DRZ as well as the nature of the DRZ material, including its mechanical response and hydraulic behavior, are important in being able to make improved predictions about the ground response, including the sinkhole's lateral expansion. These properties are poorly understood at this time and thus highly uncertain.

It is believed that salt dissolution (due to movement of fresh water or undersaturated salt water in the subsurface through pathways induced by the collapse) may have played a role, and may continue to play a role, in creating subsurface disturbances that may have significant effects on the stability assessments reported here and in the future. The salt-sediment interface may be subject to salt dissolution when structural, hydraulic, or drilling induced changes occur from what was previously a stable condition.

Geomechanical models have been used to predict the long term subsidence rates over the western part of the dome and the Bayou Corne community. While the models suggest that subsidence rates within the community will go through a period of increase between the years 2015 and 2018, up to an estimated 1 inch per year, future changes in surface subsidence rates appear likely to be relatively small. It must be noted that the models are based on assumptions of geological properties for the subsurface and the DRZ, which due to uncertainty may not match their actual properties. The model results also show a clear differentiation between areas to the east above the stiffer salt and cap rock and the area to the west above the soft sedimentary units. There is qualitative and to some extent quantitative similarity between the predicted subsidence rates and measured rates observed along Highway 70.

The sinkhole continues to grow in an oval shape rather than circular shape. This shape follows the boundary of the salt dome and is generally reproduced in geomechanical models that examine the sinkhole growth. The shape is caused by the eastern part of the sinkhole being supported by the stiffer caprock and underlying salt, with an additional factor potentially being the shape and position of the DRZ.

The size of the sinkhole in July 2014 was approximately 1700 ft. in the NE-SW direction and 1500 ft. in the NW-SE direction as defined by the -10-foot elevation contour. The ultimate size of the sinkhole is estimated from the latest 3D geomechanical models to be approximately 2200 ft. in the

NE-SW direction and 1700 ft. in the NW-SE direction. This can be considered a best estimate based on current understanding, but depends on the continuation of material flow downward, the structure and mechanics of the connection with the DRZ, and the geological properties of the sinkhole banks that result in the slope failure around its edges. A leading factor is the level of understanding of soil and sediment properties. Currently, these factors are relatively unknown.

3.4 Recommendations: Sinkhole and Underlying DRZ

BRC Charge:

- Identify measures to ensure that the threat of surface releases will be contained within the current bermed area around the sinkhole. (Note the intent of "surface releases" is interpreted as liquid pollutants including salt water and liquid hydrocarbons.)

The BRC recommends the following measures to ensure that the threat of surface releases will be contained within the current bermed area around the sinkhole.

- Continue seismic and MEQ event monitoring and reporting for VLPs and MEQs around the western edge of the salt dome, Oxy caverns, caprock, sinkhole and DRZ volumes. Both surface and borehole seismic arrays should be maintained to provide adequate coverage.
- Use geomechanical predictions of the sinkhole and subsidence evolution, validated using robust site measurements, and update these predictions as necessary, to assess the ongoing integrity of the berm so as to protect freshwater resources from discharges, for the purpose of human health.
- Use soil or sediment mechanics expertise to understand the rheology of the DRZ.
- Improve the understanding of physical properties of the soils and sedimentary formations.
- Obtain a better understanding of whether salt dissolution played a role in the DRZ formation or the sinkhole formation and whether salt dissolution continues to play a role in changing subsurface conditions.

The BRC provides the following recommendation to determine if void spaces within the DRZ are of sufficient size such that a sudden release of gas from such void spaces would pose an immediate or long-term threat to the public within the evacuation area, including Highway 70.

- Based on the current data available, assuming there are no future significant subsurface disturbances, the threat of a sudden release of large gas pockets in one incident from large structural void spaces has been greatly reduced as the seismic monitoring indicates. The risk still exists for such an incident due to the lack of understanding and significant uncertainties around the current subsurface conditions. Furthermore, there is no guarantee that unknown bodies of gas in the subsurface are not disturbed by ongoing development of the DRZ leading to a new elevated risk of this threat. These risks can be mitigated as much as possible by implementation of the monitoring framework recommended by the BRC here.

- The total volume of natural gas within void spaces, including pore spaces and induced fractures in the DRZ and in natural reservoirs in neighboring sedimentary layers, that is in the process of being liberated or could be liberated in the future as a result of the collapse, continues to be highly uncertain. This total volume could be better identified through further site characterization and/or modeling of changes observed in the cavern pressure conditions and surface subsidence.

The BRC provides the following recommendations to evaluate current or future damaged, weak, or settlement areas around the sinkhole where potential future settlement, movement, or subsidence may occur threatening public safety in the evacuation area, including Highway 70. The BRC has identified additional actions and additional monitoring measures that should be undertaken to assure public safety in the vicinity of the sinkhole and the evacuation area, including Highway 70.

- Continue to monitor the sinkhole geometry and subsidence in three dimensions and the effect of the subsidence bowl on the local bayous and community.

- Continue to develop a better understanding of the role of the DRZ on future surface subsidence considering the uncertainty in DRZ size, shape and rheology.

- Continue the ongoing real-time surface subsidence monitoring in the vicinity of the sinkhole and associated subsidence area.

- Continue site wide subsidence surveys across the Napoleonville Salt Dome.

- Continue recording of high quality waveform data for monitoring of seismic and MEQ activity to enable accurate estimation of source time, position and magnitude, for a sufficient number of events, so that data baselines and trends can be established and monitored for, but not limited to, the following purposes:

  a) Providing a daily seismic alert system for sinkhole worker safety;

  b) Data assessment should include a system of daily alerts to the State agencies for increasing numbers of MEQ events, magnitudes, and clustering of event locations within the monitored volume;

  c) Assist in providing an assessment of the ongoing stability of the sinkhole, DRZ and salt cap rock, and in providing an alert system for the stability of the Oxy 1 cavern;

  d) Assist in providing an assessment of the ongoing stability of the salt dome along the dome wall, and around and between caverns Oxy 1, 2, 3,9 and 10;

  e) Assist in providing an assessment of gas behavior and emissions within the DRZ.

Table 1 Monitoring initiatives currently being undertaken by TBC at Bayou Corne with related RRD if applicable. This monitoring should continue into the foreseeable future.

Monitoring Type	RRD	Method	Description	Data Collection Frequency	Data Availability & Reporting Frequency
Oxy 3/3-A logging	None	Wireline	Bottom tag and PRAL log	Currently every two weeks	Days to weeks after monitoring event
	None	Pressure	Pressure Gauge at top of well	Continuous	Daily, reported Monday through Friday
Sinkhole shape	None	Fathometer and wire	Sinkhole depth survey	Monthly	Monthly
MEQ	RRD-12	Surface and downhole seismic sensors	Monitoring of passive seismic events	Continuous	Raw data recorded to public database and FTP site (processing and reporting is undefined).
Subsidence	RRD-14	Level-Line Surveys	Fenstermaker Annual	Annual	Annual
			Fenstermaker Bimonthly	Every two months	Data periodically, report semiannual
			Miller (multiple)	Daily to monthly depending on area/need	Data days after survey, report semiannual
		Level Line Subsidence Surveys over caverns on the dome	As current Joe Ratigan Reporting for Cavern Operators	Annual for the whole dome *(consider also requesting semi-annual for western caverns on dome)*	Annual for whole dome *(consider also requesting semi-annual report for western caverns and dome)*
		InSAR	Satellite-based	Intermittently	Semiannual
		Real-time	Water-Levels	Real-time	Data real-time online, report semiannual
			Tilt meters	Real-time	Data real-time online, report semiannual
Cavern and well deviation	RRD-15	Gyroscopic log	Well deviation	Semiannual	Semiannual
		Caliper log	Well shape	If deflections become evident	Need based
		Sonar survey	Cavern shape	Semi-annual or when strings are removed	Semiannual
Cavern operations	RRD-17	Metered	Track daily freshwater injection, brine production, and run/down time for each cavern in production	Daily	Monthly

Table 2 Details of recommended Cavern Monitoring activities.

Description	Locations	Data Collection Frequency	Data Availability and Reporting Frequency
Pressure Monitoring for OXY-1 and OXY-3 Caverns	Oxy 1, 2, 3A, 9 and 10	Continuous	Daily, reported Monday through Friday
MITs	Oxy 2, 9	Regular and frequent	Within two weeks of completion of test or survey
Sonar surveys	Oxy 2, 9, 10	Semiannual	Within two weeks of completion of test or survey
Cavern Well Monitoring • Gyroscopic log • Multi-arm calipers (MAC)	Oxy 2, 9, 10	Semiannual	Within two weeks of completion of test or survey