RRD-01

UPGRADED SINKHOLE AREA WATER-LEVEL MONITORING SYSTEM

RECOMMENDED REQUIREMENTS DOCUMENT

Subject: **Upgrade Sinkhole Area Water-level Monitoring System**

1.0 Background

The Blue Ribbon Commission (BRC) Gas Group recommends that reducing and maintaining methane gas formation pressures in the Mississippi River Alluvial Aquifer (MRAA) to equal to hydrostatic pressure across the Bayou Corne gas area as one metric is necessary in order to lift the mandatory evacuation order. In addition, the BRC Stability Group has agreed to recommend that subsidence, seismic (both shallow and at depth), cavern pressure, and nearby cavern shape/size monitoring were deemed suitable for ongoing metrics for evaluation of current and future stability of the impacted area near Bayou Corne. This Recommended Requirements Document (RRD) defines the technical requirements for obtaining sinkhole water-level data needed to address these overall objectives. The intent of this RRD is to provide recommended requirements for use by the appropriate State agencies when directing the development of a comprehensive work plan for addressing the RRD objective.

This RRD for updating the sinkhole water-level data network has been prepared with consideration of the following site conditions and data requirements:

- Since the formation of the sinkhole on August 3, 2102, natural gas and crude oil have been migrating up from depth into the sinkhole. During periodic sinkhole "burps" a definite increase in the amount of gas and water migration to the surface is observed, and trees and other debris float to the surface of the sinkhole. Crude oil has also been observed at the surface during these events.

- RESPEC Mining & Energy (RESPEC, 2013; a Texas Brine Company contractor), currently maintains three water-level transducers (named Pad 3, IPI2, and Rig Road) inside the berm area and is presently installing new water level and inclinometer stations (**Figure 1).** This upgraded system addresses the majority of water level data needs that were originally anticipated during the preliminary BRC discussions.

- Sinkhole "burps" have also been associated with sloughing and slumping events near the sinkhole. Periodic sinkhole surveys conducted by Miller Engineers & Associates, Inc. (Miller; a Texas Brine Company contractor) indicate the volume and area of the sinkhole has continued to grow. **Figure 2** illustrates the sinkhole volume and area growth over time.

- Sinkhole water-level data have proven to be a reliable indicator of "burps" related to the migration of gas, crude oil, and formation water to the surface, as well as an indicator of sloughing and slumping of soils near the sinkhole.

- Data collected from this upgraded monitoring system will be used to monitor changes in the sinkhole to determine how sinkhole events, such as the periodic "burps" or slough/slump events, affect gas migration and subsidence of the entire area.

This RRD has been prepared as part of the overall GAS/STA-02 and STA-08 BRC data requirements. These BRC tasks address the need for upgraded sinkhole water-level monitoring for use in evaluations of gas migration and subsidence.

2.0 Objective

The objective of this RRD is to provide water levels and movement data to be used in ongoing technical efforts in the sinkhole and in the surrounding swamp area:

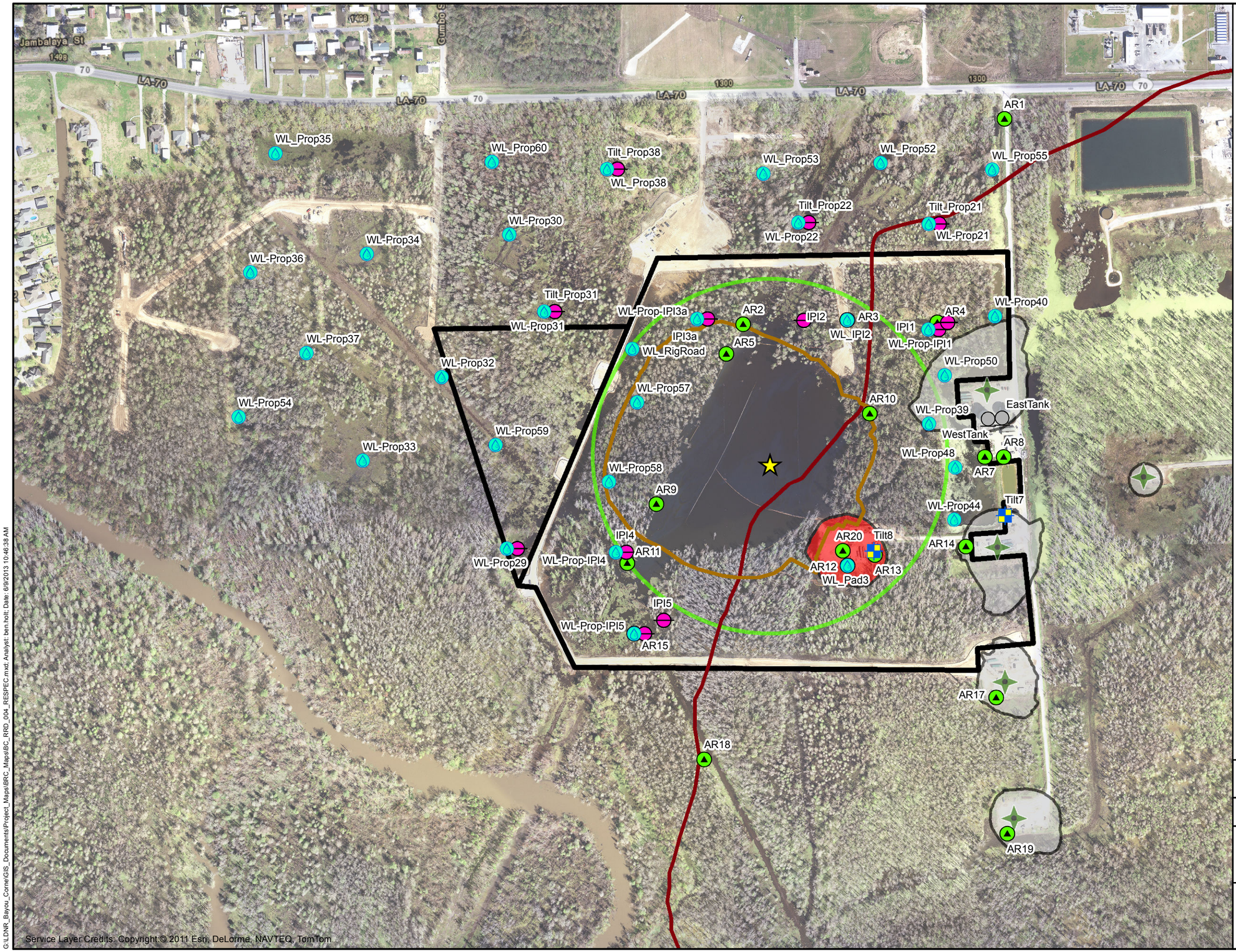
- Monitor sinkhole growth and subsidence between the southern berm and Bayou Corne.
- Integrate water level data in and around the sinkhole into the existing daily seismic warning system.
- Provide data on the hydraulic communication between the sinkhole and the failed Oxy 3 cavern through the disturbed rock zone (DRZ).
- Evaluate gas releases including the potential for release of hydrogen sulfide gas (hydrogen sulfide has not been detected in "burp" events but conditions may change in the future).
- Identify potential mechanisms related to sloughing and slumping events.

3.0 Requirements

The technical requirements of this RRD for upgraded sinkhole water-level monitoring are:

1. Establish five new water level monitoring locations, in addition to the recently upgraded RESPEC program monitoring sites, between the southern berm and Bayou Corne. At least one of these stations should be equipped with an inclinometer and InSAR reflector similar to the AR15/IP15 location.
2. Elevations should be recorded to a precision of 0.01 foot at all water level stations shown on **Figure 1**.
3. For the majority of the stations on **Figure 1**, 5 or 15-minute data recording intervals are adequate. The recording interval on the Pad 3 and Rig Road transducers should be decreased to 10-second intervals to determine wave and sloshing frequency. This frequency data is needed to assess the stability of the DRZ below the sinkhole.
4. A directional wave buoy such as the TRIAXYS Mini in **Attachment 1** is required to monitor sinkhole water movement and sloshing. The required data include wave height to the nearest 0.01 meter, wave period to the nearest second, and wave direction to the nearest degree. A gradient of shallower to deeper depths occur in the middle of the sinkhole; the buoy will be anchored at the approximate center of the sinkhole in the shallower depths since it is believed that the burp events originate in the deepest portion..
5. The data from Pad 3 and Rig Road water level stations and the wave buoy need to be streamed real-time to a system that allows continuous access to the data. This is necessary so the data can be integrated into the seismic alert system.

No additional technical procedures are needed to address these requirements.



Legend

- Sinkhole Location
- Artificial INSAR Reflector
- In-Place Inclinometer
- Tank Reflector
- Tiltmeter
- Water-Level Transducer
- Cavern Well
- Berm
- 1000' Top of Salt Contour Line
- Other Caverns
- Oxy #3
- Calculated Unstable Area
- Modeled Disturbed Rock Zone

N

0 200 400 800

Feet

LOUISIANA DEPARTMENT OF NATURAL RESOURCES

BAYOU CORNE/NAPOLEONVILLE SALT DOME EMERGENCY RESPONSE

FIGURE NUMBER 1

RESPEC SINKHOLE SUBSIDENCE AND WATER LEVEL MONITORING SYSTEM

Shaw Environmental & Infrastructure, Inc.
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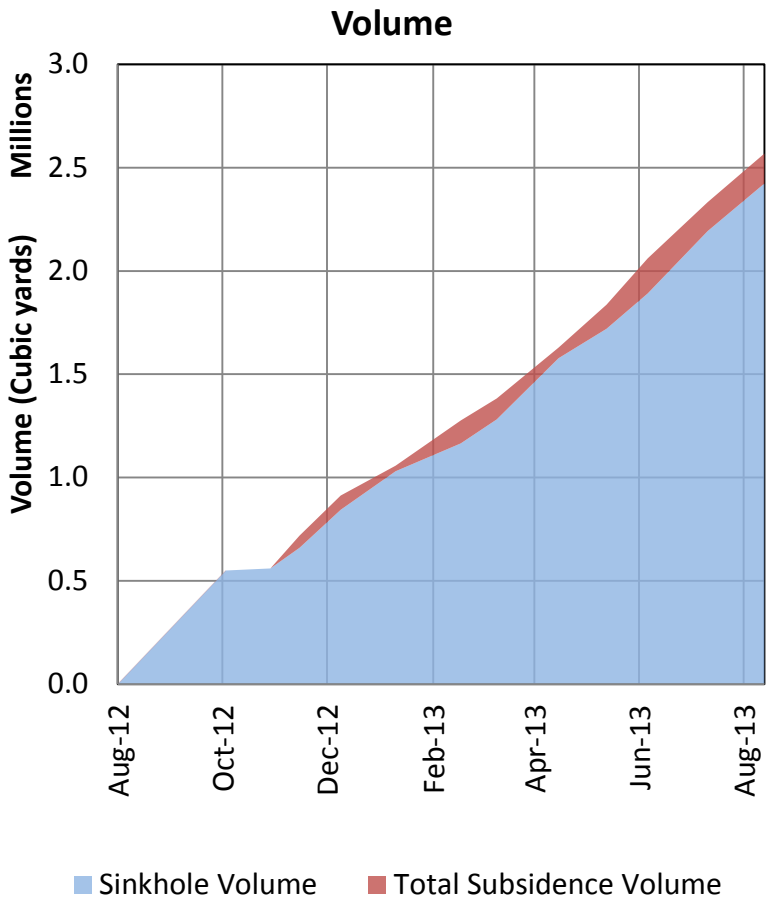

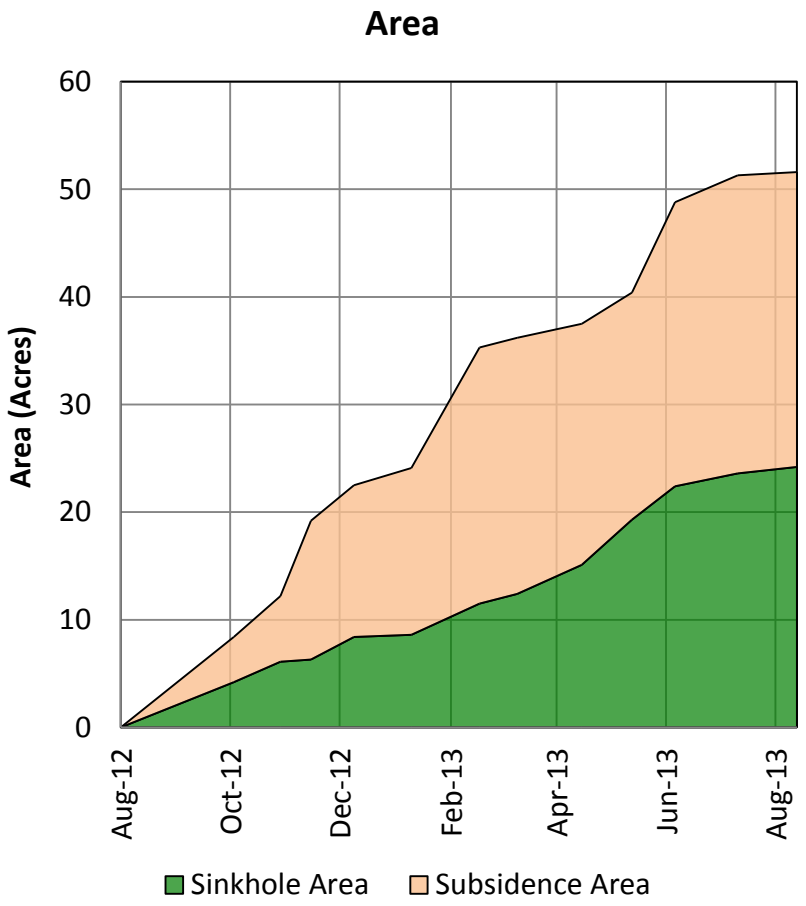

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BAYOU CORNE/NAPOLEONVILLE SALT DOME EMERGENCY RESPONSE

FIGURE NUMBER 2

BAYOU CORNE SINKHOLE VOLUME AND AREA OVER TIME

Shaw Environmental & Infrastructure, Inc.
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ATTACHMENT 1

TRIAXYS MINI DIRECTIONAL WAVE BUOY SPECIFICATIONS

AXYS TECHNOLOGIES INC.

TRIAXYS™ MINI
Directional Wave Buoy

FEATURES & BENEFITS:

- Easy to deploy
- Spin and impact resistant
- 5 year rechargeable battery life
- Supports any telemetry
- >5 years of data storage capacity
- Continuous wave sampling

Highly portable buoy designed for short-term wave measurement deployments.

TRIAXYS™

TRIAXYS™ MINI
Directional Wave Buoy

A "Mini" Revolution in Wave Measurement

TRIAXYS™ MINI
Directional Wave Buoy

The TRIAXYS™ Mini Directional Wave Buoy is an easy to deploy, rugged and economical instrument for the measurement of directional waves. The stainless steel hull has a high strength-to-weight ratio and is powder-coated for additional corrosion resistance. The buoy is relatively small (0.6 m diameter) and lightweight (60 kg) allowing for easy deployment by two people from almost any vessel.

The TRIAXYS™ Mini's standard power supply, Lithium Thionyl Chloride battery packs, allows up to 60 days of data transmission. The versatility of the Mini allows longer-term deployments of up to six months to be achieved by adding additional battery packs.

The heart of the TRIAXYS™ Mini Wave Buoy was developed from the proven AXYS WatchMan500™, which integrates sensor systems and provides onboard data processing, data logging, telemetry and diagnostic/set-up routines. The TRIAXYS™ sensor and telemetry module contains the telemetry system (e.g., VHF transmitter), data logging system, processing unit and the sensor unit, which is comprised of 3 accelerometers, 3 rate gyros and a Fluxgate compass. The processing unit samples and analyses the data and controls all the TRIAXYS™ Mini's systems.

TRIAXYS™ directional wave processing software uses an iterative algorithm based on the Fast Fourier Transform (FFT) analysis to solve the full non-linear equations of buoy motion in six degrees of freedom. The six degrees of freedom are defined by the measured accelerometer (3) and rotational rate gyro (3) signals. Roll, pitch and yaw angles are measured as well as accelerations, displacements and velocities from which heave, surge and sway are determined.

The use of surge and sway velocities instead of roll and pitch angles provides a more accurate measure of wave kinematics that defines the direction of wave propagation. The abridged data can be either contained in the internal data logger or transmitted by the previously incorporated telemetry communication to either a land or ship-based transceiver.

For operational and safety purposes, the TRIAXYS™ Mini is also capable of monitoring its moored location through the use of the onboard GPS receiver coupled with the AXYS buoy mooring WatchCircle™ Alarm.

Specifications

- **Physical Description**
  Diameter: 0.72m (29.5 inches) outside bumper
  0.6m (25.5 inches) hull
  Weight (including batteries):
  2 packs = 58 kg (128 lb)
  4 packs = 71kg (156lbs)
  Weight (excluding batteries): 43 kg (95 lb)
  Obstruction Light: Amber LED Programmable with three miles visibility
- **Materials**
  Hull: Stainless steel 316
  Lifting handles: Welded stainless steel
- **Sensors/Processor**
  Processor: WatchMan500™
  Water temperature: Thermilinear composite network
  Accelerometers: Flexure suspension servo (Range ±2g)
  Rate: Piezoelectric vibrating gyroscope (Maximum angular velocity ±80°/s)
  Compass: Microprocessor controlled Fluxgate (Accuracy ±0.5°)
  GPS: 12 channel
- **Power System**
  Operational system voltage: 10.5 to 19.0 VDC
  Batteries: lithium thionyl chloride or lead acid
  Battery packs: 2 packs standard, expandable to 4 packs
  On/Off Switch: located on communication cable
- **Telemetry Options**
  - VHF
  - INMARSAT D+
  - IRIDIUM
  - CDMA, GPRS (cellular)

Resolution/Accuracy

	Range	Resolution	Accuracy
Heave	±20 m	0.01 m	Better than 2%
Period	1.5 to 33 seconds	0.1 sec	Better than 2%
Direction	0 to 360°	1°	3°
Water Temp.	-5 to +50°C	0.1°C	±0.5°C

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