BW - 38

SOLUTION CAVERN CHARACTERIZATION PLAN

Chavez, Carl J, EMNRD

From:	danny@pwllc.net
Sent:	Tuesday, March 26, 2019 2:03 PM
To:	Chavez, Carl J, EMNRD
Cc:	Marvin Burrows
Subject:	[EXT] Llano Disposal, LLC - State 27 BSW #1 (BW-38) COA Plan Submittal
Attachments:	BW-38 COA Submittal Letter to OCD 032619.pdf; Surface Subsidence Monitoring Plan Submitted to OCD 032619.pdf; Solution Cavern Characterization Plan Submitted to OCD 032619.pdf

Carl,
Hope you are well. Attached are three files concerning plan submittals to complete the conditions of approval on BW-38.

* Cover letter
* Surface Subsidence Monitoring Plan
* Solution Cavern Characterization Plan

If you have any questions or need any additional information concerning these plans, please let me know.
Thank you,
Danny J. Holcomb
Cell: 806-471-5628
Email: danny@pwllc.net

Holcomb Consultants
6900 Spring Cherry Lane
Amarillo, Texas 79124

March 26, 2019

New Mexico Oil Conservation Division
Environmental Bureau
1220 South St. Francis Drive
Santa Fe, New Mexico 87505
Attn: Mr. Carl Chavez

Re: Discharge Plan Permit (BW-38)
Llano Disposal, LLC
UIC Class III Brine Well - State '27' BSW #1 (30-025-20592)
UL 'L', Sec 27, T16S, R33E, 1980 FSL x 660 FWL, Lea County, New Mexico

Dear Mr. Chavez,

Per Discharge Permit BW-38 approval conditions dated November 7, 2018, Llano Disposal, LLC is required to submit the following plans to the NMOCD Environmental Bureau within 180 days:

- Discharge Plan Approval Condition 2.B.1 - Surface Subsidence Monitoring Plan
- Discharge Plan Approval Condition 2.B.2 - Solution Cavern Characterization Plan

Llano previously submitted the initial surface subsidence monitoring plan in the original discharge permit application dated July 16, 2018. Please see pages 18– 19 and Attachment 'P'. Llano hereby submits supplemental information concerning the surface subsidence monitoring plan and subsequent monument installations.

Llano hereby submits the solution cavern characterization plan. This plan demonstrates that a 580 foot diameter salt solution cavern at the referenced well exceeds the NMOCD's safety factor guidelines for a stable cavern roof structure.

If you need any additional information concerning either the surface subsidence monitoring plan or the attached solution cavern characterization plan, please let us know. Thank you in advance for your consideration.

Sincerely,

Danny J. Holcomb
Holcomb Consultants
Agent for Llano Disposal, LLC
Cell: 806-471-5628
Email: danny@pwllc.net

Attachments

Llano Disposal, LLC
State '27' BSW #1 (BW-38)
API # 30-025-20592
Solution Cavern Characterization Plan

This plan characterizes the size and shape of the proposed solution cavern at the referenced brine well using geophysical methods approved by the OCD.

1. Well Configuration and Lithology

The State '27' BSW #1 (API # 30-025-20592) is located at 1980 FSL x 660 FWL, Unit Letter L, Section 27, T16S, R33E, Lea County, New Mexico. Exhibit 1 illustrates the final well completion and the well lithology. The well has two casing strings within the salt section with the smallest casing string shoe at 4578'. A CIBP with 10' cement is set at 2596' (base of salt). Another CIBP with 10' cement is set at 1800' (base of casing window). A window is cut in the 9-5/8" casing at 1780' – 1790'. A dual-string packer will be set at ~1760' with 3-1/2" steel IPC production tubing to surface. Fresh water will be pumped down the tubing-casing annulus, through an open port in the packer and then through approximately 740' of fiberglass tailpipe below the packer and set through the casing window into the salt. Fresh water will enter the salt formation at a depth of approximately 2500' which is approximately 700 feet below the upper CIBP inside the 9-5/8" casing. Below is a summary of formation lithology based on previous drilling records and Llano's experience while drilling out cement plugs, cutting the casing window, completion operations in the salt section and testing (circulating) the well:

Lithology	Depth
Surface Fill	0-40'
Water Zone	40-80'
Sandstone/Shale/Red Beds	80-1480'
Anhydrite/Sandstone/Salt	1480-2400'
Salt	2400-2606'
Anhydrite/Sandstone/Shale	2606-2764'
Dolomite/Anhydrite/SS/Shale	2764-4460'
Dolomite	4460-7180'

N-S and E-W cross-section diagrams are included in Exhibits 3A and 3B. They demonstrate that lithology is relatively consistent across the area of review. The lithology at the State '27' BSW #1 provides for approximately 920 feet of anhydrite overlying the anticipated solution cavern area.

2. Cavern Roof Stability Calculations Using Cantilever Beam Theory

Llano developed a steady state model to calculate the maximum safe cavern diameter based on ultimate stresses developed in a cantilever beam that is uniformly loaded. A minimum safety factor of 2.0 was utilized. The maximum compressive, tensional and shear stress can be assessed using general flexure bending formulas. Similar studies conducted by organizations such as DOE (WIPP) and the National Labs have determined that the uniformly loaded cantilever beam method is the most conservative approach to determine salt cavern roof stability.

Formulas:

$\sigma = My/I$ Maximum flexure stress at the outer most fibers of the beam, which are in compression and tension.

$\tau = VQ/It$ Maximum transverse shear stress, generally found near the supported end of the beam.

Definitions of Stress Elements and Units:

M = moment (foot-lbs)
I = second moment of inertia beam (inch^4)
y = distance from the center of the beam to the outer fibers (inches)
V = shear on beam, connection end (lbs)
Q = first moment of beam, end view, center axis (inches)
t = thickness (width) of the beam (inches)

Model Assumptions:

1 - The beam is considered a stiff anhydrite material of homogenous and isotropic properties. Since compressive strength properties of anhydrite are substantially larger than the tensile strength, tensional properties are utilized for the most conservative results.
2 – The cantilever beam theory assumes the highest stress occurs near the supported end of the beam.
3 – Slippage due to shearing between layers within the anhydrite beds is discounted and therefore, not considered.
4 – Physical properties of anhydrite were obtained from various sources. Average figures for these properties are utilized.
5 – The beam was selected to be a rectangle with a width of 12 inches to allow for uniform loading. The length and height (i.e. thickness) are variable inputs.
6 – The density of the overburden rocks and soil were set at 156.1 lbs/ft^3.[i]
7 – A general rule of thumb states that the maximum shear stresses are estimated as one half of the difference between the maximum and minimum normal stresses$(\sigma \max - \sigma \min)/2$. Since the ultimate tensile strength of anhydrite is used as the limiting property, the maximum shear force would be one-half of the normal stresses.[ii]
8 – The total lifetime brine production estimate was calculated based on cylinder volume then reduced by 25% to compensate for insolubles within the salt formation.
9 – Ultimate tensile strength for anhydrite was determined to be 8 Mpa or 1160 psi.[iii]
10 – The cantilever beam uniformly loaded approach presents a very simple and friendly method of modeling the stresses. However, this method can cause some error in the

calculations. The outer fibers of the anhydrite are in pure bending under tension and the shear forces are zero.

The model equations include the counter hydrostatic forces generated by the well bore hydrostatic head on the cavern formation. These forces actually push upward and help support the roof beam. The model outputs provide stress calculations on the beam with and without these hydrostatic forces.

See Exhibit 4 for a summary of the model inputs and outputs.

Model Inputs (Best Case):

1) Beam length in feet (i.e. radius of cavern) – 290 feet (found to be the largest allowable radius).

2) Beam width was kept constant at 12 inches

3) Beam height (thickness of the anhydrite layer) – 920 feet

4) Depth of the overburden (i.e. depth of the casing window) – 1780 feet

5) Thickness of the salt production zone – 206 feet

Model Output Results:

1) Maximum tensional stress on the beam when the cavern pressure is maintained. A maximum allowable tensile stress of 1160 psi was utilized. Any output number above this threshold would be considered unsafe. Model results were 299 psi for inputs referenced above.

2) Maximum tensional stress on the beam when the cavern pressure is not maintained. A maximum allowable tensile stress of 1160 psi was utilized. Any output number above this threshold would be considered unsafe. Model results were 575 psi for inputs referenced above.

3) Ratio of cavern diameter/depth to top of salt. An allowable threshold of <0.5 has been established by the NMOCD Environmental Bureau. Any output number above this threshold would be considered unsafe. Model results were 0.33 for inputs referenced above.

4) Bending safety factor when the cavern pressure is maintained. A threshold of > 2.0 was utilized. Any output number below this threshold would be considered unsafe. Model results were 3.88 safety factor for inputs referenced above.

5) Bending safety factor when the cavern pressure is <u>not</u> maintained. A threshold of > 2.0 was utilized. Any output number below this threshold would be considered unsafe. Results were 2.02 safety factor for inputs referenced above.

6) Shear safety factor when the cavern pressure is maintained. A threshold of > 2.0 was utilized. Any output number below this threshold would be considered unsafe. Model results were 5.35 safety factor for inputs referenced above.

7) Shear safety factor when the cavern pressure is <u>not</u> maintained. A threshold of > 2.0 was utilized. Any output number below this threshold would be considered unsafe. Model results were 2.78 safety factor for inputs referenced above.

8) Estimated brine production volume over the life of the brine well at maximum cavern diameter was calculated. This estimate was very conservatively calculated based on 50% of the cylinder volume. Model results were 31.52 million barrels.

9) Maximum surface static or test pressure on the cavern. Maximum allowable pressure was 300 psig.

10) Maximum cavern diameter. Model results were 580 feet.

Based on the optimum model results, the safe cavern design for this solution mined salt cavern was 580 feet maximum diameter.

3. <u>Cavern Development:</u>

The solution cavern will be allowed to grow from the bottom up, creating an inverted conical cavern. See proposed cavern conceptual shape in Exhibit 2. Insolubles embedded within the salt will drop to the bottom of the cavern. Cavern development will be controlled by the depth of injection tubing and by varying the flow rates through the initial, development and production process stages.

Llano proposes to monitor and assess cavern growth and morphology over time based on brine production volumes and future estimated cavern dissolution volumes. Brine production volumes reported in the annual reports are the mechanism to calculate cavern void space and project future production volumes.

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[i] Physical Properties of Salt, Anhydrite, and Gypsum – Preliminary Report by Eugene C. Robertson, Richard A. Robie, Kenneth G. Books, August, 1958, US Geological Survey.

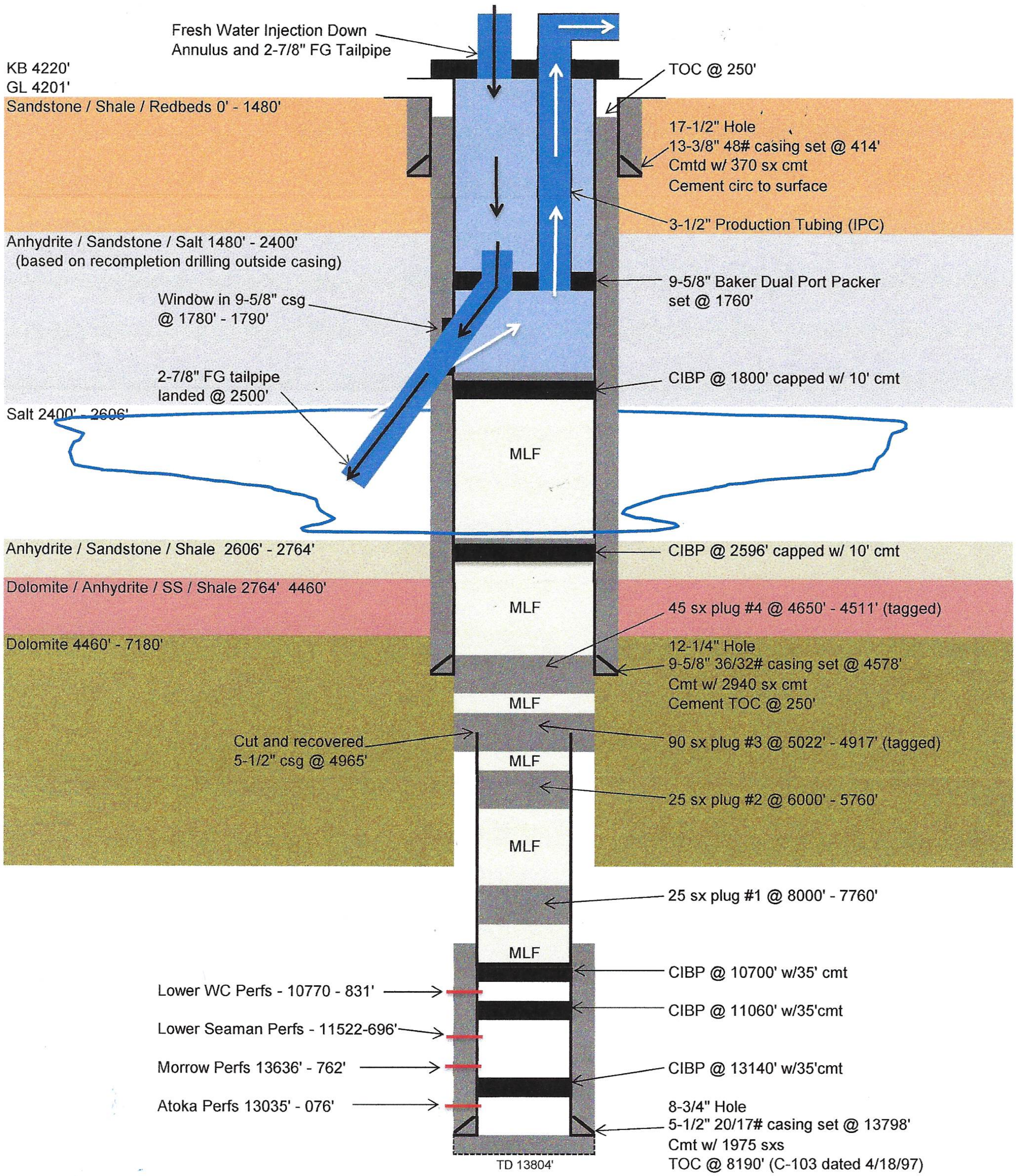
[ii] Formulas for Stress and Strain by Raymond J. Roark, Third Edition, McGraw-Hill Book Company, Inc.

[iii] Applied Salt-Rock Mechanics 1 by C. A. Baar Copyright 1977, Elsevier Scientific Publishing Company.

CURRENT WELLBORE

Configured for Brine Service Well

Llano Disposal, LLC
State 27 #1 P&A
API # 30-025-20592
1980' FSL x 660' FWL, UL 'L', Sec 27, T16S, R33E, Lea County, NM

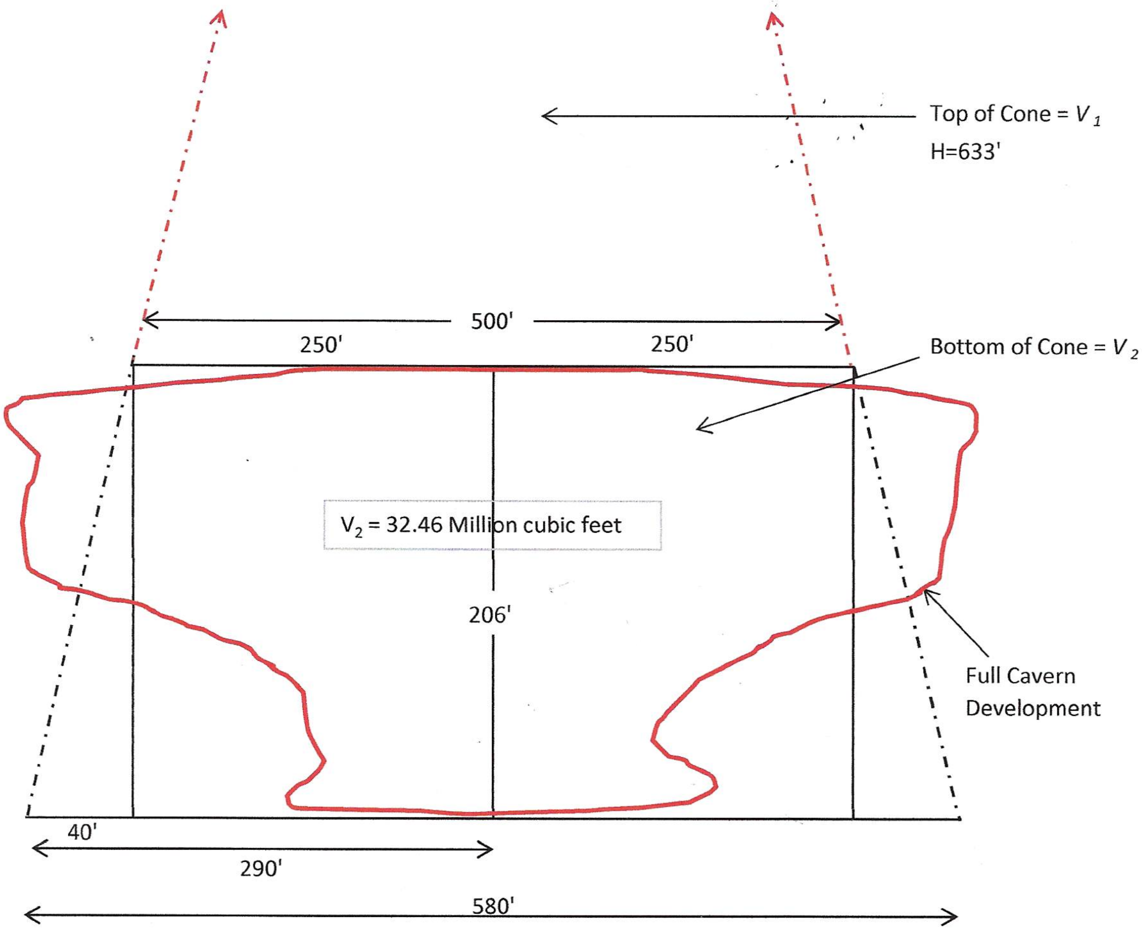


Drawing Not to Scale

Note: This wellbore diagram represents information obtained from OCD files, new logs (5/22/18) and completion drillout lithology (12/6/18).

Exhibit 1
Drawing Not to Scale

State '27' BSW #1
Cavern Volume Calculation



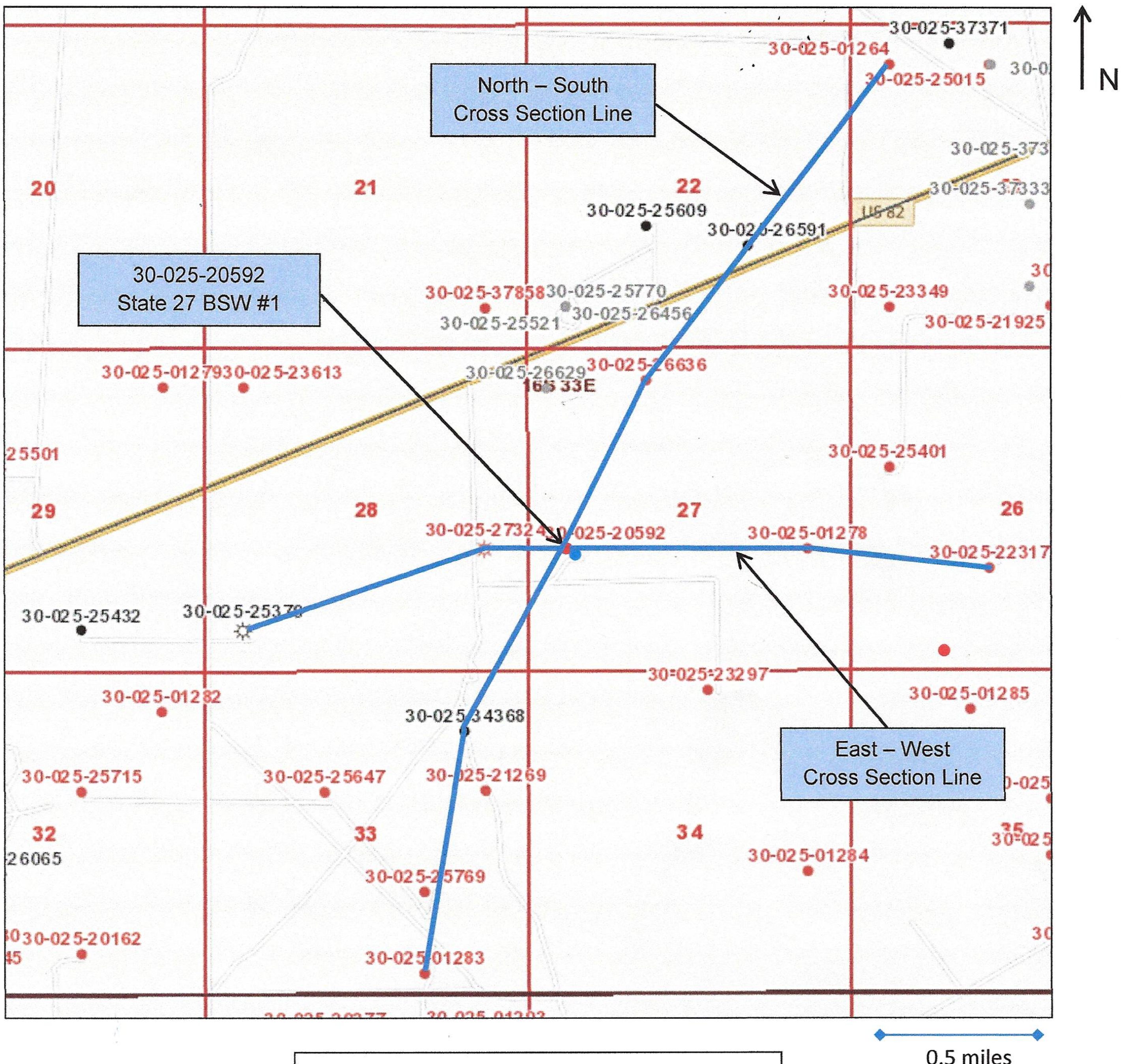
Cylinder Volume:		
$V_T = \frac{1}{3}\pi r^2 * H$	$V_1 = \frac{1}{3}\pi r^2 * H$	$V_2 = VT - V_1$
$V_T = \frac{1}{3}\pi 2902 * 839$	$V_1 = \frac{1}{3}\pi 2502 * 633$	$V_2 = 73.890\ M - 41.430\ M$
$V_T = 73.890\ M$	$V_1 = 41.430\ M$	$V_2 = 32.46\ M$

Brine Production Volume:	
$Vcyl = \pi r^2 h = \pi(250ft)^2(206ft)$	Brine = 88.59% of vol H_20 + 11.41% NaCl by volume
$Vcyl = 40{,}448{,}005\ ft^3$	Vol_{Brine} = 354.08 mft^3 brine
$Vcyl = 40.4\ M\ ft^3$ of salt	Vol_{Brine} = 63.03 m bbls brine x 50% = 31.52 m bbls

Exhibit 2
Drawing Not to Scale

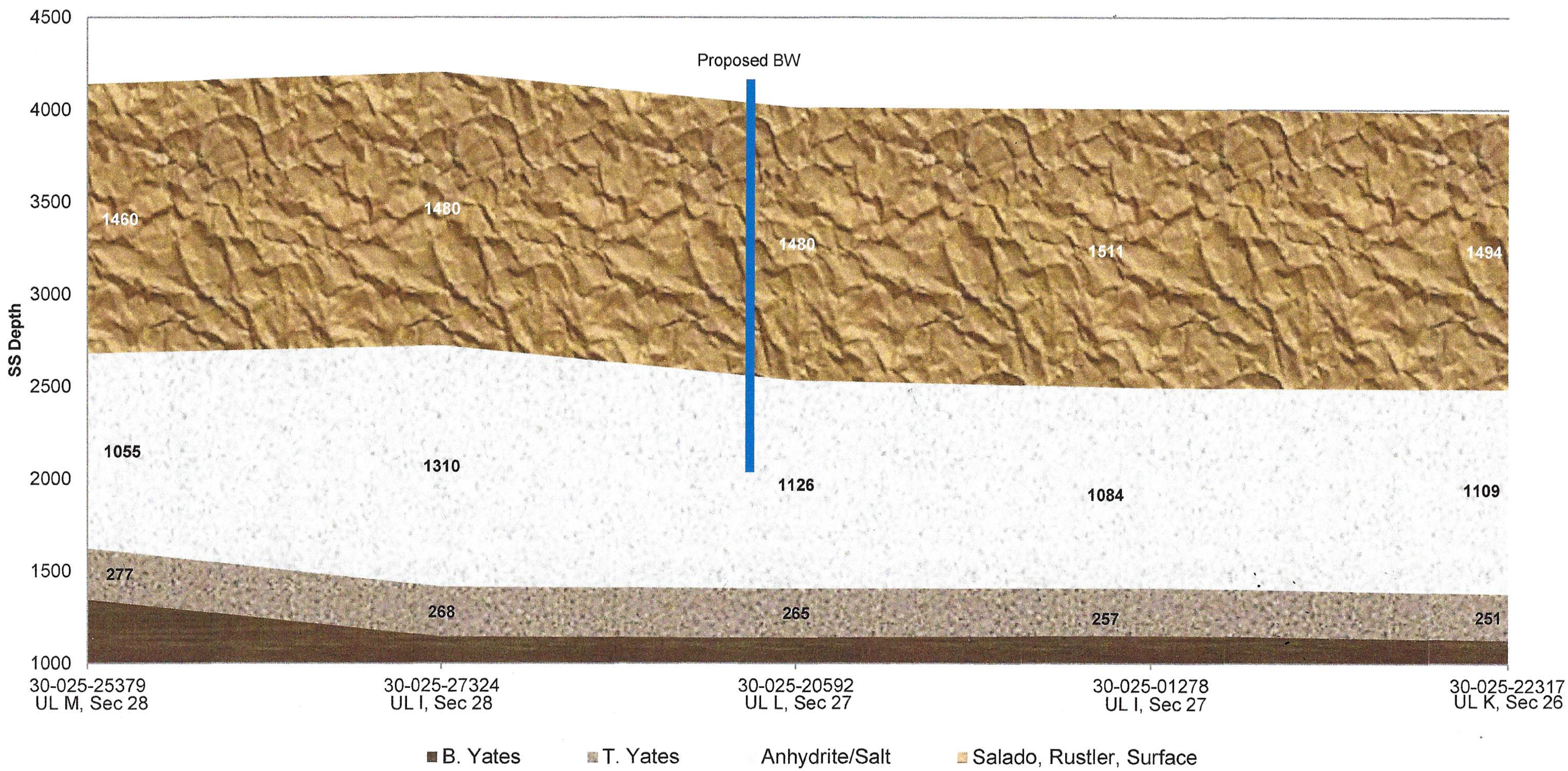
State 27 BSW #1
API # 30-025-20592
Discharge Plan Attachments

Exhibit 3A

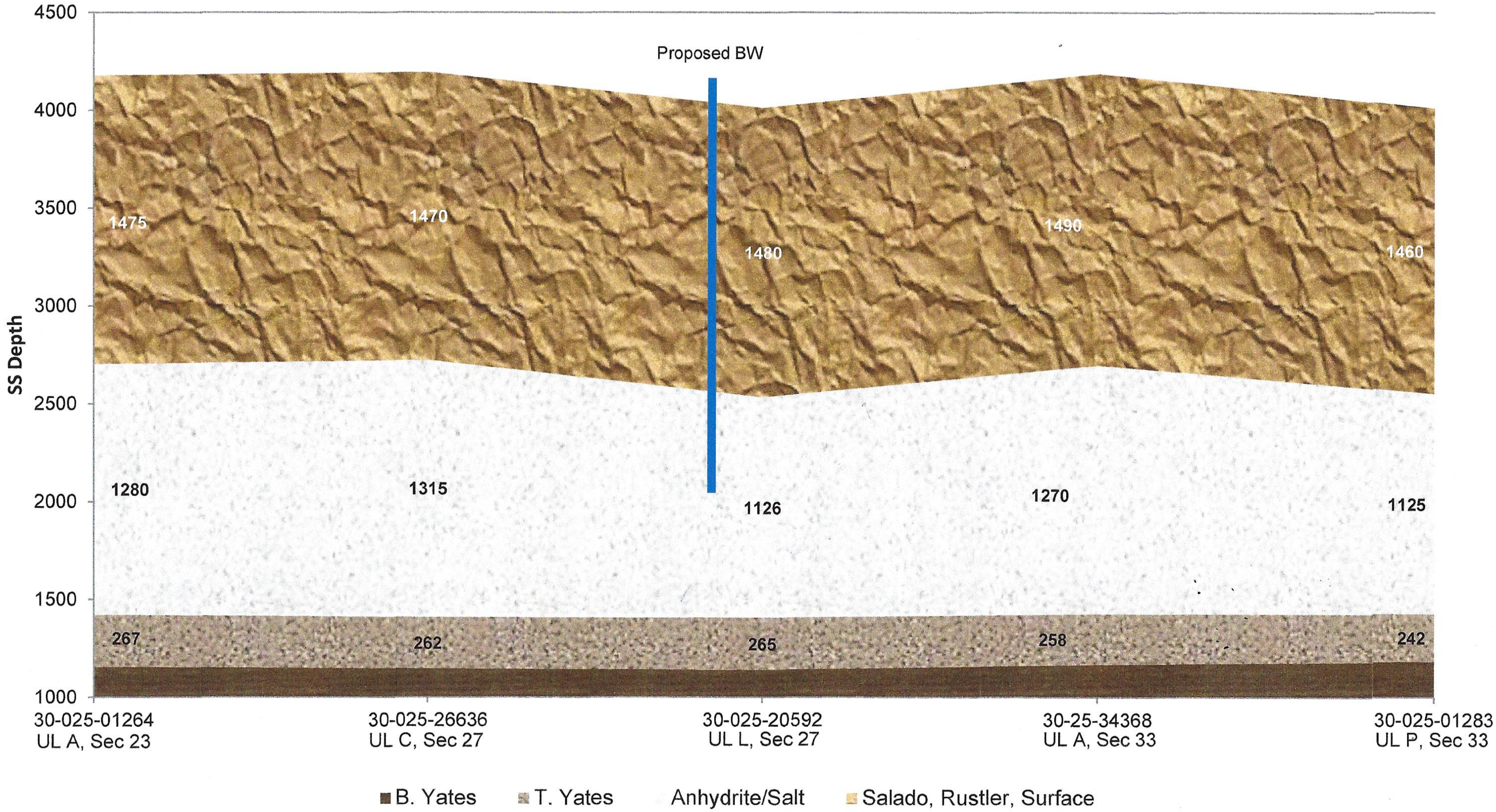


T16S, R33E
Lea County, New Mexico

State '27' #1
West to East Cross Section
Exhibit 3B



State '27' #1
North to South Cross Section
Exhibit 3B



State'27' BSW #1 Well Roof Stability Steady State Model

Cantilever Beam Design when Anhydrite Separates from Casing

Exhibit 4

Function	Value	Unit	Method
$\sigma = My/I$ - Equation For Flexure Stress (Normal Tension/Compression Stress	299.3	psi	
$\tau = VQ/It$ - Equation For Transverse Shear Stress	3649	psi	
Inputs			
Beam Length in Feet (ie. Radius of Cavern)	290	feet	input value
Beam Width	12	inches	input value
Beam Height (Anhdyrite Thickness)	920	feet	input value
Depth of Casing Window Below GL	1780	feet	input value
Estimated Thickness of Salt Production zone	206	feet	input value
Model Calculations			
M = Moment	6079235780	ft-lbs	calculation
y = Distance From Center To Outer Fibers	5520	inches	calculation
I = Second Moment of Inertia Beam	1.34557E+12	inches4	calculation
w = Total Uniform Load of Beam (Wob-wc)	144572	lbs/ft	calculation
wc = Counter Uniform Load Generated by Hydrostatic Cavern Pressure	133286	lbs/ft	calculation
Wob = Uniform Load on Beam From Overburden	277858	lbs/ft	calculation
V = Shear From Total Load on Beam (Connection End)	80578820	lbs	calculation
Q = First Moment of Beam - End View, Center Axis	731289600	inches	calculation
t = Thickness (Width) of Beam	12	inches	fixed value
P = Cavern Hydrostatic Pressure Calculated Directly Below Anhydrite or at Shoe	926	psi	calculation (w/brine wtr)
Outputs			
Maximum Bending Stress When Cavern Pressure Is Maintained	299	psi	Passed - Stable Roof
Maximum Bending Stress When Cavern Pressure Is Not Maintained	575	psi	Passed - Stable Roof
Ratio of Cavern Diameter/Depth of Window (D/H <0.5)	0.33		Passed - Within Limits
Bending Safety Factor When Cavern Pressure is Maintained (must be > 2.0)	3.88		Passed - Within Limits
Bending Safety Factor When Cavern Pressure is Not Maintained (must be > 2.0)	2.02		Passed - Within Limits
Shear Safety Factor When Cavern Pressure is Maintained (must be > 2.0)	5.35		Passed - Within Limits
Shear Safety Factor When Cavern Pressure is Not Maintained (must be > 2.0)	2.78		Passed - Within Limits
Estimated Brine Production Volume (50% of cylinder)	31.52	mmbbls	See Exhibit 2
Maximum Surface Static or Test Pressure (psig)	300	psig	
Maximum Cavern Diameter (ft)	580	feet	