July 2018

C-147 Registration Package for MOGI 9 State 1H Recycling Containment (AST) and Recycling Facility Section 09, T24S, R33E, Lea County

View to north-northwest showing the MOGI 9 State 1H production pad that will hold the AST and recycling facility.

Volume I of II

Prepared for:
Tap Rock Resources
Golden, CO

Prepared by:

R.T. Hicks Consultants, Ltd.
901 Rio Grande NW
F-142
Albuquerque, New Mexico

R. T. HICKS CONSULTANTS, LTD.
901 Rio Grande Blvd NW ▲ Suite F-142 ▲ Albuquerque, NM 87104 ▲ 505.266.5004 ▲ Since 1996
Artesia ▲ Carlsbad ▲ Durango ▲ Midland

July 06, 2018

Ms. Oliva Yu
Mr. Brad Billings
NMOCD Artesia
Via E-Mail

RE: Tap Rock Resources MOGI 9 State Com 1H Recycling Containment (AST) and Recycling Facility. Sec. 9, T24S. R33E. Lea County, NM.

Ms. Yu and Mr. Billings:

On behalf of Tap Rock Resources, Hicks Consultants is pleased to submit the attached C-147 registration package for the above-referenced location. Because the files are quite large, this submission composed of two volumes emailed separately. This transmittal letter is identical in both portions.

Volume 1 contains:
- C-147
- Previously-approved variances
- Figures and Site Survey
- Appendix A: Site Specific Information
- Appendix B: Photos
- Appendix C: Well Logs
- Appendix D: Design & Construction Plan
- Appendix E: Operation and Maintenance Plan
- Appendix F: Closure Plan

Volume 2 contains:
- Appendix G: Select Energy/Rockwater Standard Operating Procedures (SOPs)
- Appendix H: Specifications – liner, AST, Mega Blaster Pro (avian protection)

We also wish to provide the following points of clarification to the submission:

1. This submission is a Registration, not a Permit. We have checked the Permit box and labeled it “For OCD Statistics Only”, as we have done with other containment registration packages. All variances relating to the design and construction have been previously-approved by OCD, as recently as last year for XTO. Thus, we have also checked the Variance box “For OCD Statistics Only”. Because Tap Rock seeks no variance that has not been previously approved, the submission is a Registration in accordance with the Rule.

2. The liner system for the AST is best conceptualized in the drawing entitled "AST Schematic" of Appendix D – Design and Construction in Volume 1. The drawing shows a change to the primary liner as the previously-approved AST systems that uses two (2) 30-mil LLDPE liners (Devon Hackberry). The seconday liner will use a 40-mil HDPE liner rather than a 30-mil LLDPEr liner. Per the attached previously-approved variance, a 40-mil HDPE liner provides equal or better protection than a 30-mil LLDPEr liner.
3. The AST will employ a muscle wall rather than an earthen berm for the walls of the secondary containment.
4. A previously-approved (Devon Hackberry AST) variance request for anchor trenches for vertically-walled tanks is included in this submission.
5. The AST will employ the Mega Blaster Pro (documentation provided) to deter avian species from landing on the treated produced water.
6. The Select Energy/Rockwater SOP for their AST is in Appendix G of the C-147 and the Design/Construction Plan (Appendix D) and the O&M Plan (Appendix E) are abstracted from this SOP. You should read Appendix D and E before you examine the SOP.
7. The AST is located on Tap Rock Resources Mogi 9 State Com #1H production pad. Per the SOPs, the area of the pad that will accommodate the AST will be re-graded, sloped, and a Y-Trench will be excavated to allow for drainage of the AST.
8. Set up of the AST system on the secondary liner will begin on July 14, 2018. We will notify OCD Hobbs 48-hours in advanced of construction.

Please note that the previously-approved variances were written by Ron Frobel, PE. He is the author of several variances that were incorporated into the Part 34 Produced Water Recycle Rule (e.g. 45 mil LLDPE primary liner system, 30-mil LLDPE secondary liner system).

Sincerely,
R.T. Hicks Consultants

Andrew Parker

Andrew Parker
Project Scientist

Copy: Tap Rock Resources, Josh Matthews (jmathews@taprk.com)
Select Energy/Rockwater Energy Solutions
Ed Martin, State Land Office (surface owner)

District I
1625 N. French Dr., Hobbs, NM 88240
District II
811 S. First St., Artesia, NM 88210
District III
1000 Rio Brazos Road, Aztec, NM 87410
District IV
1220 S. St. Francis Dr., Santa Fe, NM 87505

State of New Mexico
Energy Minerals and Natural Resources Department
Oil Conservation Division
1220 South St. Francis Dr.
Santa Fe, NM 87505

Form C-147
Revised April 3, 2017

Recycling Facility and/or Recycling Containment

Type of Facility: ☒ Recycling Facility ☒ Recycling Containment*

Type of action: ☒ Permit (Box checked for OCD statistics only) ☒ Registration
☐ Modification ☐ Extension
☐ Closure ☐ Other (explain) ___________________

*** At the time C-147 is submitted to the division for a Recycling Containment, a copy shall be provided to the surface owner.**

Be advised that approval of this request does not relieve the operator of liability should operations result in pollution of surface water, ground water or the environment. Nor does approval relieve the operator of its responsibility to comply with any other applicable governmental authority's rules, regulations or ordinances.

1.

Operator: Tap Rock Resources, LLC (For multiple operators attach page with information) OGRID #: 372043

Address: 602 Park Point Drive, Suite 200, Golden, CO 80401

Facility or well name (include API# if associated with a well): Olympus MOGI 1 AST

OCD Permit Number: 1RF-438 (For new facilities the permit number will be assigned by the district office)

U/L or Qtr/Qtr M Section 9 Township 24 S. Range 33 E. County: Lea

Surface Owner: ☐ Federal ☒ State ☐ Private ☐ Tribal Trust or Indian Allotment

2.

☒ **Recycling Facility**:

Location of recycling facility (if applicable): Latitude 32.22527 Longitude -103.58529 NAD83

Proposed Use: ☐ Drilling* ☒ Completion* ☐ Production* ☐ Plugging *

**The re-use of produced water may NOT be used until fresh water zones are cased and cemented*

☐ Other, ***requires permit for other uses. Describe use, process, testing, volume of produced water and ensure there will be no adverse impact on groundwater or surface water.***

☐ Fluid Storage

☒ Above ground tanks ☐ Recycling containment ☐ Activity permitted under 19.15.17 NMAC explain type___________________

☐ Activity permitted under 19.15.36 NMAC explain type:___________________ ☐ Other explain ___________________

☐ For multiple or additional recycling containments, attach design and location information of each containment

☐ **Closure Report (required within 60 days of closure completion)**: ☐ Recycling Facility Closure Completion Date:___________________

3.

☒ **Recycling Containment**:

☐ Annual Extension after initial 5 years (attach summary of monthly leak detection inspections for previous year)

Center of Recycling Containment (if applicable): Latitude 32.22527 Longitude -103.58529 NAD83

☐ For multiple or additional recycling containments, attach design and location information of each containment

☒ Lined ☒ Liner type: Thickness _________mil ☒ LLDPE ☒ HDPE ☐ PVC ☐ Other ___________________

☒ String-Reinforced (primary) two 30 mil LLDPEr primary; one 40 mil HDPE secondary liner

Liner Seams: ☐ Welded ☒ Factory ☐ Other ___________________ Volume: 41,000 bbl Dimensions: L______ x W______ x D______
157.5 ft inner dia. X 12 ft heigh

☐ Recycling Containment Closure Completion Date:___________________

4.

Bonding:

☒ Covered under bonding pursuant to 19.15.8 NMAC per 19.15.34.15(A)(2) NMAC **(These containments are limited to only the wells owned or operated by the owners of the containment.)**

☐ Bonding in accordance with 19.15.34.15(A)(1). Amount of bond $________________ **(work on these facilities cannot commence until bonding amounts are approved)**

☐ Attach closure cost estimate and documentation on how the closure cost was calculated.

5.

Fencing:

☒ Four foot height, four strands of barbed wire evenly spaced between one and four feet

☐ Alternate. Please specify_______________________________________

6.

Signs:

☒ 12"x 24", 2" lettering, providing Operator's name, site location, and emergency telephone numbers

☐ Signed in compliance with 19.15.16.8 NMAC

7.

Variances:

Justifications and/or demonstrations that the proposed variance will afford reasonable protection against contamination of fresh water, human health, and the environment.

Check the below box only if a variance is requested:

☒ Variance(s): Requests must be submitted to the appropriate division district for consideration of approval. If a Variance is requested, include the variance information on a separate page and attach it to the C-147 as part of the application.

If a Variance is requested, it must be approved prior to implementation. (Box checked for OCD statistics only)

ALL CONSTRUCTION AND OPERATION VARIANCES HAVE BEEN PREVIOUSLY APPROVED BY OCD

8.

Siting Criteria for Recycling Containment

Instructions: The applicant must provide attachments that demonstrate compliance for each siting criteria below as part of the application. Potential examples of the siting attachment source material are provided below under each criteria.

General siting

Ground water is less than 50 feet below the bottom of the Recycling Containment. NM Office of the State Engineer - iWATERS database search; USGS; Data obtained from nearby wells (FIGURE 1)	☐ Yes ☒ No ☐ NA
Within incorporated municipal boundaries or within a defined municipal fresh water well field covered under a municipal ordinance adopted pursuant to NMSA 1978, Section 3-27-3, as amended. - Written confirmation or verification from the municipality; written approval obtained from the municipality (FIGURE 5)	☐ Yes ☒ No ☐ NA
Within the area overlying a subsurface mine. - Written confirmation or verification or map from the NM EMNRD-Mining and Minerals Division (FIGURE 7)	☐ Yes ☒ No
Within an unstable area. - Engineering measures incorporated into the design; NM Bureau of Geology & Mineral Resources; USGS; NM Geological Society; topographic map (FIGURE 8)	☐ Yes ☒ No
Within a 100-year floodplain. FEMA map (FIGURE 9)	☐ Yes ☒ No
Within 300 feet of a continuously flowing watercourse, or 200 feet of any other significant watercourse, or lakebed, sinkhole, or playa lake (measured from the ordinary high-water mark). (FIGURE 3) - Topographic map; visual inspection (certification) of the proposed site	☐ Yes ☒ No
Within 1000 feet from a permanent residence, school, hospital, institution, or church in existence at the time of initial application. - Visual inspection (certification) of the proposed site; aerial photo; satellite image (FIGURE 4)	☐ Yes ☒ No
Within 500 horizontal feet of a spring or a fresh water well used for domestic or stock watering purposes, in existence at the time of initial application. (FIGURES 1 & 2) - NM Office of the State Engineer - iWATERS database search; visual inspection (certification) of the proposed site	☐ Yes ☒ No
Within 500 feet of a wetland. (FIGURE 6) - US Fish and Wildlife Wetland Identification map; topographic map; visual inspection (certification) of the proposed site	☐ Yes ☒ No

9.

Recycling Facility and/or Containment Checklist:

Instructions: Each of the following items must be attached to the application. Indicate, by a check mark in the box, that the documents are attached.

X ☒ Design Plan - based upon the appropriate requirements.
X ☒ Operating and Maintenance Plan - based upon the appropriate requirements.
X ☒ Closure Plan - based upon the appropriate requirements.
X ☒ Site Specific Groundwater Data -
X ☒ Siting Criteria Compliance Demonstrations –
X ☒ **Certify that notice of the C-147 (only) has been sent to the surface owner(s)**
X

10.

Operator Application Certification:

I hereby certify that the information and attachments submitted with this application are true, accurate and complete to the best of my knowledge and belief.

Name (Print): Josh Mathews Title: Operations Engineer

Signature: Joshua Mathews Date: 07/06/2018

e-mail address: jmathews@taprk.com Telephone: 720-460-3318

11.

OCD Representative Signature: Randolph Bayliss **Approval Date:** 19Nov18

Title: Hydrologist **OCD Permit Number:** 1RF-438

☐ OCD Conditions ______

☐ Additional OCD Conditions on Attachment

Previously-Approved Variances

R.K. FROBEL & ASSOCIATES

Consulting Engineers

Mr. Randall Hicks, PG March 31, 2015
R.T. Hicks Consultants Ltd.
901 Rio Grande Boulevard
Suite F-142
Albuquerque, New Mexico 87104

RE: Technical Memorandum
LLDPE as Alternative Primary Liner System
Devon Energy / Hackberry Modular Impoundment

Dear Mr. Hicks:

At your request, I have investigated the suitability of application for two 30 mil LLDPE non-reinforced geomembranes as an alternative Primary liner in the Devon Energy /Hackberry Modular Impoundment. I have reviewed your C-147 Supplemental Information Report, Modular Tank Drawing, Design and Construction Plan as well as applicable correspondence. In consideration of the Primary lining system application (modular impoundment), size of the impoundment and depth, design details for modular tanks as well as estimated length of up to two years of service time, it is my professional opinion that two 30 mil LLDPE geomembranes will provide the requisite barrier against processed water loss. The two 30 mil LLDPE liners will function equal to or better than 60 mil HDPE, 30 mil PVC or 45 mil LLDPE as a primary liner system. The following are discussion points that will exhibit the attributes for using two 30 mil LLDPE geomembranes as the primary lining system:

<u>The nature and formulation of LLDPE resin is very similar to HDPE</u>. The major difference is that LLDPE is lower density, lower crystallinity (more flexible and less chemical resistant). However LLDPE will resist aging and degradation and remain intact for many years in exposed conditions. Although the lifetime of LLDPE in covered conditions (i.e., secondary liner) will be somewhat reduced with respect to HDPE, a secondary liner of LLDPE will outlast an exposed HDPE liner. In fact, according to the Geosynthetic Research Institute (GRI) study on lifetime prediction (GRI Paper No. 6), the half life of HDPE (GRI GM 13) exposed is > 36 years and the half-life of LLDPE (GRI GM 17) exposed is approximately 36 years (the Devon Energy Modular Impoundment life span is expected to be only 2 years maximum). It is understood that in order to ensure compliance of materials, 60 mil HDPE must meet or exceed GRI GM 13. Likewise, the primary or secondary liner must meet or exceed GRI GM 17 for non-reinforced LLDPE. Adhering to the minimum requirements of the GRI Specifications, two 30 mil LLDPE geomembranes when used as a primary liner system in the Devon Modular Impoundment will be equally as protective as a 60 mil HDPE liner.

<u>Flexibility Requirements.</u> 30 mil LLDPE geomembranes are less stiff and far more flexible than HDPE or 45 mil reinforced LLDPE and in this regard are preferred for installations in vertical wall tanks such as the Devon Modular Impoundment. LLDPE

provides a very flexible sheet that enables it to be fabricated into large panels, folded for shipping and installed on vertical walls transitioned to flat bottom. LLDPE will conform to the tank dimensions under hydrostatic loading.

Thermal Fusion Seaming Requirements. Thermal seaming and QC seam test requirements for geomembranes are product specific and usually prescribed by the sheet manufacturer. Both dual wedge and single wedge thermal fusion welding is commonly used on LLDPE and QC testing by air channel (ASTM D 5820) or High Pressure Air Lance (ASTM D 4437) is fully acceptable and recognized as industry standards. In this regard, there should be no exception or recommended practice for seaming and QC testing in the OCD rules. This would be fully covered in comprehensive specifications for both the Primary and Secondary geomembranes that would be reviewed by OCD.

Potential for Leakage through the Primary Liners. Leakage through geomembrane liners is directly a function of the height of liquid head above any hole or imperfection. The drainage media provides immediate drainage to a low point or outside the Modular Impoundment and thus no hydrostatic head or driving gradient is available to push leakage water through a hole. In this regard, secondary geomembrane materials can be (and usually are) much less robust in both thickness and polymer type.

Leakage through any Primary geomembrane is driven by size of hole and depth and will be detected by the increase of waste water in the drainage system and the volume being pumped out of the secondary containment. In this regard and for this variance, the Primary consists of 2 layers of 30 mil LLDPE geomembrane which will out perform a single layer of HDPE or LLDPE for potential leakage. Thus, if a leak occurs through the top layer, it will be effectively contained by the second layer. If required, location of holes in the Primary can be found by Electrical Leak Location Survey (ELLS) using a towed electrode (ASTM D 7007). Holes found can then be repaired and thus water seepage into the Secondary will be kept to a minimum. Dependent on OCR requirements for Action Leakage Rate (ALR), the leakage volumes may only be monitored. For example, a typical ALR is < 20 gpad whereas a rapid and large leak (RLL) may be > 100 gpad. Most states specify maximum ALR values for waste water impoundments usually in the range of 100 to 500 gpad. However, New Mexico does not specify any ALR for waste water impoundments (GRI Paper No. 15).

HDPE can not be prefabricated into large panels and thus 30 mil LLDPE offers the following for Primary Liner Modular Containment:

- Prefabrication in factory controlled conditions into very large panels (up to 35,000 sf) results in ease of installation, less or no thermal fusion field seams and less on site QC and CQA.

- Large prefabricated panels of 30 mil LLDPE will provide better control of thermal fusion welding in a factory environment that will improve the liner system integrity for the long term.

- The LLDPE geomembrane provides superior flexibility, lay flat characteristics and conformability which allows for more intimate contact with the underlying drainage media and tank walls.

- Two layers of the 30 mil LLDPE provide redundancy. Additionally, the bottom layer provides protection for the top layer during installation as well reduction in leakage due to pinholes (no driving head on the second 30 mil liner)

- Ease of installation of large prefabricated custom size panels results in a greater reduction of installation time and associated installation and QC costs.

- The LLDPE geomembrane is easily repaired using the same thermal fusion bonding method without the need for special surface grinding/preparation for extrusion welding used in repair of HDPE geomembranes.

In summary, it is my professional opinion that the double 30 mil LLDPE geomembranes will provide a Primary liner system that is equal to or better than a single 60 mil HDPE, 30 mil PVC or 45 mil reinforced LLDPE liner and will provide the requisite protection of fresh water, public health and the environment for many years and especially for the estimated two year life of the Devon Energy / Hackberry Modular Impoundment.

If you have any questions on the above technical memorandum or require further information, give me a call at 303-679-0285 or email geosynthetics@msn.com

Sincerely Yours,

R K Frobel

Ronald K. Frobel, MSCE, PE

References:

C-147 Supplemental Information
Devon Energy Modular Impoundment
Prepared by Hicks Consultants and Rockwater Energy Solutions

Title 19, Chapter 15, Part 34 NMAC (2015 Revision)

Geosynthetic Research Institute (GRI) Published Standards and Papers 2013

ASTM Standards 2013

Attachments:

R. K. Frobel C. V.

4898 Tarry Glen Drive
Suwanee, GA 30024

(404) 596-1838

November 3, 2017

Mr. Rod Kirch
Exterme Plastics Plus
15931 Interstate 35 Frontage Road
Moore, TX 78057

Project: Containment Liner

RE: Hydraulic Performance of HDPE

Dear Rod:

40-mil HDPE provides equal or better protection of fresh water, public health and the environment than 30-mil string reinforced LLDPE. Also the 40-mil HDPE liner has a hydraulic conductivity no greater than 1×10^{-9} cm/sec. Liner compatibility shall meet or exceed the EPA SW-846 method 9090A or subsequent relevant publications.

Respectfully,

Clay Reichert, P.E.
Technical Manager

R.K. FROBEL & ASSOCIATES
Consulting Engineers

Mr. Randall Hicks, PG November 26, 2017
R.T. Hicks Consultants Ltd.
901 Rio Grande NW
Suite F-142
Albuquerque, New Mexico 87104

RE: Technical Memorandum
40 mil HDPE Geomembrane Equivalency as a Secondary Liner System
Merchant Recycling Containment and Recycling Facility
Lea County, New Mexico

Dear Mr. Hicks:

At your request, I have investigated the suitability of application for 40 mil HDPE geomembrane as an equivalent secondary liner to 30 mil scrim reinforced LLDPE (LLDPEr) in the Merchant Recycling Facility Containment Design. In summary, it is my professional opinion that the specified 40 mil HDPE geomembrane will provide a secondary liner system that is equal to or better than 30 mil scrim reinforced LLDPEr and will provide the requisite protection of fresh water, public health and the environment for many years and especially for the estimated design and operation life of the Merchant Recycling Containment.

I have reviewed your C-147 Registration Package and the Design documentation provided by R.T Hicks Consultants. It is understood that the lining system is composed of a 60 mil HDPE Primary liner, geonet drainage layer and a 40 mil HDPE Secondary liner. In consideration of the secondary lining system application, size of impoundment and depth, design details as well as the chemical nature of typical processed water, it is my professional opinion that the 40 mil HDPE geomembrane will provide the requisite barrier against processed water loss and will function effectively as a secondary liner. The following are discussion points that hopefully will exhibit the equivalency of a 40 mil HDPE secondary liner to that of a 30 mil LLDPEr.

<u>The nature and formulation of the 40 mil HDPE resin is the same as the Primary 60 mil HDPE</u>. The major difference is that the 40 mil HDPE is lower in thickness (more flexible and less puncture resistant). However, in covered conditions, HDPE will resist aging and degradation and remain intact for many decades. In fact, a secondary liner of 40 mil HDPE will outlast an exposed 60 mil HDPE liner. According to the Geosynthetic Research Institute (GRI) study on lifetime prediction (GRI Paper No. 6), the half life of HDPE (GRI GM 13) exposed is > 36 years and the half-life of HDPE covered or buried is greater than 100 years (the Merchant Recycling Facility life span is expected to be only 10 years maximum). It is understood that in order to ensure compliance of materials, the primary 60 mil HDPE to be used must meet or exceed GRI GM 13 Standards. Likewise, the secondary liner that is not exposed to the same environmental and chemical conditions must meet or exceed GRI GM 13 for non-reinforced HDPE. Adhering to the

minimum requirements of the GRI Specifications, 40 mil HDPE when used as a secondary liner will be equally as protective as the primary 60 mil HDPE liner (reference: www.geosynthetic-institute.org/grispecs) and equally as protective as a 30 mil scrim reinforced LLDPEr liner.

Durability of Geomembranes is directly affected by exposure conditions. Buried or covered geomembranes are not affected by the same degradation mechanisms (UV, Ozone, Chemical, Stress, Temperature, etc) as are fully exposed geomembranes. In this regard, the secondary liner material and thickness can be much less robust than the fully exposed primary liner which in this case is 60 mil HDPE. This is also the case for landfill lining systems where the secondary geomembrane in a bottom landfill cell may be 40 mil HDPE.

Thermal Fusion Seaming Requirements. Thermal seaming and QC seam test requirements for geomembranes are product specific and usually prescribed by the sheet manufacturer. Dual wedge thermal fusion welding is commonly used on HDPE and QC testing by air channel (ASTM D 5820) is fully acceptable and recognized as an industry standard. In this regard, there should be no exception requirement for seaming and QC testing as both the Primary and Secondary geomembranes are HDPE. This is fully covered in comprehensive specifications for both the Primary and Secondary geomembranes (Reference: www.ASTM.org/Standards).

Potential for Leakage through the Primary and Secondary Liners. Leakage through geomembrane liners is directly a function of the height of liquid head above any hole or imperfection. The geonet drainage media provides immediate drainage to a low point or sump and thus no hydrostatic head or driving gradient is available to push leakage water through a hole in the secondary liner. In this regard, secondary geomembrane materials can be (and usually are) much less in thickness and also polymer type. Hydraulic Conductivity through the 40 mil HDPE liner material is extremely low due to the polymer type, structure and crystallinity and exceeds requirements of EPA SW-846 Method 9090A.

Chemical Attack. Chemical attack to polymeric geomembranes is directly a function of type of chemical, temperature and exposure time. Again, the HDPE Primary provides the chemically resistant liner and is QC tested to reduce potential defects or holes. If there is a small hole, the geonet drain takes any leakage water immediately to the sump for extraction. Thus, exposure time is very limited on a secondary liner in addition to low temperature, little volume and virtually no head pressure. In this regard, a chemically resistant geomembrane material such as 40 mil HDPE can be specified for the secondary and is a fully acceptable alternate to 30 mil scrim reinforced LLDPEr.

Mechanical Properties Characteristics. Geomembranes of different polymer and/or structure (i.e., reinforced vs non-reinforced) can not be readily compared using such characteristics as tensile stress/strain, tear, puncture and polymer requirements. For a 40 mil HDPE liner material to function as a Secondary liner it should meet or exceed the manufacturers minimum requirements for Density, Tensile Properties, Tear, Puncture as well as other properties such as UV resistance. The sheet material must also meet or exceed GRI GM 13 minimum requirements. In this regard, a 40 mil HDPE will be equivalent to a 30 mil LLDPEr as a secondary liner for the conditions listed below:

- The subgrade or compacted earth foundation will be smooth, free of debris or loose rocks, dry, unyielding and will support the lining system.
- The side slopes for the containment shall be equal to or less than 3H:1V.
- The physical properties and condition of the subgrade or liner foundation (i.e., density, slope, moisture) will be inspected and certified by a Professional Engineer that it meets or exceeds specification requirements.
- Immediately prior to installation, the installation contractor shall inspect and sign off on the subgrade conditions that they meet or exceed the HDPE manufacturer and installers requirements.
- A protective geotextile will be placed on the finished and accepted subgrade between subgrade and the 40 mil HDPE Secondary liner.
- A 200 mil geonet will be placed over the 40 mil HDPE Secondary Liner.
- A 60 mil HDPE Primary liner will be placed over the 200 mil geonet drainage layer.

If you have any questions on the above technical memorandum or require further information, give me a call at 720-289-0300 or email geosynthetics@msn.com

Sincerely Yours,

R K Frobel

Ronald K. Frobel, MSCE, PE

References:

C-147 Registration Package
Merchant Recycling and Containment
Section 35 T 21 SR 33 E Lea County
November 2016

Design Documents
Merchant Recycling and Containment

Geosynthetic Research Institute (GRI) Published Standards and Papers 2017
www.geosynthetic-institute.org

ASTM Geosynthetics Standards 2017
www.ASTM.org/Standards

19103 Gundle Road
Houston, Texas 77073

[O]281.443.8564
[F]281.875.6010
[TF]800.435.2008

November 2, 2017

Attn: Mr. Rod Kirch

Project: Containment Liner

RE: UV Resistance and Chemical Resistance of HDPE

Dear Rod,

Polyethylene (PE) has a simple chain structure with a repeating unit,-(CH2)-. Its physical properties are greatly dependent upon the chain length, structure, and density. HDPE is a semi-crystalline polymer which consists of amorphous (disorder region) and crystalline (ordered structure phases). Due to the long linear chain structure, the degree of crystallinity of HDPE is much higher than LLDPE. The differences in crystallinity can affect the oxidation behavior partly because the diffusion of oxygen through the amorphous region is much easier than through the crystalline region.

Regarding the UV resistance of the two type of polyethylene, attached is the GRI White Paper #6, Geomembrane Lifetime Prediction: Unexposed and Exposed Condition. On page 10, the authors stated "The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE;e.g., 10% versus 50%. This has theeffect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE." On page 23, Table 6, it listed the lifetime prediction of various types of geomembrane, including 1.5mm HDPE and 1.0mm LLDPE.

According to Geosynthetics from David I. Cook in Table 6, page 17, the chemical resistance of HDPE is rated "Excellent" and LLDPE is rated "Good". We also attached part of the report, p.15 to 18, for your information.

Please feel free to contact me if you have any question.

Sincerely,

Connie Wong, Ph.D.,
Support Engineer
cowong@gseworld.com

These EN requirement standards instruct manufacturers to declare the mean value and tolerance of certain product characteristics. The required characteristics depend on the end use and function (separation, filtration, etc.) of the fabric. These characteristics are determined by some of the test methods listed in **Table 3**. Some tests (referred to as H tests in the standards) are mandatory, i.e., required by Mandate M/107 issued by the European Community to the European standardisation committee for geotextiles, CEN 189. Some (referred to as A tests in the standards) are relevant to all conditions of use. The A tests are not legally required but are commercially important. A third test category (S) is relevant to specific conditions of use.

For more information and detail on the CPD and CE marking of geotextiles, the reader is recommended to consult a relevant and useful web site on quality and standardisation of geotextiles (www.vinci-quality.com).

It should be noted that ‘geotextile related products’ includes all other categories of geosynthetic except geomembranes and GCLs. The latter two groups are now known as ‘geosynthetic barriers’ and are in a separate CPD sector from geotextiles and related products.

The application standards for geosynthetic barriers are, at the time of writing, still at the provisional stage (prENs). There are five provisional geosynthetic barrier standards (www.vinci-quality.com):

- prEN 13361 reservoir and dam construction
- prEN 13362 canal construction
- prEN 13491 fluid barrier in tunnel and underground structures
- prEN 13492 liquid waste containment
- prEN 13493 solid and hazardous waste storage

4 Geomembranes

4.1 Description and Manufacturing

Geomembranes are thin, flexible sheets of material with very low permeability. They are manufactured from synthetic or bituminous products and may be strengthened with a fabric or film. Geomembranes are employed invariably as a barrier to prevent the passage of gases and fluids.

A commonly accepted definition of a geomembrane from the ASTM is:

> A geomembrane is a continuous membrane liner or barrier having sufficiently low permeability to control migration of fluids in a constructed project, structure or dam.

The original geomembranes were made of butyl rubber. Nowadays, polyvinyl chloride (PVC) or some form of polyethylene account for a high proportion of the total geomembrane useage. The different types of geomembrane polymer will be discussed in more detail later (Section 4.2).

The manufacture of geomembranes commences with the production of the raw materials, i.e., the polymer resin and a wide range of additives such as stabilisers, plasticisers, softeners, fillers, processing aids etc.

The raw materials can then be processed in three ways:

The first method produces the simplest type of geomembrane; single ply and non-reinforced. In this method the raw materials are blended and compounded before being extruded as sheets or cylinders. The extruder produces sheet material 0.1 to 5 mm thick and 1 to 5 m wide. Calendering, or pressing the sheets between counter rotating rollers, works them into uniform thickness and improves the mechanical properties. Full thickness sheets can also be blown into a large long bubble which is cut and opened into the final sheet form.

In the second method, multi-ply geomembranes are made by laminating several layers together. Laminated geomembranes can be non-reinforced or reinforced by inclusion of a fabric scrim between the layers. The scrim improves the mechanical properties (e.g., tensile and tear strength) of the composite material but does not reinforce the soil on which the geomembrane is placed.

The third production method is known as spread coating. In this method, a geotextile, usually a needle-punched non-woven, is used as a substrate on which the molten polymer is spread into its final thickness.

Geomembrane manufacturing methods are described in more detail in (a.9).

The surface of some geomembranes is roughened or textured, by spraying or embossing, to increase the soil/polymer friction (a.19). Three common techniques are coextrusion, lamination and impingement (a.20):

- Coextrusion uses a blowing agent in the extrudate which expands on cooling to cause a roughened surface.
- In lamination, a sheet containing a foam is adhered to a conventional sheet. The foaming agent provides a froth that produces a rough, textured laminate stuck to the smooth, solid sheet.
- Impingement is the projection of hot particles on to the smooth sheet.

A review of these texturing techniques and a discussion on characterisation of the surface topography has been presented by Zettler and co-workers (7).

4.2 Polymers

The vast majority of geomembranes are thin sheets of flexible thermoplastic or thermosetting polymeric materials. The main polymers used are (a.9):

Thermoplastic polymers

- Polyethylene (PE) – high density (HDPE), medium density (MDPE), linear low density (LLDPE), low density (LDPE), very low density (VLDPE)
- Polypropylene (PP)
- Polyvinyl chloride (PVC)
- Chlorinated polyethylene (CPE)
- Polyamide (PA)

Thermoset polymers

- Isoprene-isobutylene (IIR) or butyl rubber
- Epichlorohydrin rubber
- Ethylene-propylene-diene terpolymer (EDPM)
- Polychloroprene (Neoprene)
- Ethylene-propylene terpolymer (EPT)
- Ethylene-vinyl acetate (EVA)
- Ethylene interpolymer alloy (EIA)

Combination polymers

- PVC-nitrile rubber
- PE-EPDM
- PVC-EVA
- Crosslinked CPE
- Chlorosulfonated polyethylene (CSPE) ‘Hypalon’

Others

- Bitumen impregnated geotextiles
- Elastomer impregnated geotextiles
- Aluminium foil coated geomembranes for protection against hydrocarbons (329).

Which geomembrane polymer to choose depends, as usual, on its properties, availability and, of course, on the application and structure in which the geomembrane is to be incorporated. The properties will be discussed in more detail in Section 4.4 (Testing).

No study appears to have been performed which compares the properties of all these polymers as geomembrane sheets. However, **Table 6** (a.21) provides a useful qualitative comparison of geomembrane liners made from eight polymers and, another type of geosynthetic barrier known as a geosynthetic clay liner (GCL). The attributes considered are physical properties, durability, installation damage, seaming and cost.

Table 6 refers to seaming methods, that is to say the techniques used to join together the membrane sheets either at the factory or on site. Production of a leak tight and durable seam is clearly vital otherwise the geomembrane’s function as a fluid barrier is lost. There are several general seaming methods. The choice is governed by the polymer and site requirements.

- Solvent: A liquid solvent is brushed between two sheets of membrane followed by pressure to form the seal.
- Adhesive: A glue dissolved in a solvent is applied by brush or roller to the membrane sheets which are brought together after the surface becomes tacky.

Table 6 Geomembranes; comparison of polymers								
Attribute	**HDPE**	**LLDPE**	**PVC**	**EPDM**	**EIA**	**Reinforced CSPE**	**Flexible PP**	**GCL**
Chemical resistance	Excellent	Good	Fair	Good	Excellent (when cured)	Excellent	Excellent	Fair
Hydrocarbon resistance	Good	Good	Fair	Good	Excellent (when cured)	Good	Good	Poor
Weathering; UV resistance	Excellent	Fair	Poor	Excellent	Excellent (when cured)	Excellent	Excellent	Poor
Thermal stability	Poor	Poor	Good	Excellent	Good	Excellent	Good – excellent when reinforced	Good
Tensile properties	Good	Good	Good	Good	Excellent	Excellent	Good – excellent when reinforced	Good
Elongation; uniaxial	Excellent	Excellent	Good	Good	Fair	Good	Excellent	Fair
Elongation; multiaxial	Poor	Excellent	Excellent	Good	Fair	Good	Excellent	Fair
Puncture resistance	Fair	Excellent	Excellent	Good	Excellent	Good	Good	Good
Stress cracking	Fair	Good	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur	Does not occur
Resistance to installation damage	Fair	Fair	Excellent	Excellent	Good	Good	Excellent	Good
Seaming methods	Thermal/ excellent	Thermal/ excellent	Thermal or solvent bonding/ good	Tape seams/good	Thermal/ excellent	Thermal or solvent bonding good	Thermal/ excellent	Laps only
Ease of repair in service	Good	Good	Good	Good	Good	Poor needs adhesives	Excellent	NA
Flexibility	Fair	Excellent	Good	Good	Good	Good	Excellent	NA
Roll cost	Low	Low/ medium	medium	Medium/ high	High	High	Medium	Medium
Reproduced with permission from M. Sadlier (a.21)								

- Thermal: There is a range of thermal methods in which the opposing surfaces are melted by some means such as hot air or electrically heated knife or wedge. The melted surfaces are pressed together by rollers.
- Mechanical: The usual mechanical joining methods are utilisation of sticky tapes or sewing. The sewn seams are subsequently waterproofed.

The solvent and adhesive methods tend to be used for thermoplastic polymers and elastomers such as PVC, CPE, EDPM, and CSPE. Thermal methods can be employed for most thermoplastic polymers but are especially important for semi-crystalline polyethylene materials like HDPE and LDPE. A more detailed description of geomembrane seaming is given in Chapter 5 of Designing with Geosynthetics by Koerner (a.9).

Some further advantages and disadvantages of specific polymers are now given.

PVC (polyvinyl chloride)

- Tough without reinforcement
- Good seams by dielectric, solvent or heat
- Elasticised for flexibility, plasticiser leaches with time

CPE (chlorinated polyethylene)

- Seams easy to make by dielectric or solvent
- Plasticised with PVC

CSPE (chlorosulfonated polyethylene thermoplastic rubber)

- Good seams by heat or adhesive

Butyl

- Poor field seams
- Low gas permeability

CP (chloroprene/neoprene cured rubber)

- Fair field seams using solvent and tape

HDPE

- Good seams by thermal or extrusion methods
- Low friction surfaces
- High thermal expansion and contraction

MDPE, LDPE and VLDPE

- Good seams by thermal or extrusion methods
- Moderate thermal expansion and contraction

LLDPE

- High friction surface
- Good seams by thermal or extrusion methods
- Large variation in thickness

Further comparative properties are given in **Table 7** which has been generated from information in references a.9 and a.22.

Table 7 Geomembrane polymers: advantages and disadvantages

Factor	PVC	CPE	CSPE	Butyl	CP	HDPE	MDPE LDPE VLDPE	LLDPE
Cost	low	medium	medium	medium to high	high	low	low	medium
Chemical resistance	-	good	good	-	good	excellent	good	very good
Weathering	poor	good	excellent	fair to good	good	-	-	-
High temperature	poor	-	fair	good	good	-	-	-
Cold crack	poor	good	good	-	-	-	-	-
Stress crack	-	-	-	-	-	sensitive	none	none

CP = chloroprene rubber

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GRI White Paper #6

- on -

Geomembrane Lifetime Prediction:
Unexposed and Exposed Conditions

by

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Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions

1.0 Introduction

Without any hesitation the most frequently asked question we have had over the past thirty years' is "how long will a particular geomembrane last".[*] The two-part answer to the question, largely depends on whether the geomembrane is covered in a timely manner or left exposed to the site-specific environment. Before starting, however, recognize that the answer to either covered or exposed geomembrane lifetime prediction is neither easy, nor quick, to obtain. Further complicating the answer is the fact that all geomembranes are formulated materials consisting of (at the minimum), (i) the resin from which the name derives, (ii) carbon black or colorants, (iii) short-term processing stabilizers, and (iv) long-term antioxidants. If the formulation changes (particularly the additives), the predicted lifetime will also change. See Table 1 for the most common types of geomembranes and their approximate formulations.

Table 1 - Types of commonly used geomembranes and their approximate formulations (based on weight percentage)

Type	Resin	Plasticizer	Fillers	Carbon Black	Additives
HDPE	95-98	0	0	2-3	0.25-1
LLDPE	94-96	0	0	2-3	0.25-3
fPP	85-98	0	0-13	2-4	0.25-2
PVC	50-70	25-35	0-10	2-5	2-5
CSPE	40-60	0	40-50	5-10	5-15
EPDM	25-30	0	20-40	20-40	1-5

HDPE = high density polyethylene
LLDPE = linear low density polyethylene
fPP = flexible polypropylene
PVC = polyvinyl chloride (plasticized)
CSPE = chlorsulfonated polyethylene
EPDM = ethylene propylene diene terpolymer

[*] More recently, the same question has arisen but focused on geotextiles, geogrids, geopipe, turf reinforcement mats, fibers of GCLs, etc. This White Paper, however, is focused completely on geomembranes due to the tremendous time and expense of providing such information for all types of geosynthetics.

The possible variations being obvious, one must also address the degradation mechanisms which might occur. They are as follows accompanied by some generalized commentary.

- Ultraviolet Light - This occurs only when the geosynthetic is exposed; it will be the focus of the second part of this communication.
- Oxidation - This occurs in all polymers and is the major mechanism in polyolefins (polyethylene and polypropylene) under all conditions.
- Ozone - This occurs in all polymers that are exposed to the environment. The site-specific environment is critical in this regard.
- Hydrolysis - This is the primary mechanism in polyesters and polyamides.
- Chemical - Can occur in all polymers and can vary from water (least aggressive) to organic solvents (most aggressive).
- Radioactivity - This is not a factor unless the geomembrane is exposed to radioactive materials of sufficiently high intensity to cause chain scission, e.g., high level radioactive waste materials.
- Biological - This is generally not a factor unless biologically sensitive additives (such as low molecular weight plasticizers) are included in the formulation.
- Stress State – This is a complicating factor which is site-specific and should be appropriately modeled in the incubation process but, for long-term testing, is very difficult and expensive to acheive.
- Temperature - Clearly, the higher the temperature the more rapid the degradation of all of the above mechanisms; temperature is critical to lifetime and furthermore is the key to

time-temperature-superposition which is the basis of the laboratory incubation methods which will be followed.

2.0 Lifetime Prediction: Unexposed Conditions

Lifetime prediction studies at GRI began at Drexel University under U. S. EPA contract from 1991 to 1997 and was continued under GSI consortium funding until ca. 2002. Focus to date has been on HDPE geomembranes placed beneath solid waste landfills due to its common use in this particular challenging application. Incubation of the coupons has been in landfill simulation cells (see Figure 1) maintained at 85, 75, 65 and 55°C. The specific conditions within these cells are oxidation beneath, chemical (water) from above, and the equivalent of 50 m of solid waste mobilizing compressive stress. Results have been forthcoming over the years insofar as three distinct lifetime stages; see Figure 2.

Stage A - Antioxidant Depletion Time

Stage B - Induction Time to the Onset of Degradation

Stage C - Time to Reach 50% Degradation (i.e., the Halflife)

2.1 Stage A - Antioxidant Depletion Time

The dual purposes of antioxidants are to (i) prevent polymer degradation during processing, and (ii) prevent oxidation reactions from taking place during Stage A of service life, respectively. Obviously, there can only be a given amount of antioxidants in any formulation. Once the antioxidants are depleted, additional oxygen diffusing into the geomembrane will begin to attack the polymer chains, leading to subsequent stages as shown in Figure 2. The duration of the antioxidant depletion stage depends on both the type and amount of the various antioxidants, i.e., the precise formulation.

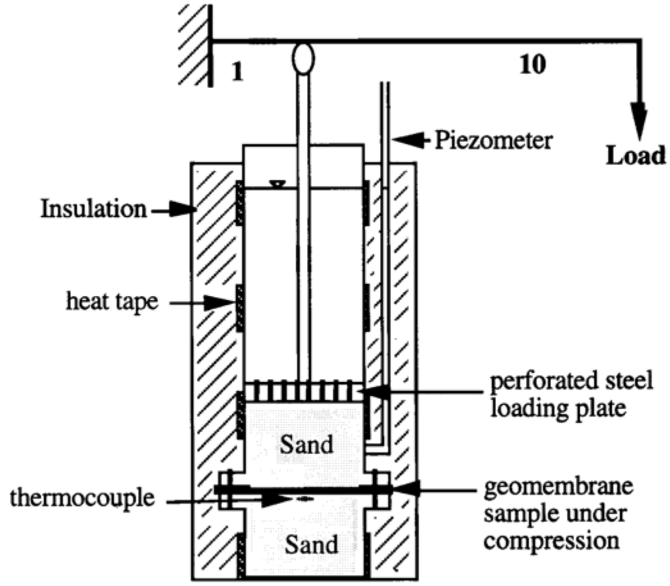


Figure 1. Incubation schematic and photograph of multiple cells maintained at various constant temperatures.

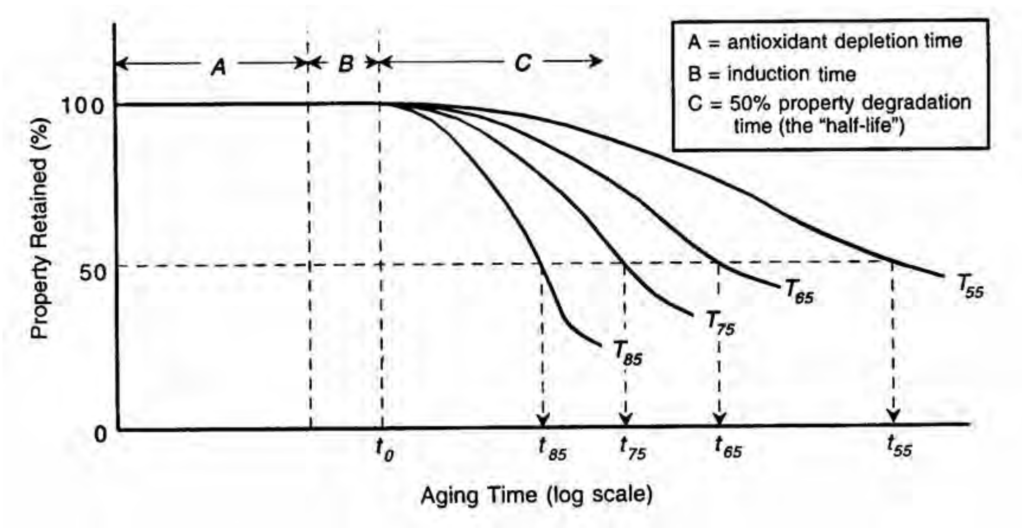


Figure 2. Three individual stages in the aging of most geomembranes.

The depletion of antioxidants is the consequence of two processes: (i) chemical reactions with the oxygen diffusing into the geomembrane, and (ii) physical loss of antioxidants from the geomembrane. The chemical process involves two main functions; the scavenging of free radicals converting them into stable molecules, and the reaction with unstable hydroperoxide (ROOH) forming a more stable substance. Regarding physical loss, the process involves the distribution of antioxidants in the geomembrane and their volatility and extractability to the site-specific environment.

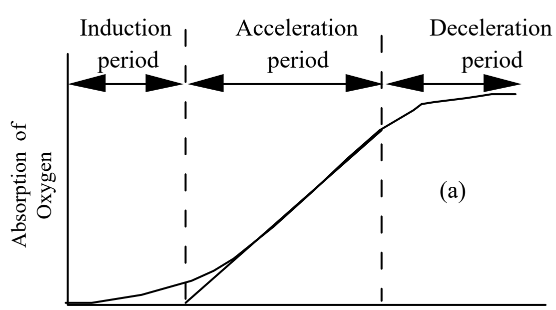
Hence, the rate of depletion of antioxidants is related to the type and amount of antioxidants, the service temperature, and the nature of the site-specific environment. See Hsuan and Koerner (1998) for additional details.

2.2 Stage B - Induction Time to Onset of Degradation

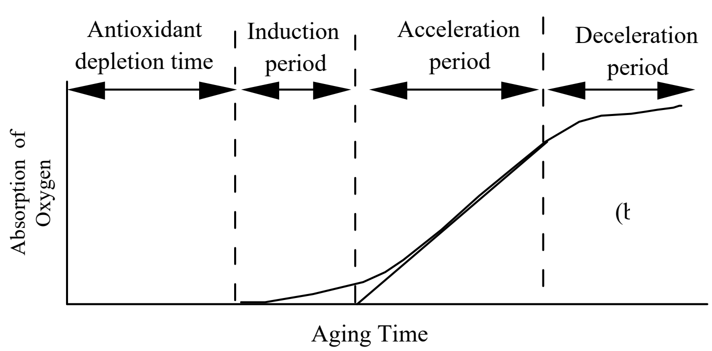
In a pure polyolefin resin, i.e., one without carbon black and antioxidants, oxidation occurs extremely slowly at the beginning, often at an immeasurable rate. Eventually, oxidation occurs more rapidly. The reaction eventually decelerates and once again becomes very slow.

This progression is illustrated by the S-shaped curve of Figure 3(a). The initial portion of the curve (before measurable degradation takes place) is called the induction period (or induction time) of the polymer. In the induction period, the polymer reacts with oxygen forming hydroperoxide (ROOH), as indicated in Equations (1)-(3). However, the amount of ROOH in this stage is very small and the hydroperoxide does not further decompose into other free radicals which inhibits the onset of the acceleration stage.

In a stabilized polymer such as one with antioxidants, the accelerated oxidation stage takes an even longer time to be reached. The antioxidants create an additional depletion time stage prior to the onset of the induction time, as shown in Figure 3(b).



(a) Pure unstabilized polyethylene



(b) Stabilized polyethylene

Figure 3. Curves illustrating various stages of oxidation.

$$RH \rightarrow R\bullet + H\bullet \tag{1}$$

(aided by energy or catalyst residues in the polymer)

$$R\bullet + O2 \rightarrow ROO\bullet \tag{2}$$

$$ROO\bullet + RH \rightarrow ROOH + R\bullet \tag{3}$$

In the above, RH represents the polyethylene polymer chains; and the symbol "•" represents free radicals, which are highly reactive molecules.

2.3 Stage C - Time to Reach 50% Degradation (Halflife)

As oxidation continues, additional ROOH molecules are being formed. Once the concentration of ROOH reaches a critical level, decomposition of ROOH begins, leading to a substantial increase in the amount of free radicals, as indicated in Equations (4) to (6). The additional free radicals rapidly attack other polymer chains, resulting in an accelerated chain reaction, signifying the end of the induction period, Rapopport and Zaikov (1986). This indicates that the concentration of ROOH has a critical control on the duration of the induction period.

$$ROOH \rightarrow RO\bullet\ OH\bullet \text{ (aided by energy)} \tag{4}$$

$$RO\bullet + RH \rightarrow ROH + R\bullet \tag{5}$$

$$OH\bullet + RH \rightarrow H2O + R\bullet \tag{6}$$

A series of oxidation reactions produces a substantial amount of free radical polymer chains (R•), called alkyl radicals, which can proceed to further reactions leading to either cross-linking or chain scission in the polymer. As the degradation of polymer continues, the physical and mechanical properties of the polymer start to change. The most noticeable change in physical properties is the melt index, since it relates to the molecular weight of the polymer. As for mechanical properties, both tensile break stress (strength) and break strain (elongation) decrease.

Ultimately, the degradation becomes so severe that all tensile properties start to change (tear, puncture, burst, etc.) and the engineering performance is jeopardized. This signifies the end of the so-called "service life" of the geomembrane.

Although quite arbitrary, the limit of service life of polymeric materials is often selected as a 50% reduction in a specific design property. This is commonly referred to as the halflife time, or simply the "halflife". It should be noted that even at halflife, the material still exists and can function, albeit at a decreased performance level with a factor-of-safety lower than the initial design value.

2.4 Summary of Lifetime Research-to-Date

Stage A, that of antioxidant depletion for HDPE geomembranes as required in the GRI-GM13 Specification, has been well established by our own research and corroborated by others, e.g., Sangram and Rowe (2004). The GRI data for standard and high pressure Oxidative Induction Time (OIT) is given in Table 2. The values are quite close to one another. Also, as expected, the lifetime is strongly dependent on the service temperature; with the higher the temperature the shorter the lifetime.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Stage "B", that of induction time, has been obtained by comparing 30-year old polyethylene water and milk containers (containing no long-term antioxidants) with currently produced containers. The data shows that degradation is just beginning to occur as evidenced by slight changes in break strength and elongation, but not in yield strength and elongation. The lifetime for this stage is also given in Table 2.

Stage “C”, the time for 50% change of mechanical properties is given in Table 2 as well. The data depends on the activation energy, or slope of the Arrhenius curve, which is very sensitive to material and experimental techniques. The data is from Gedde, et al. (1994) which is typical of the HDPE resin used for gas pipelines and is similar to Martin and Gardner (1983).

Summarizing Stages A, B, and C, it is seen in Table 2 that the halflife of covered HDPE geomembranes (formulated according to the current GRI-GM13 Specification) is estimated to be 449-years at 20°C. This, of course, brings into question the actual temperature for a covered geomembrane such as beneath a solid waste landfill. Figure 4 presents multiple thermocouple monitoring data of a municipal waste landfill liner in Pennsylvania for over 10-years, Koerner and Koerner (2005). Note that for 6-years the temperature was approximately 20°C. At that time and for the subsequent 4-years the temperature increased to approximately 30°C. Thus, the halflife of this geomembrane is predicted to be from 166 to 446 years within this temperature range. The site is still being monitored, see Koerner and Koerner (2005).

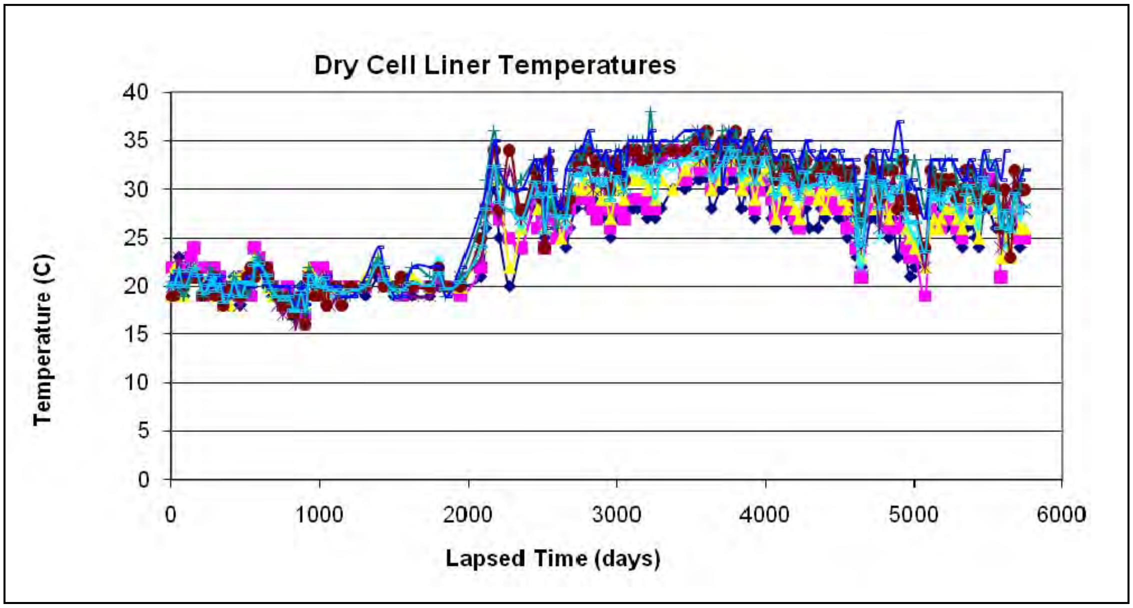


Figure 4. Long-term monitoring of an HDPE liner beneath a municipal solid waste landfill in Pennsylvania.

2.5 Lifetime of Other Covered Geomembranes

By virtue of its widespread use as liners for solid waste landfills, HDPE is by far the widest studied type of geomembrane. Note that in most countries (other than the U.S.), HDPE is the required geomembrane type for solid waste containment. Some commentary on other-than HDPE geomembranes (recall Table 1) follows:

2.5.1 Linear Low Density Polyethylene (LLDPE) geomembranes

The nature of the LLDPE resin and its formulation is very similar to HDPE. The fundamental difference is that LLDPE is a lower density, hence lower crystallinity, than HDPE; e.g., 10% versus 50%. This has the effect of allowing oxygen to diffuse into the polymer structure quicker, and likely decreases Stages A and C. How much is uncertain since no data is available, but it is felt that the lifetime of LLDPE will be somewhat reduced with respect to HDPE.

2.5.2 Plasticizer migration in PVC geomembranes

Since PVC geomembranes necessarily have plasticizers in their formulations so as to provide flexibility, the migration behavior must be addressed for this material. In PVC the plasticizer bonds to the resin and the strength of this bonding versus liquid-to-resin bonding is significant. One of the key parameters of a stable long-lasting plasticizer is its molecular weight. The higher the molecular weight of the plasticizer in a PVC formulation, the more durable will be the material. Conversely, low molecular weight plasticizers have resulted in field failures even under covered conditions. See Miller, et al. (1991), Hammon, et al. (1993), and Giroud and Tisinger (1994) for more detail in this regard. At present there is a considerable difference (and cost) between PVC geomembranes made in North America versus Europe. This will be apparent in the exposed study of durability in the second part of this White Paper.

2.5.3 Crosslinking in EPDM and CSPE geomembrnaes

The EPDM geomembranes mentioned in Table 1 are crosslinked thermoset materials. The oxidation degradation of EPDM takes place in either ethylene or propylene fraction of the co-polymer via free radical reactions, as expressed in Figure 5, which are described similarly by Equations (4) to (6).

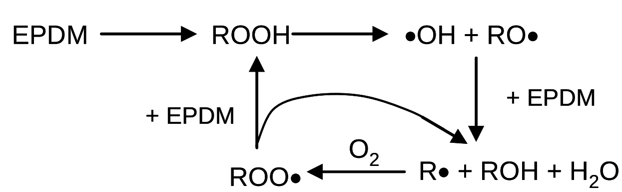


Figure 5. Oxidative degradation of crosslinked EPDM geomembranes, (Wang and Qu, 2003).

For CSPE geomembranes, the degradation mechanism is dehydrochlorination by losing chlorine and generating carbon-carbon double bonds in the main polymer chain, as shown in Figure 6.

The carbon-carbon double bonds become the preferred sites for further thermodegradation or cross-linking in the polymer, leading to eventual brittleness of the geomembrane.

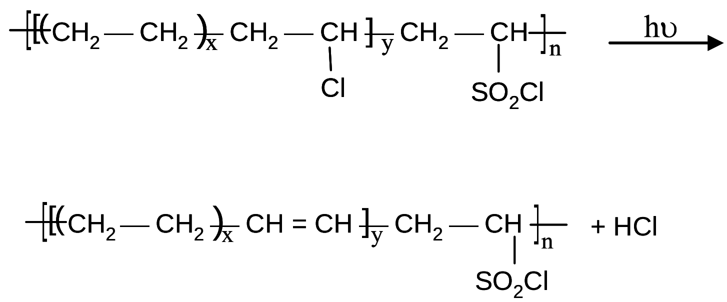


Figure 6. Dechlorination degradation of crosslinked CSPE geomembranes (Chailan, et al., 1995).

Neither EPDM nor CSPE has had a focused laboratory study of the type described for HDPE reported in the open literature. Most of lifetime data for these geomembranes is antidotal by virtue of actual field performance. Under covered conditions, as being considered in this section, there have been no reported failures by either of these thermoset polymers to our knowledge.

3.0 Lifetime Prediction: Exposed Conditions

Lifetime prediction of exposed geomembranes have taken two very different pathways; (i) prediction from anecdotal feedback and field performance, and (ii) from laboratory weathering device predictions.

3.1 Field Performance

There is a large body of anecdotal information available on field feedback of exposed geomembranes. It comes form two quite different sources, i.e., dams in Europe and flat roofs in the USA.

Regarding exposed geomembranes in dams in Europe, the original trials were using 2.0 mm thick polyisobutylene bonded directly to the face of the dam. There were numerous problems encountered as described by Scuero (1990). Similar experiences followed using PVC geomembranes. In 1980, a geocomposite was first used at Lago Nero which had a 200 g/m^2 nonwoven geotextile bonded to the PVC geomembrane. This proved quite successful and led to the now-accepted strategy of requiring drainage behind the geomembrane. In addition to thick nonwoven geotextiles, geonets, and geonet composites have been successful. Currently over 50 concrete and masonry dams have been rehabilitated in this manner and are proving successful for over 30-years of service life. The particular type of PVC plasticized geomembranes used for these dams is proving to be quite durable. Tests by the dam owners on residual properties show only nominal changes in properties, Cazzuffi (1998). As indicated in Miller, et al. (1991) and Hammond, et al. (1993), however, different PVC materials and formulations result in very different behavior; the choice of plasticizer and the material's thickness both being of paramount importance. An excellent overview of field performance is recently available in which 250 dams which have been waterproofed by geomembranes is available from ICOLD (2010).

Regarding exposed geomembranes in flat roofs, past practice in the USA is almost all with EPDM and CSPE and, more recently, with fPP. Manufacturers of these geomembranes regularly warranty their products for 20-years and such warrants appear to be justified. EPDM and CSPE, being thermoset or elastomeric polymers, can be used in dams without the necessity of having seams by using vertical attachments spaced at 2 to 4 m centers, see Scuero and Vaschetti (1996). Conversely, fPP can be seamed by a number of thermal fusion methods. All of these geomembrane types have good conformability to rough substrates as is typical of concrete and masonry dam rehabilitation. It appears as though experiences (both positive and negative) with geomembranes in flat roofs should be transferred to all types of waterproofing in civil engineering applications.

3.2 Laboratory Weatherometer Predictions

For an accelerated simulation of direct ultraviolet light, high temperature, and moisture using a laboratory weatherometer one usually considers a worst-case situation which is the solar maximum condition. This condition consists of global, noon sunlight, on the summer solstice, at normal incidence. It should be recognized that the UV-A range is the target spectrum for a laboratory device to simulate the naturally occurring phenomenon, see Hsuan and Koerner (1993), and Suits and Hsuan (2001).

The Xenon Arc weathering device (ASTM D4355) was introduced in Germany in 1954. There are two important features; the type of filters and the irradiance settings. Using a quartz inner and borosilicate outer filter (quartz/boro) results in excessive low frequency wavelength degradation. The more common borosilicate inner and outer filters (boro/boro) shows a good correlation with solar maximum conditions, although there is an excess of energy below 300 nm wavelength. Irradiance settings are important adjustments in shifting the response although they do not eliminate the portion of the spectrum below 300 nm frequency. Nevertheless, the Xenon Arc device is commonly used method for exposed lifetime prediction of all types of geosynthetics.

UV Fluorescent devices (ASTM D7238) are an alternative type of accelerated laboratory test device which became available in the early 1970's. They reproduce the ultraviolet portion of the sunlight spectrum but not the full spectrum as in Xenon Arc weatherometers. Earlier FS-40 and UVB-313 lamps give reasonable short wavelength output in comparison to solar maximum. The UVA-340 lamp was introduced in 1987 and its response is seen to reproduce ultraviolet light quite well. This device (as well as other types of weatherometers) can handle elevated temperature and programmed moisture on the test specimens.

Research at the Geosynthetic Institute (GSI) has actively pursued both Xenon and UV Fluorescent devices on a wide range of geomembranes. Table 3 gives the geomembranes that were incubated and the number of hours of exposure as of 12 July 2005.

Table 5 - Details of the GSI laboratory exposed weatherometer study on various types of geomembranes

Geomembrane Type	Thickness (mm)	UV Fluorescent Exposure*	Xenon Exposure*	Comment
1. HDPE (GM13)	1.50	8000 hrs.	6600 hrs.	Basis of GRI-GM13 Spec
2. LLDPE (GM17)	1.00	8000	6600	Basis of GRI-GM-17 Spec
3. PVC (No. Amer.)	0.75	8000	6600	Low Mol. Wt. Plasticizer
4. PVC (Europe)	2.50	7500	6600	High Mol. Wt. Plasticizer
5. fPP (BuRec)	1.00	2745**	4416**	Field Failure at 26 mos.
6. fPP-R (Texas)	0.91	100	100	Field Failure at 8 years
7. fPP (No. Amer.)	1.00	7500	6600	Expected Good Performance

*As of 12 July 2005 exposure is ongoing
**Light time to reach halflife of break and elongation

3.3 Laboratory Weatherometer Acceleration Factors

The key to validation of any laboratory study is to correlate results to actual field performance. For the nonexposed geomembranes of Section 2 such correlations will take hundreds of years for properly formulated products. For the exposed geomembranes of Section 3, however, the lifetimes are significantly shorter and such correlations are possible. In particular, Geomembrane #5 (flexible polypropylene) of Table 3 was an admittedly poor geomembrane formulation which failed in 26 months of exposure at El Paso, Texas, USA. The reporting of this failure is available in the literature, Comer, et al. (1998). Note that for both UV Fluorescent and Xenon Arc laboratory incubation of this material, failure (halflife to 50% reduction in strength and elongation) occurred at 2745 and 4416 hours, respectively. The comparative analysis of laboratory and field for this case history allows for the obtaining of acceleration factors for the two incubation devices.

3.3.1 Comparison between field and UV Fluorescent weathering

The light source used in the UV fluorescent weathering device is UVA with wavelengths from 295-400 nm. In addition, the intensity of the radiation is controlled by the Solar Eye irradiance control system. The UV energy output throughout the test is 68.25 W/m^2.

The time of exposure to reach 50% elongation at break was as follows:

= 2745 hr. of light
= 9,882,000 seconds

Total energy in MJ/m^2 = 68.25 W/m^2 $\times$ 9,882,000
= 674.4 MJ/m^2

The field site was located at El Paso, Texas. The UVA radiation energy (295-400 nm) at this site is estimated based on data collected by the South Florida Testing Lab in Arizona (which is a similar atmospheric location). For 26 months of exposure, the accumulated UV radiation energy is 724 MJ/m^2 which is very close to that generated from the UV fluorescent weatherometer. Therefore, direct comparison of the exposure time between field and UV fluorescent is acceptable.

Field time vs. Fluorescent UV light time: **Thus, the acceleration factor is 6.8.**
= 26 Months = 3.8 Months

3.3.2 Comparison between field and Xenon Arc weathering

The light source of the Xenon Arc weathering device simulates almost the entire sunlight spectrum from 250 to 800 nm. Depending of the age of the light source and filter, the solar energy ranges from 340.2 to 695.4 W/m^2, with the average value being 517.8 W/m^2.

The time of exposure to reach 50% elongation at break

= 4416 hr. of light
= 15,897,600 seconds

Total energy in MJ/m^2 = 517.8 W/m^2 $\times$ 15,897,600
= 8232 MJ/m^2

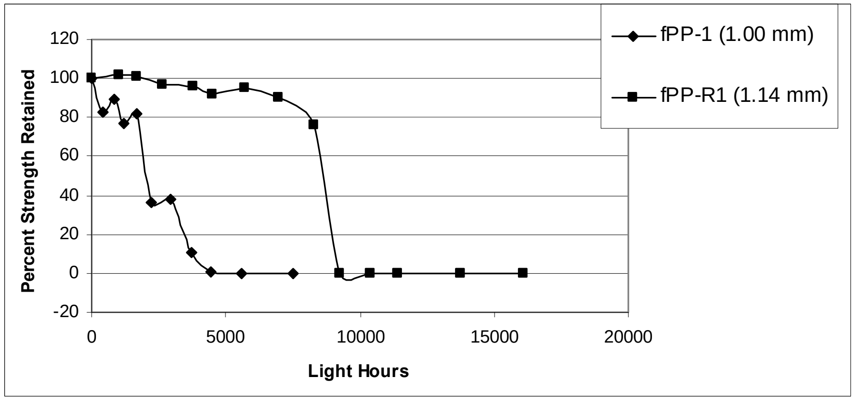
The solar energy in the field is again estimated based on data collected by the South Florida Testing Lab in Arizona. For 26 months of exposure, the accumulated solar energy (295-800 nm) is 15,800 MJ/m^2, which is much higher than that from the UV Fluorescent device. Therefore, direct comparison of halflives obtained from the field and Xenon Arc device is not anticipated to be very accurate. However, for illustration purposes the acceleration factor based on Xenon Arc device would be as follows:

Field	vs.	Xenon Arc	:	**Thus, the acceleration factor is 4.3.**
= 26 Months		= 6.1 Months		

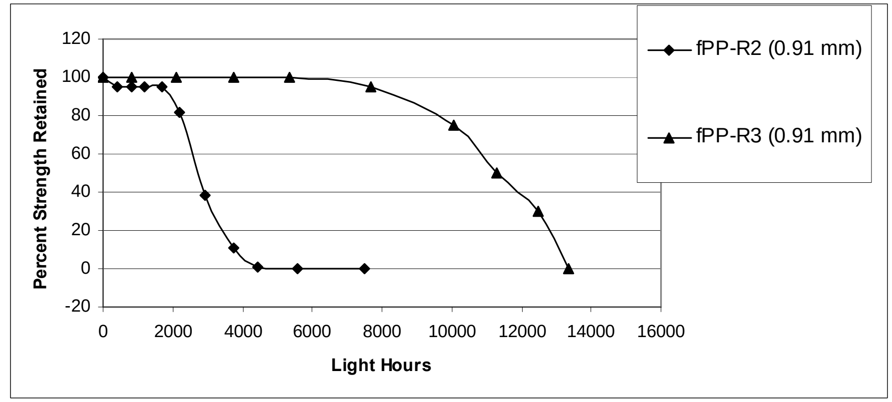
The resulting conclusion of this comparison of weathering devices is that the UV Fluorescent device is certainly reasonable to use for long-term incubations. When considering the low cost of the device, its low maintenance, its inexpensive bulbs, and ease of repair it (the UV Fluorescent device) will be used exclusively by GSI for long-term incubation studies.

3.3.3 Update of exposed lifetime predictions

There are presently (2011) four field failures of flexible polypropylene geomembranes and using unexposed archived samples from these sites their responses in laboratory UV Fluorescent devices per ASTM D7328 at 70°C are shown in Figure 5. From this information we deduce that the average correlation factor is approximately *1200 light hours* $\simeq$ *one-year in a hot climate.* This value will be used accordingly for other geomembranes.



(a) Two Sites in West Texas



(b) Two Sites in So. Calif.

Lab-to-Field Correlation Factors
(ASTM D7238 @ 70°C)

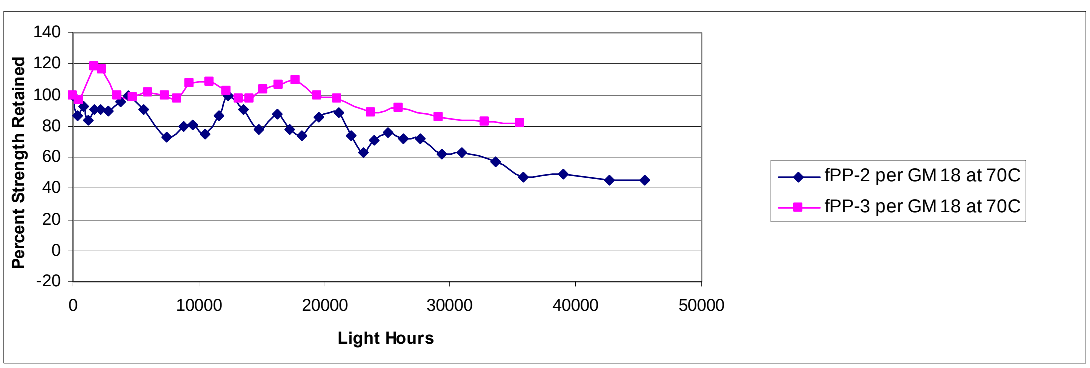
Method	Thickness (mm)	Field (yrs.)	Location	Lab (lt. hr.)	Factor (lt. hrs./1.0 yr.)
fPP-1	1.00	$\simeq 2$	W. Texas	1800	900
fPP-R1	1.14	$\simeq 8$	W. Texas	8200	1025
fPP-R2	0.91	$\simeq 2$	So. Calif.	2500	1250
fPP-R3	0.91	$\simeq 8$	So. Calif.	11200	1400
					1140*

*Use 1200 lt. hr. = 1.0 year in hot climates

Figure 5. Four field failures of fPP and fPP-R exposed geomembranes.

Exposure of a number of different types of geomembranes in laboratory UV Fluorescent devices per ASTM D7238 at 70°C has been ongoing for the six years (between 2005 and 2011) since this White Paper was first released. Included are the following geomembranes:

- Two black 1.0 mm (4.0 mil) unreinforced flexible polypropylene geomembranes formulated per GRI-GM18 Specification; see Figure 6a.
- Two black unreinforced polyethylene geomembranes, one 1.5 mm (60 mil) high density per GRI-GM13 Specification and the other 1.0 mm (40 mil) linear low density per GRI-GM17 Specification; see Figure 6b.
- One 1.0 (40 mil) black ethylene polypropylene diene terpolymer geomembrane per GRI-GM21 Specification; see Figure 6c.
- Two polyvinyl chloride geomembranes, one black 1.0 mm (40 mil) formulated in North America and the other grey 1.5 mm (60 mil) formulated in Europe; see Figure 6d.



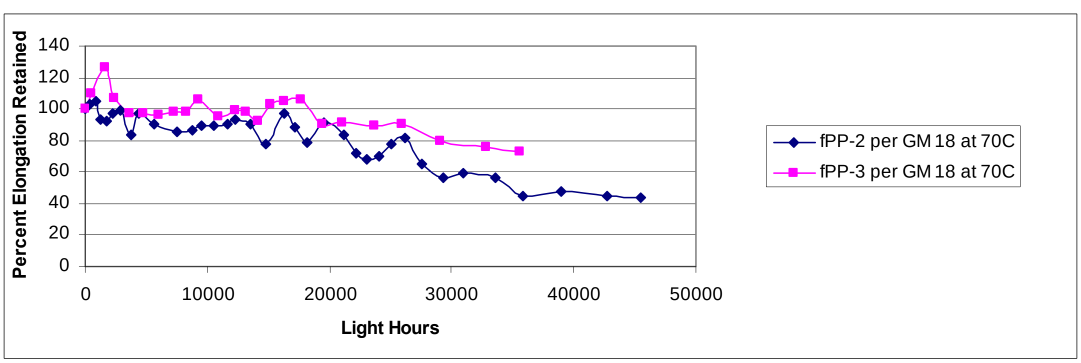
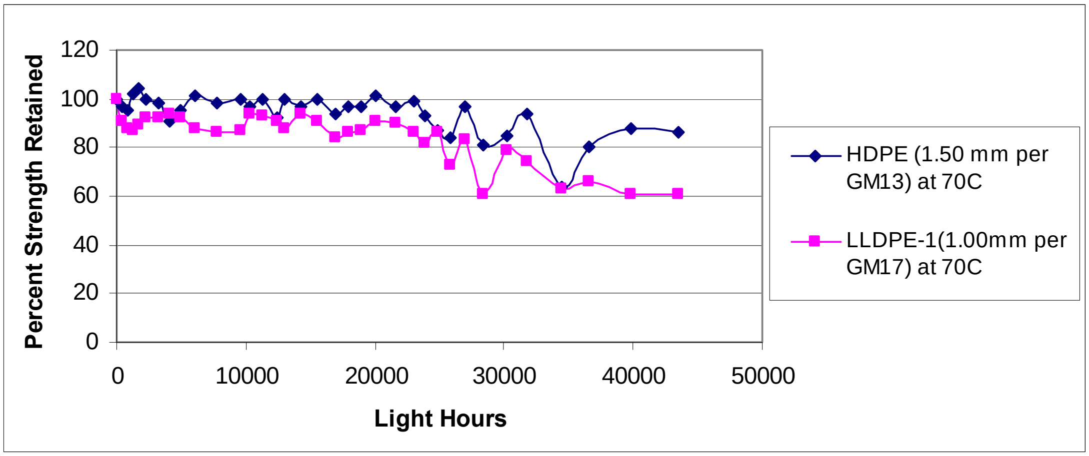


Figure 6a. Flexible polyethylene (fPP) geomembrane behavior.



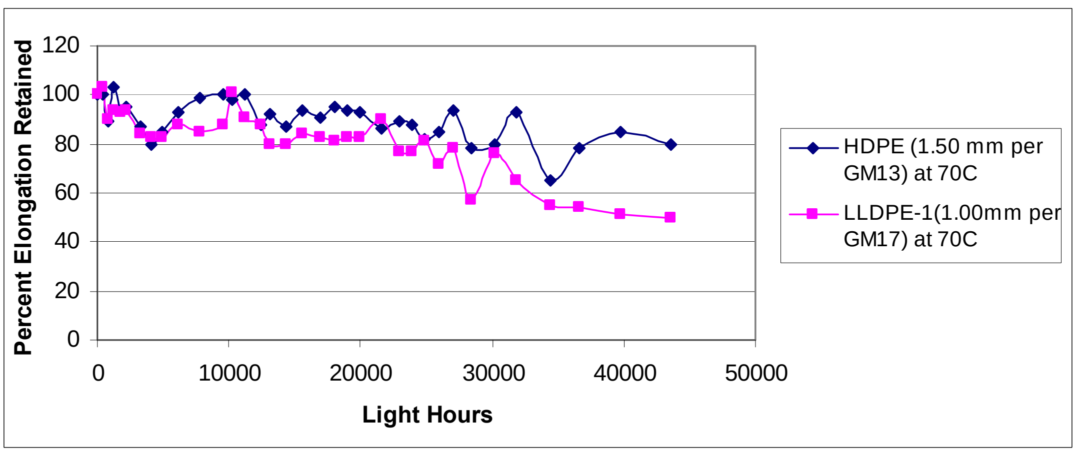
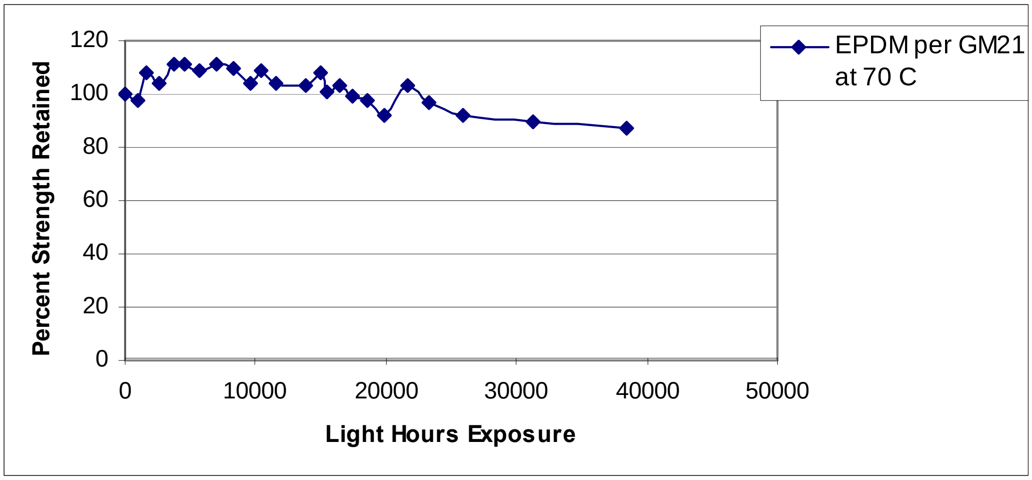


Figure 6b. Polyethylene (HDPE and LLDPE) geomembrane behavior.



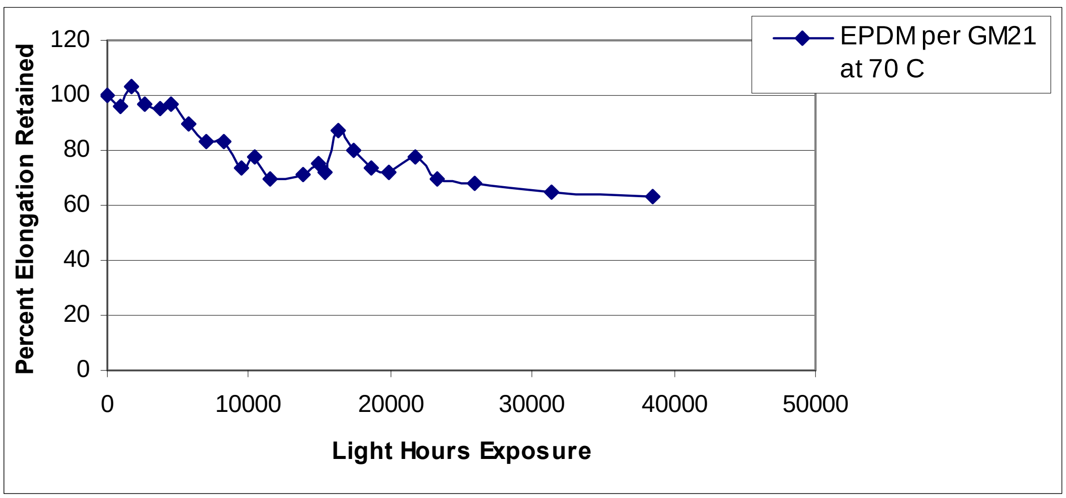


Figure 6c. Ethylene polypropylene diene terpolymer (EPDM) geomembrane.

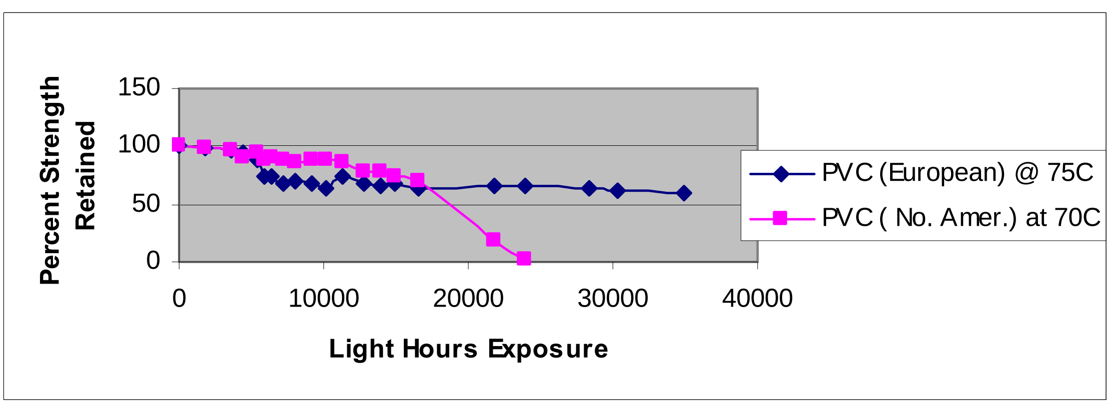


Figure 6d. Polyvinyl chloride (PVC) geomembranes.

From the response curves of the various geomembranes shown in Figure 6a-d, the 50% reduction value in strength or elongation (usually elongation) was taken as being the "halflife". This value is customarily used by the polymer industry as being the materials lifetime prediction value. We have done likewise to develop Table 6 which is our predicted values for the designated exposed geomembrane lifetimes to date.

Table 6 – Exposed lifetime prediction results of selected geomembranes to date

Type	Specification	Prediction Lifetime in a Dry and Arid Climate
HDPE	GRI-GM13	> 36 years (ongoing)
LLDPE	GRI-GM17	$\simeq$ 36 years (halflife)
EPDM	GRI-GM21	> 27 years (ongoing)
fPP-2	GRI-GM18	$\simeq$ 30 years (halflife)
fPP-3	GRI-GM18	> 27 years (ongoing)
PVC-N.A.	(see FGI)	$\simeq$ 18 years (halflife)
PVC-Eur.	proprietary	> 32 years (ongoing)

4.0 Conclusions and Recommendations

This White Paper is bifurcated into two very different parts; covered (or buried) lifetime prediction of HDPE geomembranes and exposed (to the atmosphere) lifetime prediction of a number of geomembrane types. In the covered geomembrane study we chose the geomembrane type which has had the majority of usage, that being HDPE as typically used in waste containment applications. Invariably whether used in landfill liner or cover applications *the geomembrane is covered.* After ten-years of research Table 2 (repeated here) was developed which is the conclusion of the covered geomembrane research program. Here it is seen that HDPE decreases its predicted lifetime (as measured by its halflife) from 446-years at 20°C, to 69-years at 40°C. Other geomembrane types (LLDPE, fPP, EPDM and PVC) have had essentially no focused effort on their covered lifetime prediction of the type described herein. That said, all are candidates for additional research in this regard.

Table 2 - Lifetime prediction of HDPE (nonexposed) at various field temperatures

In Service Temperature (°C)	Stage "A" (years)			Stage "B" (years)	Stage "C" (years)	Total Prediction* (years)
	Standard OIT	High Press. OIT	Average OIT			
20	200	215	208	30	208	446
25	135	144	140	25	100	265
30	95	98	97	20	49	166
35	65	67	66	15	25	106
40	45	47	46	10	13	69

*Total = Stage A (average) + Stage B + Stage C

Exposed geomembrane lifetime was addressed from the perspective of field performance which is very unequivocal. Experience in Europe, mainly with relatively thick PVC containing high molecular weight plasticizers, has given 25-years of service and the geomembranes are still in use. Experience in the USA with exposed geomembranes on flat roofs, mainly with EPDM and CSPE, has given 20^+-years of service. The newest geomembrane type in such applications is fPP which currently carries similar warranties.

Rather than using the intricate laboratory setups of Figure 1 which are necessary for covered geomembranes, exposed geomembrane lifetime can be addressed by using accelerating laboratory weathering devices. Here it was shown that the UV fluorescent device (per ASTM D7238 settings) versus the Xenon Arc device (per ASTM D 4355) is equally if not slightly more intense in its degradation capabilities. As a result, all further incubation has been using the UV fluorescent devices per D7238 at 70°C.

Archived flexible polypropylene geomembranes at four field failure sites resulted in a correlation factor of 1200 light hours equaling one-year performance in a hot climate. Using this value on the incubation behavior of seven commonly used geomembranes has resulted in the following conclusions (recall Figure 6 and Table 6);

- HDPE geomembranes (per GRI-GM13) are predicted to have lifetimes greater than 36-years; testing is ongoing.
- LLDPE geomembranes (per GRI-GM17) are predicted to have lifetimes of approximately 36-years.
- EPDM geomembranes (per GRI-GM21) are predicted to have lifetimes of greater than 27-years; testing is ongoing.
- fPP geomembranes (per GRI-GM18) are predicted to have lifetimes of approximately 30-years.
- PVC geomembranes are very dependent on their plascitizer types and amounts, and probably thicknesses as well. The North American formulation has a lifetime of approximately 18-years, while the European formulation is still ongoing after 32-years.

Regarding continued and future recommendations with respect to lifetime prediction, GSI is currently providing the following:

(i) Continuing the exposed lifetime incubations of HDPE, EPDM and PVC (European) geomembranes at 70°C.

(ii) Beginning the exposed lifetime incubations of HDPE, LLDPE, fPP, EPDM and both PVC's at 60°C and 80°C incubations.

(iii) With data from these three incubation temperatures (60, 70 and 80°C), time-temperature-superposition plots followed by Arrhenius modeling will eventually provide information such as Table 2 for covered geomembranes. This is our ultimate goal.

(iv) Parallel lifetime studies are ongoing at GSI for four types of geogrids and three types of turf reinforcement mats at 60, 70 and 80°C.

(v) GSI does not plan to duplicate the covered geomembrane study to other than the HDPE provided herein. In this regard, the time and expense that would be necessary is prohibitive.

(vi) The above said, GSI is always interested in field lifetime behavior of geomembranes (and other geosynthetics as well) whether covered or exposed.

Acknowledgements

The financial assistance of the U. S. Environmental Protection Agency for the covered HDPE lifetime study and the member organizations of the Geosynthetic Institute and its related institutes for research, information, education, accreditation and certification is sincerely appreciated. Their identification and contact member information is available on the Institute's web site at <<geosynthetic-institute.org>>.

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R.K. FROBEL & ASSOCIATES
Consulting Engineers

Mr. Randall Hicks, PG March 31, 2015
R.T. Hicks Consultants Ltd.
901 Rio Grande Boulevard
Suite F-142
Albuquerque, New Mexico 87104

RE: Technical Memorandum
Slopes and Anchor Trench Variance
NMAC 19.15.34.12.A(2) & (3)
Devon Energy / Hackberry Modular Impoundment

Dear Mr. Hicks:

At your request, I have reviewed the suitability of application of two 30 mil LLDPE geomembranes as an alternative Primary liner system for the Devon Energy / Hackberry Modular Impoundment. In consideration of liners in traditional pits, the NMOCD rules require a maximum 2H:1V slope and anchorage at the top of slope in soil backfill anchor trench. I have also reviewed your C-147 Supplemental Information Report, Modular Tank Drawing, Design and Construction Plan as well as applicable correspondence. In consideration of the LLDPE Primary lining system application (Modular Impoundment), size of impoundments and depth, design details for modular tanks as well as the fact that this is an above ground storage tank (not constructed in an excavated or raised embankment pit), it is my professional opinion that the LLDPE geomembranes will provide the requisite barrier against potential produced water loss and will function within the vertical walls of the Modular Impoundment the same as or better than an in-ground pit with slopes. The following are discussion points that will exhibit the positive attributes of a Modular Impoundment System:

Side Slope

The design of soil side slope (inclination) is a geotechnical engineering design consideration. Liquid impoundments such as fresh water or process water containments are usually built within an excavation or with raised earthen embankments. For a liquid impoundment with an exposed liner system, the slope soils and construction dictate slope inclination and very detailed slope stability analysis may be required to determine if slope failure within the embankment will occur once loaded with impounded water. Slope failure may also occur during construction or when the impoundment is empty. A maximum slope is usually specified and is dependent on soil type and cohesive strength, saturated or unsaturated conditions, etc. Detailed analysis for slope stability can be found in “Designing with Geosynthetics” by R.M Koerner as well as many geotechnical books.

A modular impoundment, on the other hand, consists of a professionally designed steel tank ring with vertical walls. There is no slope to consider as the segmental steel sections are set vertically. Design of steel tanks as regards hydrostatic loading, wind loading,

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seismic loads, etc. are thoroughly referenced with detailed procedures in the design code - American Petroleum Institute (API) 650-98 "Welded Steel Tanks for Oil Storage". There are no requirements for maximum slope inclination other than perhaps 90 degrees or vertical wall.

Anchor Trench

All earthen impoundments with a geomembrane lining system require some form of top of slope anchor, the most common of which is an excavated and backfilled anchor trench usually set back at least 3 ft from the top of slope. Again, there are detailed procedures for anchor trench design in "Designing with Geosynthetics" by R.M Koerner.

A Modular Impoundment requires mechanical anchoring of the geomembrane at the top of the vertical steel wall using standard liner clips that prevent the geomembrane or geomembrane layers from slipping down the side wall. There are no requirements for an "anchor trench" as this is not an in-ground impoundment.

In summary, it is my professional opinion that two 30 mil LLDPE geomembranes installed within the vertical walls of a Modular Impoundment will provide the requisite protection of fresh water, public health and the environment for many years and especially for the estimated two year life of the Devon Energy / Hackberry Modular Impoundment. In particular, there is no requirement for a maximum interior slope angle of 2H:1V due to the fact that this impoundment is a steel tank with vertical walls. Additionally, there is no requirement for an anchor trench as the geomembrane is attached to the top of the Modular Impoundment vertical walls with large steel clips.

If you have any questions on the above technical memorandum or require further information, give me a call at 303-679-0285 or email geosynthetics@msn.com

Sincerely Yours,

R K Frobel

Ronald K. Frobel, MSCE, PE

References:

C-147 Supplemental Information
Devon Energy / Hackberry Modular Impoundment Design and Construction Plan
Prepared by R. T. Hicks Consultants Ltd.

NMOCD Recycling Rule, Title 19, Chapter 15 – Produced Water, Drilling Fluids and Liquid Oil Field Waste – Section 19.15 Part 34 (2015)

American Petroleum Institute (API) 650-98 "Welded Steel Tanks for Oil Storage"

Koerner, R.M., 2005 "Designing With Geosynthetics" Prentice Hall Publishers

Attachments:

R. K. Frobel C.V.

From:	Randall Hicks
To:	"Kristin Pope"
Subject:	FW: Devon Energy West Tank (Tank 2) MWFM Modular Impoundment Form C-144
Date:	Monday, March 16, 2015 10:37:22 AM

From: Oberding, Tomas, EMNRD [mailto:Tomas.Oberding@state.nm.us]
Sent: Tuesday, November 25, 2014 10:48 AM
To: Andrew Parker
Cc: Henderson, Jason E.; 'Bruening, Josh'; clayton@blm.gov; 'James Amos'; 'Randall Hicks'
Subject: RE: Devon Energy West Tank (Tank 2) MWFM Modular Impoundment Form C-144

Aloha Mr. Parker et al,

Again, thank you for submitting this application.

OCD grants conditional approval. Please obtain confirmation from the BLM.

The OCD permit number is:
P1-06572

Let me know if you have any questions or updates.
Mahalo
-Doc

Tomáš 'Doc' Oberding, PhD
Senior Environmental Specialist – New Mexico Oil Conservation Division
Energy, Minerals and Natural Resources Department
1625 N. French Dr.
Hobbs, NM 88240
(O): (575) 393-6161 ext 111
(C): 575-370-3180
(F): (575) 393-0720
E-Mail: tomas.oberding@state.nm.us
Website: http://www.emnrd.state.nm.us/ocd/

From: Andrew Parker [mailto:andrew@rthicksconsult.com]
Sent: Tuesday, November 25, 2014 8:38 AM
To: Oberding, Tomas, EMNRD
Cc: Henderson, Jason E.; 'Bruening, Josh'; clayton@blm.gov; 'James Amos'; 'Randall Hicks'
Subject: Devon Energy West Tank (Tank 2) MWFM Modular Impoundment Form C-144

Dr. Oberding:

Attached is the C-144 permit package for Devon Energy's MWFM modular impoundment identified as Tank 2 (West Tank). The location for the West Tank MWFM Modular Impoundment is located in Section 13 T26 R34E.

The contents of the attached C-144 permit package is duplicated from the November 24, 2014 Tank 1 (East Tank) submittal. Please note that Tank 2 will be associated with the Rattlesnake Fed Unit 8H well (API 30-025-40067) as highlighted on Table 1 in the attached C-144 package.

R.T. Hicks Consultants will be meeting with the BLM and a representative from Devon Energy either next week or the week after to present the attached C-144 submission. The BLM is copied on this transmission.

____

Andrew Parker
RT Hicks Consultants
Durango Field Office
(970) 570-9535

Figures and Site Survey

R.T. Hicks Consultants, Ltd.
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

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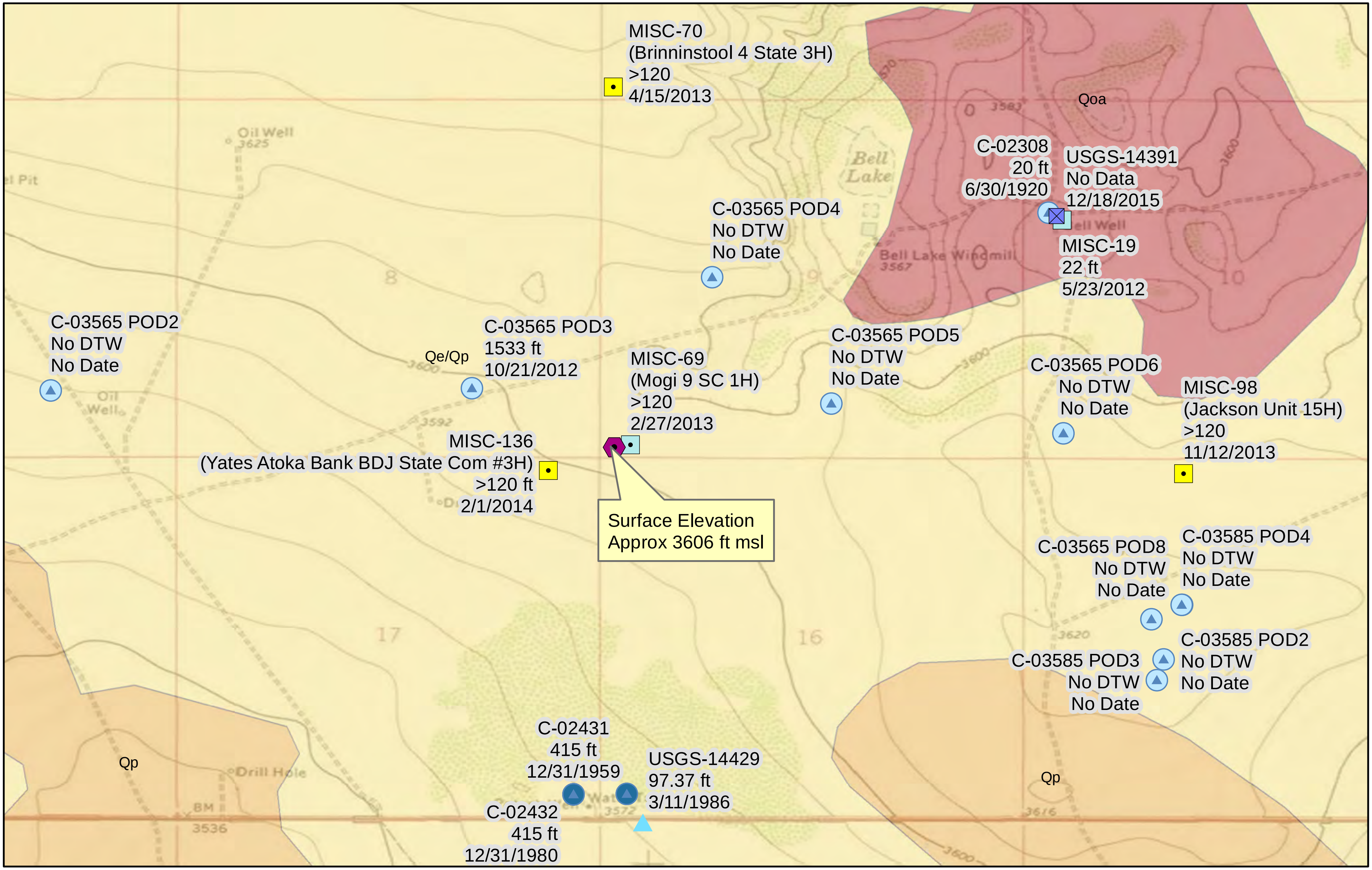

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Depth To Water and Geology

Tap Rock Resources at MOGI 9 State Com 1
Produced Water Above Ground Tank

Figure 1

June 2018

Legend

Produced Water Tank

USGS Gauging Station (DTW, Date)

Aquifer Code, Well Status

Ogallala

121OGLL, Obstruction was encountered in the well (no water level was recorded).

Misc. Water Wells (Well ID, DTW)

Well Depth (ft)

No Data

<= 150

OSE Water Wells (DTW, Date)

Well Depth (ft)

<= 150

501 - 1000

NM Geology

Map Unit, Description

Qe/Qp, Quaternary-Eolian Piedmont Deposits

Qoa, Quaternary-Older Alluvial Deposits

Qp, Quaternary-Piedmont Alluvial Deposits

R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Depth To Water and Geology	Figure 1 LEGEND
	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

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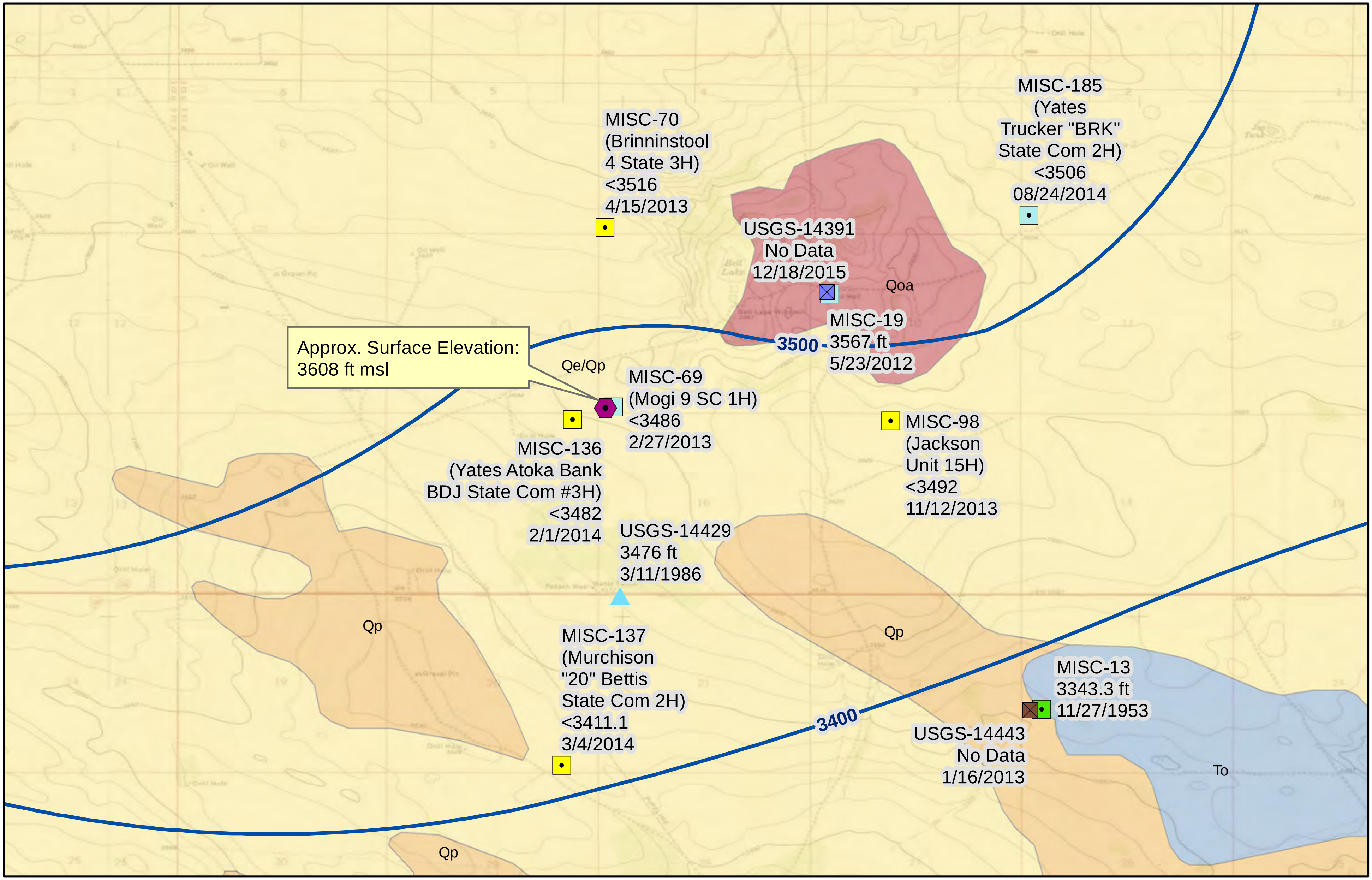

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Potentiometric Surface and Groundwater Elevation

Tap Rock Resources at MOGI 9 State Com 1
Produced Water Above Ground Tank

Figure 2

June 2018

Legend

Produced Water Tank

USGS Gauging Station (GW Elev, Date)

Aquifer Code, Well Status

Ogallala

121OGLL, Obstruction was encountered in the well (no water level was recorded).

121OGLL, Well was destroyed (no water level was recorded).

Misc. Water Wells (GW Elev, Date)

Well Depth (ft)

No Data

<= 150

151 - 350

Potentiometric Surface (ft msl)

Isocontours

Isocontour

NM Geology

Map Unit, Description

Qe/Qp, Quaternary-Eolian Piedmont Deposits

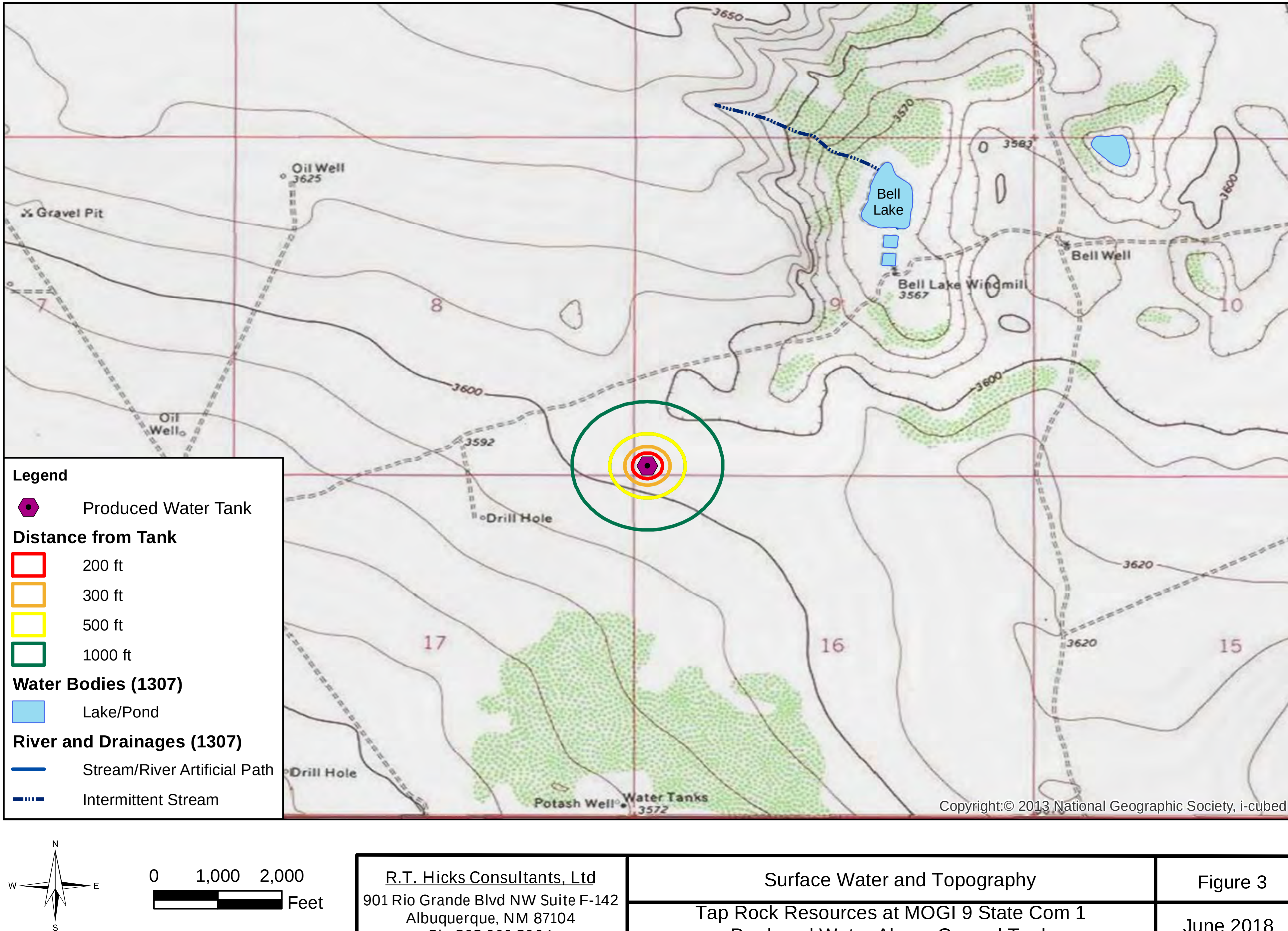
Qoa, Quaternary-Older Alluvial Deposits

Qp, Quaternary-Piedmont Alluvial Deposits

To, Tertiary-Ogallala Formation

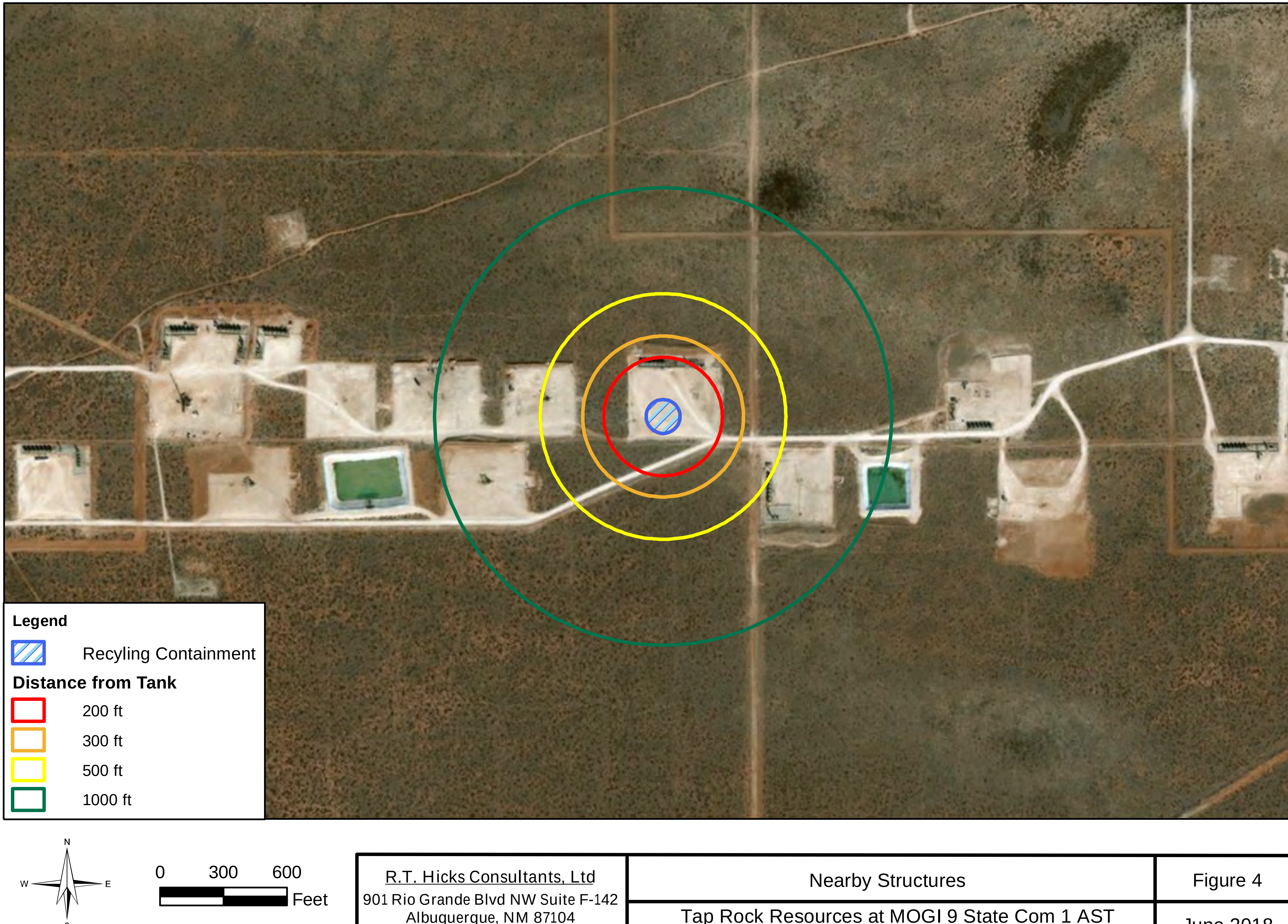
R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Potentiometric Surface and Groundwater Elevation	Figure 2 LEGEND
	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure3_SurfaceWater.mxd



R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Surface Water and Topography	Figure 3
	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure4_NearbyStructures.mxd



R.T. Hicks Consultants, Ltd
901 Rio Grande Blvd NW Suite F-142
Albuquerque, NM 87104
Ph: 505.266.5004

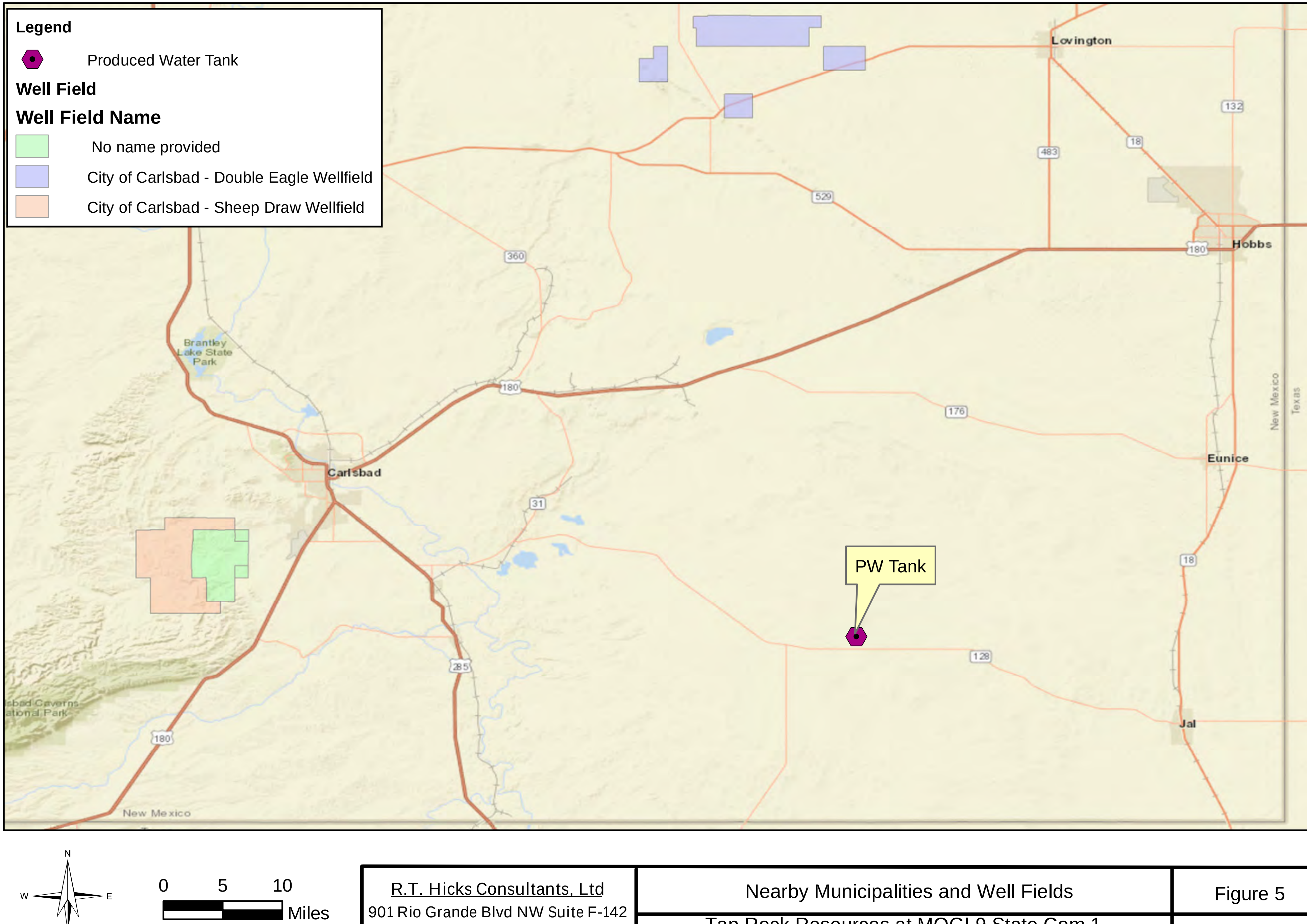
Nearby Structures

Tap Rock Resources at MOGI 9 State Com 1 AST
Produced Water Above Ground Tank

Figure 4

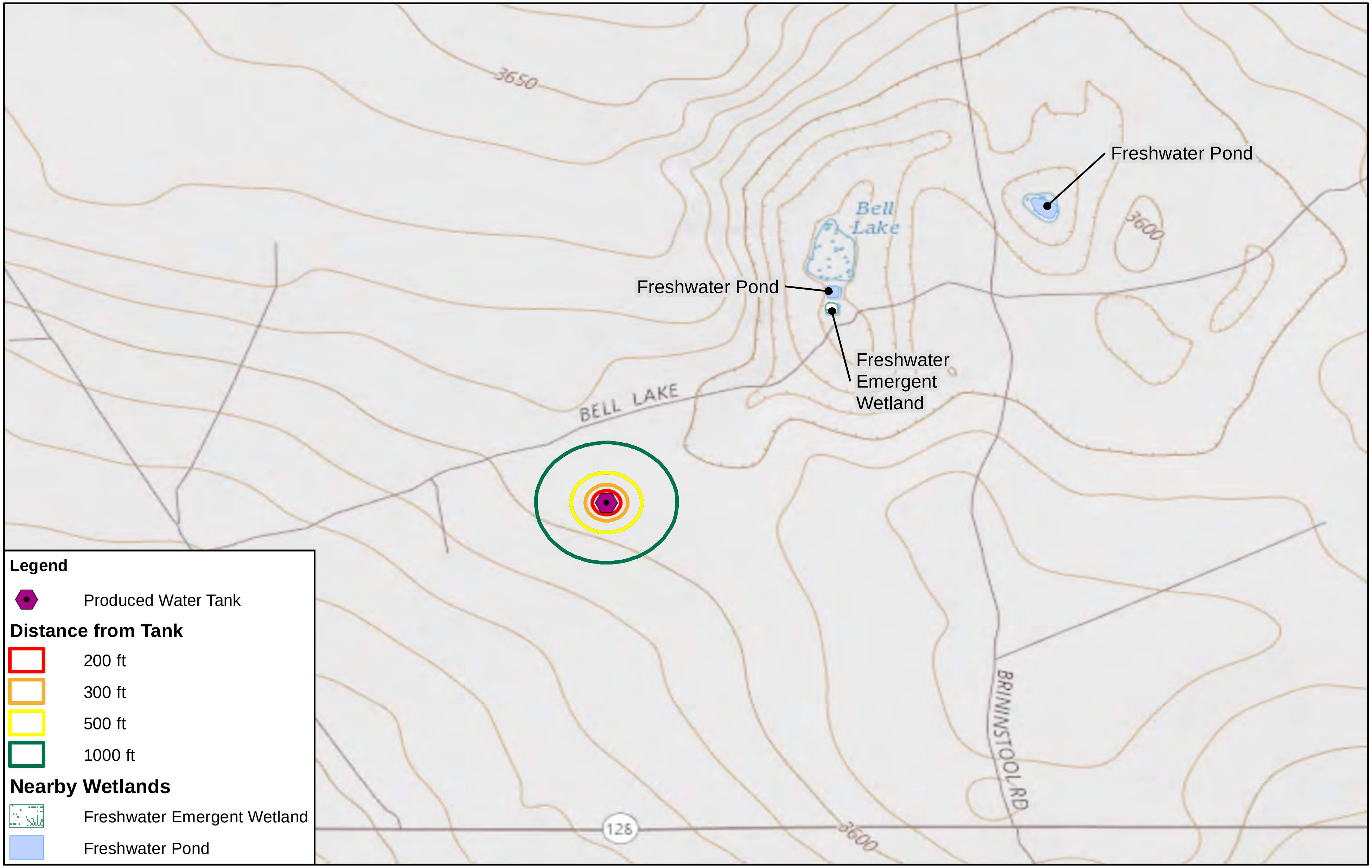
June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure5_wellFields.mxd



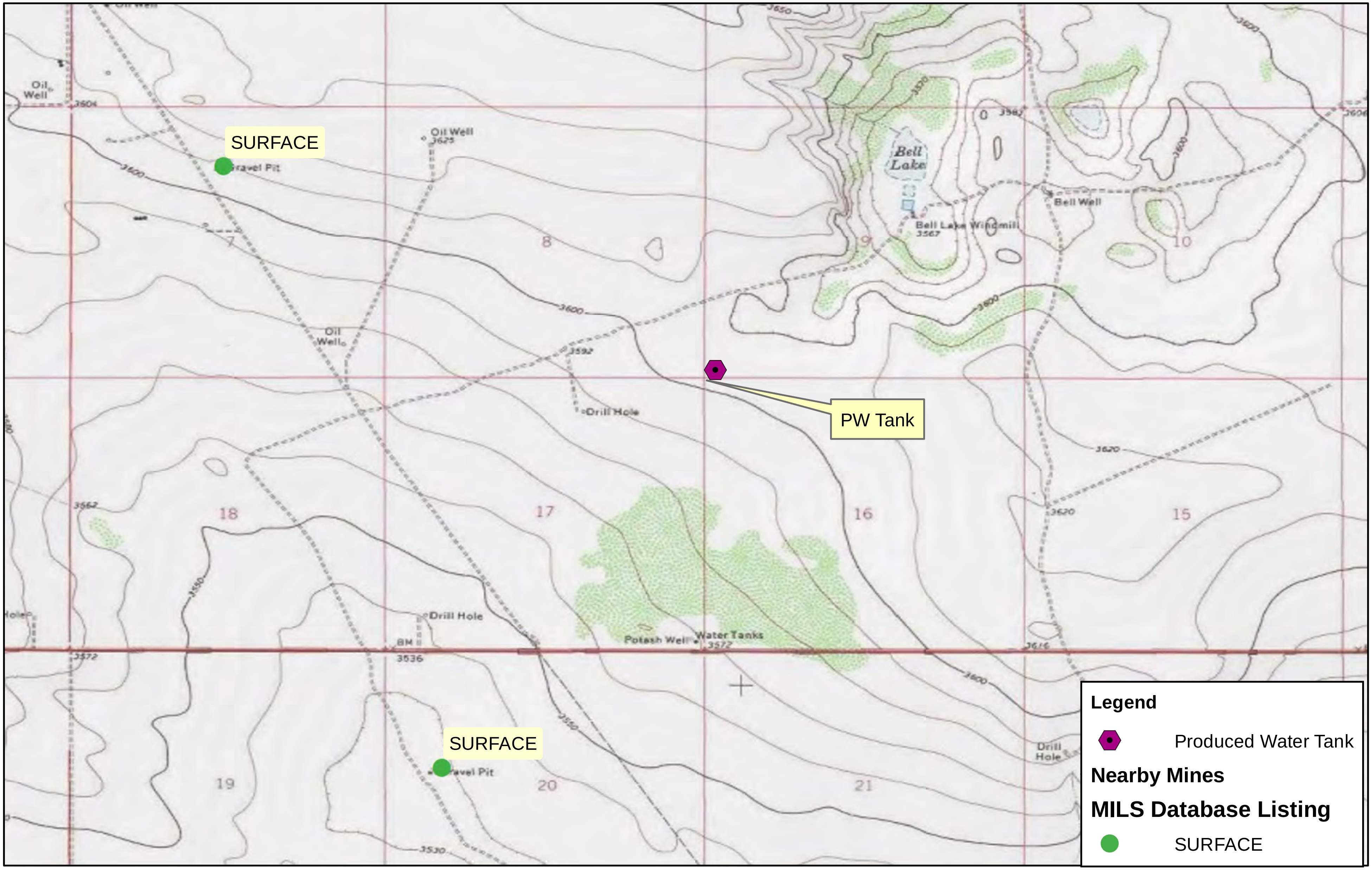
R.T. Hicks Consultants, Ltd	Nearby Municipalities and Well Fields	Figure 5
901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure6_wetlands.mxd



R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Nearby Wetlands	Figure 6
	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure7_minesMinerals.mxd

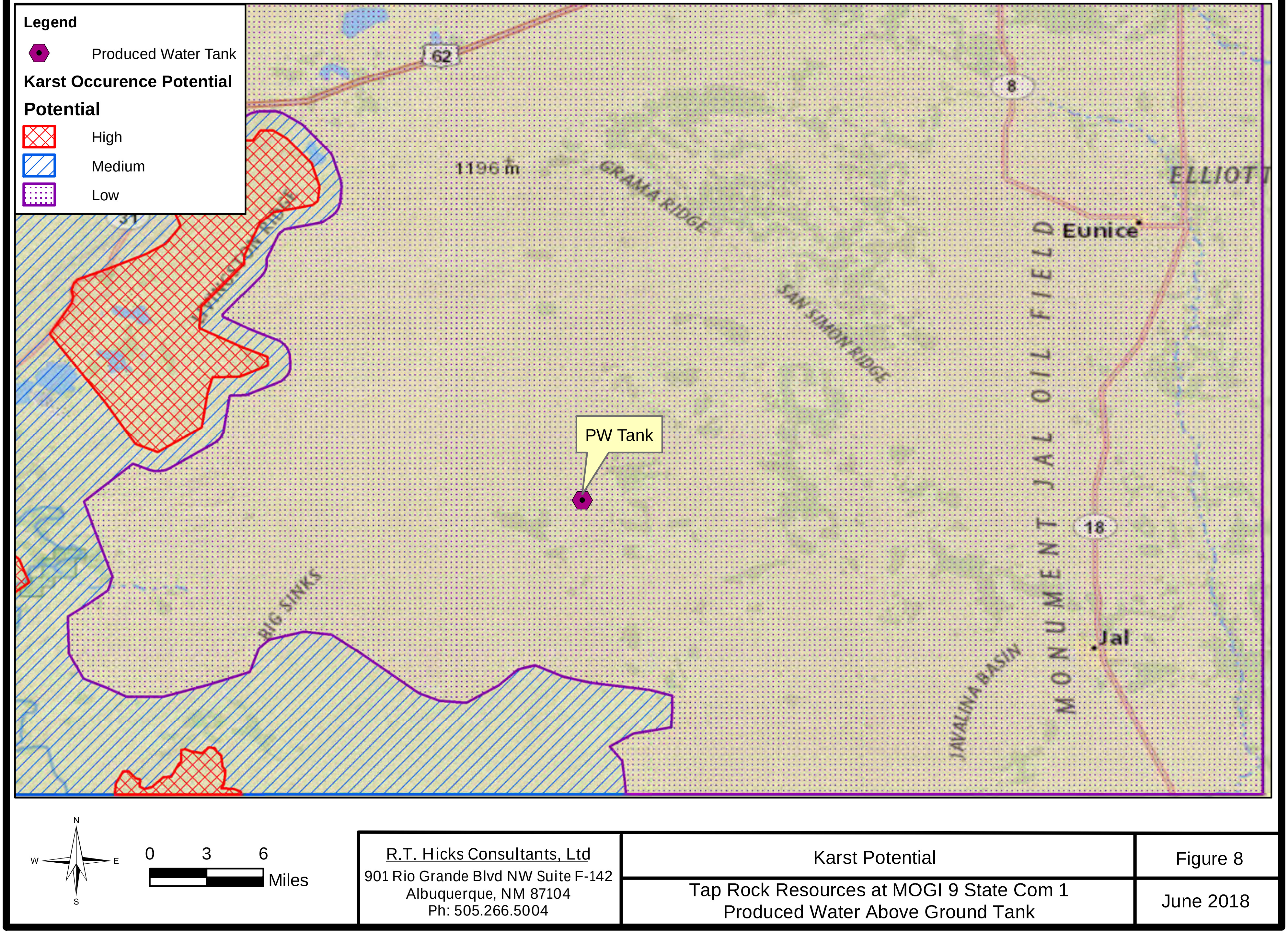


0 0.25 0.5 Miles

R.T. Hicks Consultants, Ltd
901 Rio Grande Blvd NW Suite F-142
Albuquerque, NM 87104
Ph: 505.266.5004

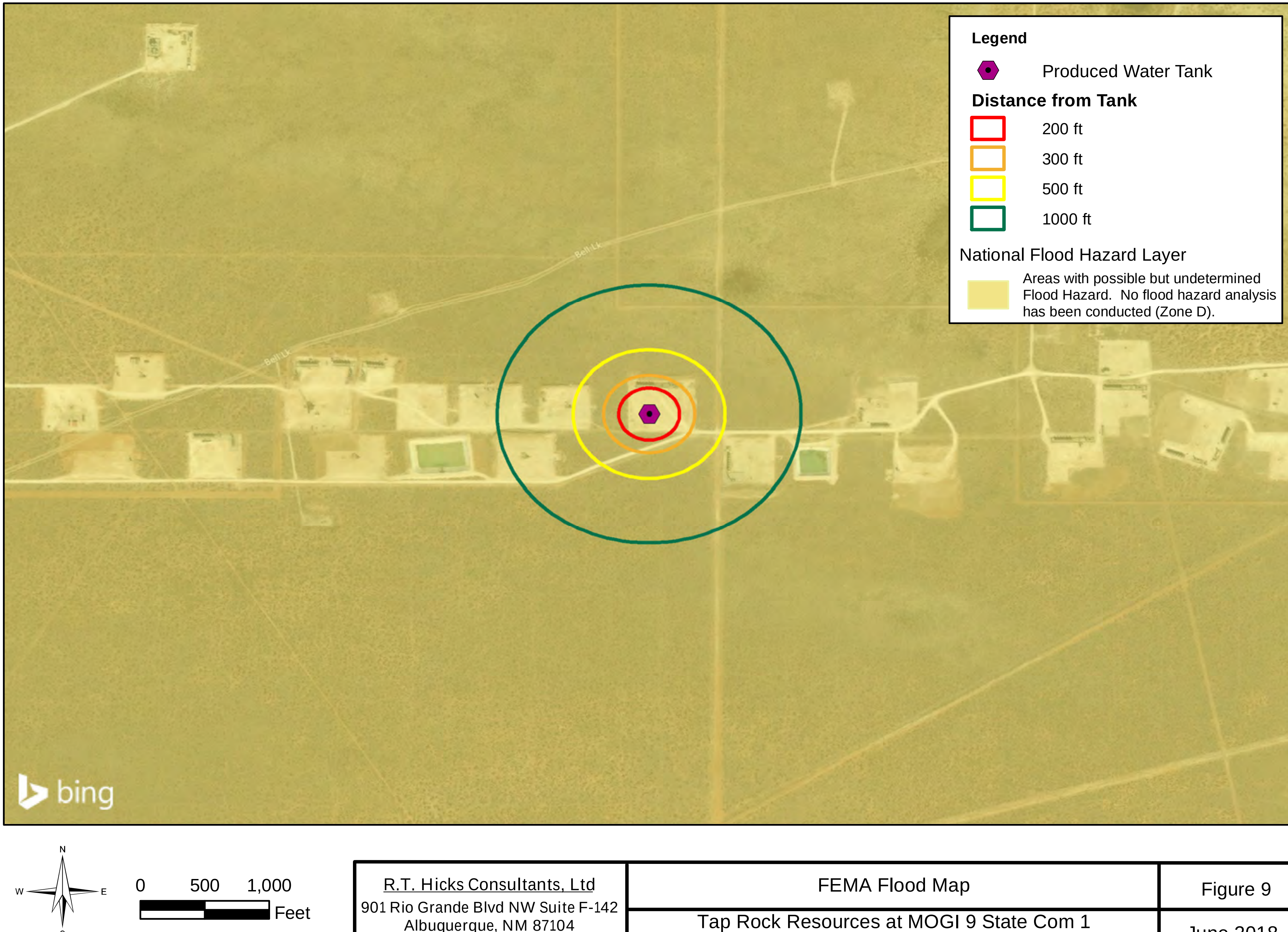
Nearby Mines and Minerals	Figure 7
Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure8_karstPotential.mxd



R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 Ph: 505.266.5004	Karst Potential	Figure 8
	Tap Rock Resources at MOGI 9 State Com 1 Produced Water Above Ground Tank	June 2018

M:\Taprock\AST MOGI 1\ap_nmGIS\Figures\figure9_femaFlood.mxd



R.T. Hicks Consultants, Ltd
901 Rio Grande Blvd NW Suite F-142
Albuquerque, NM 87104
Ph: 505.266.5004

FEMA Flood Map

Tap Rock Resources at MOGI 9 State Com 1
Produced Water Above Ground Tank

Figure 9

June 2018

District I
1625 N. French Dr., Hobbs, NM 88240
Phone: (575) 393-6161 Fax: (575) 393-0720
District II
811 S. First St., Artesia, NM 88210
Phone: (575) 748-1283 Fax: (575) 748-9720
District III
1000 Rio Brazos Road, Aztec, NM 87410
Phone: (505) 334-6178 Fax: (505) 334-6170
District IV
1220 S. St. Francis Dr., Santa Fe, NM 87505
Phone: (505) 476-3460 Fax: (505) 476-3462

State of New Mexico
Energy, Minerals & Natural Resources Department
OIL CONSERVATION DIVISION
1220 South St. Francis Dr.
Santa Fe, NM 87505

Form C-102
Revised August 1, 2011
Submit one copy to appropriate District Office

☐ AMENDED REPORT

WELL LOCATION AND ACREAGE DEDICATION PLAT

[1] API Number	[2] Pool Code	[3] Pool Name
	96674	Triple X; Bone Spring, West

[4] Property Code	[5] Property Name	[6] Well Number
	MOGI 9 STATE COM	1H

[7] OGRID No.	[8] Operator Name	[9] Elevation
15363	MURCHISON OIL & GAS, INC.	3606.1

[10] Surface Location

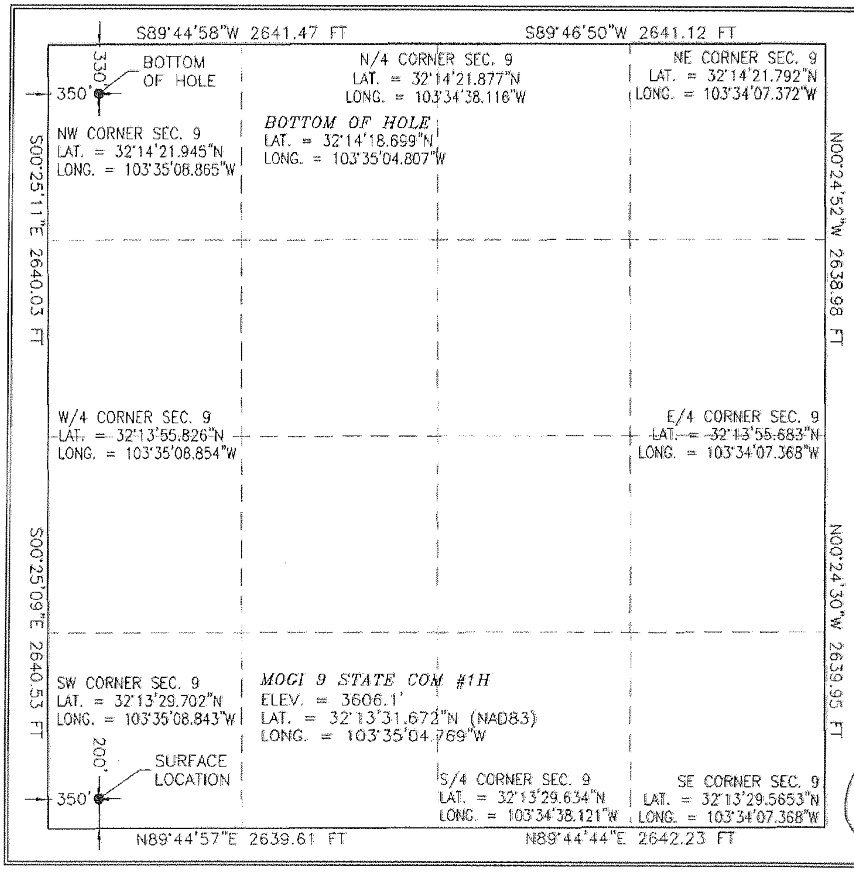
UL or lot no.	Section	Township	Range	Lot Idn	Feet from the	North/South line	Feet from the	East/West line	County
M	9	24 S	33 E		200	SOUTH	350	WEST	LEA

[11] Bottom Hole Location If Different From Surface

UL or lot no.	Section	Township	Range	Lot Idn	Feet from the	North/South line	Feet from the	East/West line	County
D	9	24 S	33 E		330	NORTH	350	WEST	LEA

[12] Dedicated Acres	[13] Joint or Infill	[14] Consolidation Code	[15] Order No.
160			

No allowable will be assigned to this completion until all interests have been consolidated or a non-standard unit has been approved by the division.



[17] OPERATOR CERTIFICATION

I hereby certify that the information contained herein is true and complete to the best of my knowledge and belief, and that this organization either owns a working interest or unleased mineral interest in the land including the proposed bottom hole location or has a right to drill this well at this location pursuant to a contract with an owner of such a mineral or working interest, or to a voluntary pooling agreement or a compulsory pooling order heretofore entered by the division.

Signature: Michael Daugherty   Date: 1/31/13

Michael S. Daugherty, COO
Printed Name

mdaugherty@jdmii.com
E-mail Address

[18] SURVEYOR CERTIFICATION

I hereby certify that the well location shown on this plat was plotted from field notes of actual surveys made by me or under my supervision, and that the same is true and correct to the best of my belief.

JANUARY 30, 2013
Date of Survey

Signature and Seal of Professional Surveyor: Filimon F. Jaramillo

Certificate Number: FILIMON F. JARAMILLO, PLS 12797

SURVEY NO. 1496A

Appendix A

Site Specific Data

R.T. Hicks Consultants, Ltd.
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

Distance to Groundwater

Figure 1, Figure 2, and the discussion presented in Appendix A demonstrates that groundwater (fresh water as defined by NMOCD Rules) at the location is greater than 100 feet beneath the recycling containment (AST) that will contain fluids that cannot be classified as "low-chloride."

Figure 1 is a geologic/ topographic map that shows:

1. The AST identified as a purple hexagon with the surface elevation.
2. The locations of the Mogi 9 State 1H (Misc-69), Brininstool 4 State 3H (Misc-70), Jackson Unit 15H (Misc-98), and Atoka Bank BDJ State Com 3H (Misc-136) where we evaluated cuttings during the 120-foot casing borings.
3. Water wells from the OSE database as a blue triangle inside colored circles that indicate well depth. OSE wells are often miss-located in the WATERS database as older wells are plotted in the center of the quarter, quarter, quarter, of the Section Township and Range.
4. Water wells from the USGS database as large triangles color-coded to the formation the well was completed in.
5. Water wells, which are not documented in the public databases but were identified by field inspection or other published reports as colored squares.
6. The depth-to-water from the most recent available measurement for each well is provided adjacent to the well symbol.

Figure 2 is an area topographic map that shows:

1. The location of the AST as a purple hexagon.
2. Water wells measured by the USGS, the year of the measurement and the calculated elevation of the groundwater surface.
3. Isocontour lines displaying the elevation of the groundwater surface.

Geology

Quaternary Age eolian and piedmont deposits (Qe/Qp on Figure 1) are the dominant exposed material in the area. These deposits are a thin covering of the underlying Tertiary Ogallala Formation or, in some places, the redbeds of the Dockum Group. The Ogallala Formation (To) is locally exposed and consists primarily of sand with some clay, silt and gravel, generally capped by caliche. Based on information from Ground-Water Report 6 (GWR-6) *Geology and Ground-Water Conditions in Southern Lea County, New Mexico* by Alexander Nicholson and Alfred Clebsch (1961), the top of the redbeds near Bell Lake is about 3500-3600 above sea level (see Plate 1 of GWR-6). Because the area outside of the Bell Lake Sink lies at an elevation of 3600 feet, the Ogallala Formation, if it is present, could be about 100 feet thick near Bell Lake. In other nearby areas, the thickness of the Ogallala could be more or less than 100 feet.

Topographically, the western three quarters of the area of interest slopes gently to the southeast or, in the southwest corner of Figures 1 and 2, to the southwest. This sloping surface is punctuated by several closed depressions. The Bell Lake Sink, northeast of the proposed AST, a 2-mile wide circular depression is the most obvious of several. These depressions have been described as an ancient collapse feature (breccia pipes) associated with the removal of salt due to upward groundwater flow from the Capitan Reef[1].

Groundwater Data

We relied upon the most recent data measured by the USGS to create the water table elevation map shown in Figure 2. While the "Misc" well data (see Figure 1) are generally measured water levels, this dataset contains errors (generally of location) that are not present in the USGS data. Water level data from the OSE database rely upon observed water levels by drillers during the completion of the water well. The OSE dataset provides some useful data in certain areas. The Bell Lake area contains sufficient high-quality data that we did not rely on OSE data.

For the potentiometric surface map (Figure 2), we honored all data that we know are accurate to the best of our knowledge. For example, data from the Atoka Bank 3H rathole (Misc. 136), Jackson Unit 15H rathole (Misc-98), the Mogi 9 State 1H rathole (Misc-69) and the Brininstool 4 State 3H rathole (Misc-70) are lithologic data logged by Hicks Consultants during drilling – the cuttings were dust/dry at a depth of 120 feet. While the borings terminated above the regional aquifer, they provide data that are useful for the mapping. It is these data that help define the horizontal limits of water bodies that are perched within the Bell Lake Sink and similar depressions.

OSE well series C-03565 and C-03585 are associated with Intercontinental Potash USA exploratory wells. We visited several of the listed wells and observed permanent markers delineating the location of the plugged boring. C-03565 POD3 (2,000-ft northwest) has a depth to water of 1,533ft. Review of the driller log (Appendix C) shows that this is the total depth of the boring and no groundwater was observed.

From the data presented, we conclude:

- The elevation of the groundwater surface beneath the proposed AST is ≤3,486 feet above mean sea level.
- The perched, shallow groundwater zones present within the Bell Lake Sink and the area of Misc-13, about 3 miles southeast of the location (see Appendix A) do not extend to the area beneath the proposed AST.
- The distance between the bottom of the AST (surface of existing well pad) and the potentiometric surface of the regional aquifer is approximately (3,608-3,486=) ≥122 feet.

Distance to Surface Water

Figure 3 and the site visit demonstrates that the location is not within 300 feet of a continuously flowing watercourse or 200-feet of any other significant watercourse, lakebed, sinkhole, or playa lake (measured from the ordinary high-water mark).

[1] See http://nmgs.nmt.edu/publications/guidebooks/downloads/57/57_p 233-242.pdf

- The map depicts an "intermittent stream" located on the north-northeast end of Bell Lake approximately 1 mile north of the subject site.
- No continuously-flowing watercourses or other water bodies, as defined by NMOCD Rules, exist within the prescribed setback criteria for a recycling containment at this location.
- The Bell Lake Sink is a topographic low area located north-northeast of the proposed AST. Neither Bell Lake nor the smaller surface water body shown east of Bell Lake contains surface water during the majority of the year. Google Earth images suggest the excavated areas south of the lakebed contained water periodically from 1996 to 2012.
- The Bell Lake Sink is an ancient collapse feature but is not considered a sinkhole as typically used in NMOCD Rules.

Distance to Permanent Residence or Structures

Figure 4 and the site visit demonstrates that the location is not within 1000 feet from an occupied permanent residence, school, hospital, institution, church, or other structure in existence at the time of initial application.

- The nearest structures are oil and gas wells, and tank batteries, and temporary pits in varies phases of closure.
- A cattle gathering area with corrals is located about 1 mile northeast of the location.

Distance to Non-Public Water Supply

Figures 1 and Figure 2 demonstrates that the location is not within 500 horizontal feet of a spring or fresh water well used for domestic or stock watering purposes, in existence at the time of initial application.

- Figure 1 shows the locations of all area water wells, active or plugged.
- The nearest active water wells are located approximately 1 mile north at the Bell Lake ranch headquarters and approximately 1.5 miles southwest. Plugged/abandoned wells do exist in the Bell Lake Sink.
- There are no known domestic water wells located within 1,000 feet of the proposed AST.
- OSE well series C-03565 and C-03585 are associated with Intercontinental Potash USA exploratory wells. We visited several of the listed wells and observed permanent markers delineating the location of the plugged boring.
- No springs were identified within the mapping area (see Figure 3).

Distance to Municipal Boundaries and Fresh Water Fields

Figure 5 demonstrates that the location is not within incorporated municipal boundaries or within defined municipal fresh water well fields covered under a municipal ordinance adopted pursuant to NMSA 1978, Section 3-27-3, as amended.

- The closest municipality is Jal, NM approximately 28 miles to the southeast.
- The closest public well field is located approximately 50 miles to the west and/or 50 miles north.

Distance to Wetlands

Figure 6 demonstrates the location is not within 300 feet of wetlands.

- The nearest designated wetland is a "freshwater emergent wetland" located approximately 0.66 mile to the northeast (Bell Lake area excavations).
- North of this emergent wetland is the excavation designated as a "freshwater pond."

Distance to Subsurface Mines

Figure 7 and our general reconnaissance of the area demonstrate that the nearest mines are caliche pits. This location is not within an area overlying a subsurface mine.

- The nearest mapped caliche pit is located more than 2 miles southwest.

Distance to High or Critical Karst Areas

Figure 8 shows the location of the temporary AST with respect to BLM Karst areas.

- The proposed temporary AST is located within a "low" potential karst area.
- The nearest "high" or "critical" potential karst area is located approximately 18 miles west of the site.
- No evidence of solution voids were observed near the site during the field inspection.
- No evidence of unstable ground was observed in the area.

Distance to 100-Year Floodplain

Figure 9 demonstrates that the location is within Zone D as designated by the Federal Emergency Management Agency with respect to the Flood Insurance Rate 100-Year Floodplain.

- Zone D is described as areas with possible but undetermined flood hazards. No flood hazard analysis has been conducted.
- Our field inspection and examination of the topography permits a conclusion that the location is not within any floodplain and has low risk for flooding.

Appendix B

Site Inspection Photos and Survey

R.T. Hicks Consultants, Ltd.
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

Photo 1: Viewing north from center of AST. Tank battery is visible on north edge of production pad.

Photo 2: Viewing east from center of AST.

Photo 3: Viewing south from center of AST.

Photo 4: Viewing west from center of AST.

Photo 5: Viewing west from 400-feet east-northeast of AST. MOGI 1H tank battery is visible photo right.

Photo 6: Viewing southwest from 500-feet northeast of AST. MOGI 1H tank battery visible photo right.

Photo 7: Viewing east from 500-feet west of AST. The EATA FAJITA State 4H pump jack is visible photo left.

Photo 8: Viewing north from 250-feet south of AST. MOGI 1H is visible in photo center background.

Photo 9: Photo viewing north from south edge of production pad. The AST will be placed 75-feet from flare.

Photo 10: View of plugged casing of OSE well C-03565 POD 3; 2,000-feet northwest of AST. Photo is viewing southeast toward AST

Photo 11: View of plugged casing of OSE well C-03565 POD 5; 2,500-feet northeast of AST.

Photo 12: Abandoned water well 1.2 miles northeast of AST. Depth to water measured 19.5-ft below ground surface.

District I
1625 N. French Dr., Hobbs, NM 88240
Phone: (575) 393-6161 Fax: (575) 393-0720
District II
811 S. First St., Artesia, NM 88210
Phone: (575) 748-1283 Fax: (575) 748-9720
District III
1000 Rio Brazos Road, Aztec, NM 87410
Phone: (505) 334-6178 Fax: (505) 334-6170
District IV
1220 S. St. Francis Dr., Santa Fe, NM 87505
Phone: (505) 476-3460 Fax: (505) 476-3462

State of New Mexico
Energy, Minerals & Natural Resources Department
OIL CONSERVATION DIVISION
1220 South St. Francis Dr.
Santa Fe, NM 87505

HOBBS OCD
MAY 06 2013
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Form C-102
Revised August 1, 2011
Submit one copy to appropriate District Office

X AMENDED REPORT

WELL LOCATION AND ACREAGE DEDICATION PLAT

[1] API Number	[2] Pool Code	[3] Pool Name
30-025-40975	96674	TRIPLE X; BONE SPRING, WEST

[4] Property Code	[5] Property Name	[6] Well Number
21707	MOGI 9 STATE COM	1H

[7] OGRID No.	[8] Operator Name	[9] Elevation
15363	MURCHISON OIL & GAS, INC.	3606.1

[10] Surface Location

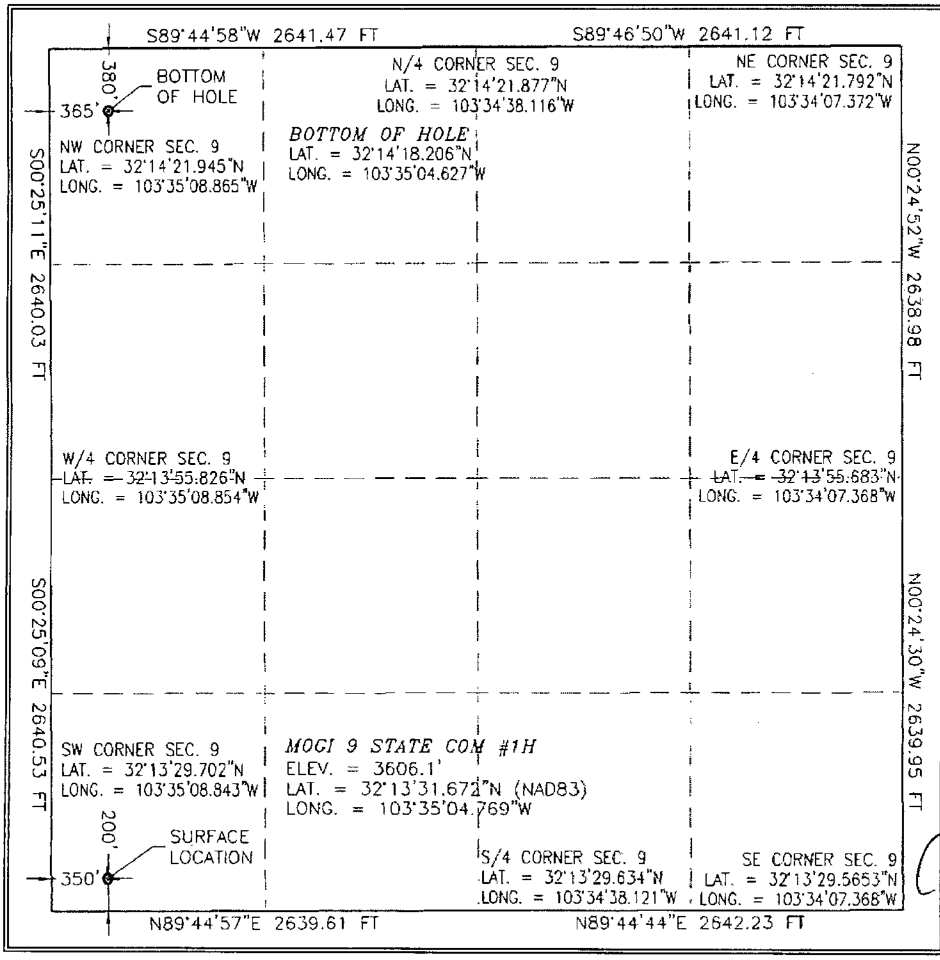
UL or lot no.	Section	Township	Range	Lot Idn	Feet from the	North/South line	Feet from the	East/West line	County
M	9	24 S	33 E		200	SOUTH	350	WEST	LEA

[11] Bottom Hole Location If Different From Surface

UL or lot no.	Section	Township	Range	Lot Idn	Feet from the	North/South line	Feet from the	East/West line	County
D	9	24 S	33 E		380	NORTH	365	WEST	LEA

[12] Dedicated Acres	[13] Joint or Infill	[14] Consolidation Code	[15] Order No.
160			

No allowable will be assigned to this completion until all interests have been consolidated or a non-standard unit has been approved by the division.



[17] OPERATOR CERTIFICATION

I hereby certify that the information contained herein is true and complete to the best of my knowledge and belief, and that this organization either owns a working interest or unleased mineral interest in the land including the proposed bottom hole location or has a right to drill this well at this location pursuant to a contract with an owner of such a mineral or working interest, or to a voluntary pooling agreement or a compulsory pooling order heretofore entered by the division.

Michael Daugherty 4/17/13

Signature Date

Michael S. Daugherty, COO

Printed Name

mdaugherty@jdmii.com

E-mail Address

[18] SURVEYOR CERTIFICATION

I hereby certify that the well location shown on this plat was plotted from field notes of actual surveys made by me or under my supervision, and that the same is true and correct to the best of my belief.

APRIL 16, 2013

Date of Survey

12797

Signature and Seal of Professional Surveyor:

Certificate Number: FILIMON F. JARAMILLO, PLS 12797

SURVEY NO. 1496B

NOV 14 2013

Appendix C

Well Logs

R.T. Hicks Consultants, Ltd.
901 Rio Grande Blvd. NW, Suite F-142
Albuquerque, NM 87104

WELL RECORD & LOG

OFFICE OF THE STATE ENGINEER

www.ose.state.nm.us

STATE ENGINEER OFFICE
ROSWELL, NEW MEXICO

2012 DEC 11 P 4: 02

1. GENERAL AND WELL LOCATION

POD NUMBER (WELL NUMBER): ICP-085	OSE FILE NUMBER(S): C-3565 POD 3
WELL OWNER NAME(S): Intercontinental Potash (USA)	PHONE (OPTIONAL): 575-942-2799
WELL OWNER MAILING ADDRESS: 600 West Bender Boulevard	CITY: Hobbs / STATE: NM / ZIP: 88240

WELL LOCATION (FROM GPS)		DEGREES	MINUTES	SECONDS	
	LATITUDE	32	13	39.75 N	* ACCURACY REQUIRED: ONE TENTH OF A SECOND
	LONGITUDE	103	35	27.62 W	* DATUM REQUIRED: WGS 84

DESCRIPTION RELATING WELL LOCATION TO STREET ADDRESS AND COMMON LANDMARKS

2. OPTIONAL

(2.5 ACRE)	(10 ACRE)	(40 ACRE)	(160 ACRE)	SECTION	TOWNSHIP	RANGE
¼	¼	¼	¼	8	24 ☐ NORTH ☑ SOUTH	33 ☑ EAST ☐ WEST

SUBDIVISION NAME	LOT NUMBER	BLOCK NUMBER	UNIT/TRACT
HYDROGRAPHIC SURVEY		MAP NUMBER	TRACT NUMBER

3. DRILLING INFORMATION

LICENSE NUMBER: WD #331	NAME OF LICENSED DRILLER: Phillip Stewart	NAME OF WELL DRILLING COMPANY: Stewart Brothers Drilling Co.

DRILLING STARTED	DRILLING ENDED	DEPTH OF COMPLETED WELL (FT)	BORE HOLE DEPTH (FT)	DEPTH WATER FIRST ENCOUNTERED (FT)
9/27/2012	10/21/2012	NA	1533 FT	NA

COMPLETED WELL IS: ☐ ARTESIAN ☑ DRY HOLE ☐ SHALLOW (UNCONFINED) — STATIC WATER LEVEL IN COMPLETED WELL (FT): NA

DRILLING FLUID: ☐ AIR ☑ MUD ☐ ADDITIVES – SPECIFY: ETH GEL, PLATINUM PAC, BI-CARB, SODA ASH,

DRILLING METHOD: ☑ ROTARY ☐ HAMMER ☐ CABLE TOOL ☐ OTHER – SPECIFY: TACKLE, MYLOGEL, NaCl

DEPTH (FT) FROM	TO	BORE HOLE DIA. (IN)	CASING MATERIAL	CONNECTION TYPE (CASING)	INSIDE DIA. CASING (IN)	CASING WALL THICKNESS (IN)	SLOT SIZE (IN)
0	1250	12.625	J-55 #36 steel	theaded	8.921	0.302	
1250	1533	8.75	NA				

4. WATER BEARING STRATA

DEPTH (FT) FROM	TO	THICKNESS (FT)	FORMATION DESCRIPTION OF PRINCIPAL WATER-BEARING STRATA (INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES)	YIELD (GPM)
NA		NA	NA	NA

METHOD USED TO ESTIMATE YIELD OF WATER-BEARING STRATA	TOTAL ESTIMATED WELL YIELD (GPM)
Bypass flow	na

FOR OSE INTERNAL USE

WELL RECORD & LOG (Version 6/9/08)

FILE NUMBER	POD NUMBER	TRN NUMBER
LOCATION		PAGE 1 OF 2

STATE ENGINEER OFFICE
ROSWELL, NEW MEXICO

2012 DEC 11 P 4:03

5. SEAL AND PUMP

TYPE OF PUMP: ☐ SUBMERSIBLE ☐ TURBINE ☐ JET ☐ CYLINDER ☑ NO PUMP – WELL NOT EQUIPPED ☐ OTHER – SPECIFY:

ANNULAR SEAL AND GRAVEL PACK	DEPTH (FT)		BORE HOLE DIA. (IN)	MATERIAL TYPE AND SIZE	AMOUNT (CUBIC FT)	METHOD OF PLACEMENT
	FROM	TO				
	NA		NA	NA	NA	NA

6. GEOLOGIC LOG OF WELL

DEPTH (FT)		THICKNESS (FT)	COLOR AND TYPE OF MATERIAL ENCOUNTERED (INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES)	WATER BEARING?
FROM	TO			
0	20	20	Caliche	☐ YES ☑ NO
20	55	35	Gutuna Fm. - red siltstones and sandstones	☐ YES ☑ NO
55	1227	1181	Dewey Lake Fm.Red siltstones and mudstones, gray/green mottling	☐ YES ☑ NO
1227	1262	35	Rustler Fm./A-5, white anhydrite	☐ YES ☑ NO
1262	1295	33	H-4 sub-mbr. - milky white halite	☐ YES ☑ NO
1295	1310	15	A-4 sub-mbr. - white anhydrite	☐ YES ☑ NO
1310	1330	20	Magenta Dolomite	☐ YES ☑ NO
1330	1375	45	A-3 sub-mbr. white anhydrite	☐ YES ☑ NO
1375	1479	112	H-3 sub-mbr. - milky halite	☐ YES ☑ NO
1479	1489	10	Ore zone, anhydrite and white polyhalite	☐ YES ☑ NO
1489	1533	44	Halite, with some anhydrite	☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO

ATTACH ADDITIONAL PAGES AS NEEDED TO FULLY DESCRIBE THE GEOLOGIC LOG OF THE WELL

7. TEST & ADDITIONAL INFO

WELL TEST — METHOD: ☐ BAILER ☐ PUMP ☐ AIR LIFT ☐ OTHER – SPECIFY: NA

TEST RESULTS - ATTACH A COPY OF DATA COLLECTED DURING WELL TESTING, INCLUDING START TIME, END TIME, AND A TABLE SHOWING DISCHARGE AND DRAWDOWN OVER THE TESTING PERIOD.

ADDITIONAL STATEMENTS OR EXPLANATIONS:

8. SIGNATURE

THE UNDERSIGNED HEREBY CERTIFIES THAT, TO THE BEST OF HIS OR HER KNOWLEDGE AND BELIEF, THE FOREGOING IS A TRUE AND CORRECT RECORD OF THE ABOVE DESCRIBED HOLE AND THAT HE OR SHE WILL FILE THIS WELL RECORD WITH THE STATE ENGINEER AND THE PERMIT HOLDER WITHIN 20 DAYS AFTER COMPLETION OF WELL DRILLING:

SIGNATURE OF DRILLER: Rodney D. Stewart — DATE: 12-10-12

WELL RECORD & LOG

OFFICE OF THE STATE ENGINEER

www.ose.state.nm.us

STATE ENGINEER OFFICE
ROSWELL, NEW MEXICO

2012 DEC 11 P 4: 02

1. GENERAL AND WELL LOCATION

POD NUMBER (WELL NUMBER)	OSE FILE NUMBER(S)		
ICP-085	C-3565 POD 3		
WELL OWNER NAME(S)	PHONE (OPTIONAL)		
Intercontinental Potash (USA)	575-942-2799		
WELL OWNER MAILING ADDRESS	CITY	STATE	ZIP
600 West Bender Boulevard	Hobbs	NM	88240

WELL LOCATION (FROM GPS)		DEGREES	MINUTES	SECONDS	
	LATITUDE	32	13	39.75 N	* ACCURACY REQUIRED: ONE TENTH OF A SECOND
	LONGITUDE	103	35	27.62 W	* DATUM REQUIRED: WGS 84

DESCRIPTION RELATING WELL LOCATION TO STREET ADDRESS AND COMMON LANDMARKS

2. OPTIONAL

(2.5 ACRE)	(10 ACRE)	(40 ACRE)	(160 ACRE)	SECTION	TOWNSHIP	RANGE
¼	¼	¼	¼	8	24 ☐ NORTH ☑ SOUTH	33 ☑ EAST ☐ WEST

SUBDIVISION NAME	LOT NUMBER	BLOCK NUMBER	UNIT/TRACT

HYDROGRAPHIC SURVEY	MAP NUMBER	TRACT NUMBER

3. DRILLING INFORMATION

LICENSE NUMBER	NAME OF LICENSED DRILLER	NAME OF WELL DRILLING COMPANY
WD #331	Phillip Stewart	Stewart Brothers Drilling Co.

DRILLING STARTED	DRILLING ENDED	DEPTH OF COMPLETED WELL (FT)	BORE HOLE DEPTH (FT)	DEPTH WATER FIRST ENCOUNTERED (FT)
9/27/2012	10/21/2012	NA	1533 FT	NA

COMPLETED WELL IS: ☐ ARTESIAN ☑ DRY HOLE ☐ SHALLOW (UNCONFINED)

STATIC WATER LEVEL IN COMPLETED WELL (FT): NA

DRILLING FLUID: ☐ AIR ☑ MUD ☐ ADDITIVES - SPECIFY: ETH GEL, PLATINUM PAC, BI-CARB, SODA ASH,

DRILLING METHOD: ☑ ROTARY ☐ HAMMER ☐ CABLE TOOL ☐ OTHER - SPECIFY: TACKLE, MYLOGEL, NaCl

DEPTH (FT) FROM	DEPTH (FT) TO	BORE HOLE DIA. (IN)	CASING MATERIAL	CONNECTION TYPE (CASING)	INSIDE DIA. CASING (IN)	CASING WALL THICKNESS (IN)	SLOT SIZE (IN)
0	1250	12.625	J-55 #36 steel	theaded	8.921	0.302	
1250	1533	8.75	NA				

4. WATER BEARING STRATA

DEPTH (FT) FROM	DEPTH (FT) TO	THICKNESS (FT)	FORMATION DESCRIPTION OF PRINCIPAL WATER-BEARING STRATA (INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES)	YIELD (GPM)
NA		NA	NA	NA

METHOD USED TO ESTIMATE YIELD OF WATER-BEARING STRATA	TOTAL ESTIMATED WELL YIELD (GPM)
Bypass flow	na

FOR OSE INTERNAL USE

WELL RECORD & LOG (Version 6/9/08)

FILE NUMBER	POD NUMBER	TRN NUMBER
LOCATION		PAGE 1 OF 2

5. SEAL AND PUMP						
TYPE OF PUMP:	☐ SUBMERSIBLE ☐ TURBINE	☐ JET ☐ CYLINDER	☑ NO PUMP – WELL NOT EQUIPPED ☐ OTHER – SPECIFY:			
ANNULAR SEAL AND GRAVEL PACK	DEPTH (FT) FROM	DEPTH (FT) TO	BORE HOLE DIA. (IN)	MATERIAL TYPE AND SIZE	AMOUNT (CUBIC FT)	METHOD OF PLACEMENT
	NA		NA	NA	NA	NA

6. GEOLOGIC LOG OF WELL

DEPTH (FT) FROM	DEPTH (FT) TO	THICKNESS (FT)	COLOR AND TYPE OF MATERIAL ENCOUNTERED (INCLUDE WATER-BEARING CAVITIES OR FRACTURE ZONES)	WATER BEARING?
0	20	20	Caliche	☐ YES ☑ NO
20	55	35	Gutuna Fm. - red siltstones and sandstones	☐ YES ☑ NO
55	1227	1181	Dewey Lake Fm.Red siltstones and mudstones, gray/green mottling	☐ YES ☑ NO
1227	1262	35	Rustler Fm./A-5, white anhydrite	☐ YES ☑ NO
1262	1295	33	H-4 sub-mbr. - milky white halite	☐ YES ☑ NO
1295	1310	15	A-4 sub-mbr. - white anhydrite	☐ YES ☑ NO
1310	1330	20	Magenta Dolomite	☐ YES ☑ NO
1330	1375	45	A-3 sub-mbr. white anhydrite	☐ YES ☑ NO
1375	1479	112	H-3 sub-mbr. - milky halite	☐ YES ☑ NO
1479	1489	10	Ore zone, anhydrite and white polyhalite	☐ YES ☑ NO
1489	1533	44	Halite, with some anhydrite	☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO
				☐ YES ☐ NO

ATTACH ADDITIONAL PAGES AS NEEDED TO FULLY DESCRIBE THE GEOLOGIC LOG OF THE WELL

7. TEST & ADDITIONAL INFO

WELL TEST	METHOD: ☐ BAILER ☐ PUMP ☐ AIR LIFT ☐ OTHER – SPECIFY: NA
	TEST RESULTS - ATTACH A COPY OF DATA COLLECTED DURING WELL TESTING, INCLUDING START TIME, END TIME, AND A TABLE SHOWING DISCHARGE AND DRAWDOWN OVER THE TESTING PERIOD.

ADDITIONAL STATEMENTS OR EXPLANATIONS:

8. SIGNATURE

THE UNDERSIGNED HEREBY CERTIFIES THAT, TO THE BEST OF HIS OR HER KNOWLEDGE AND BELIEF, THE FOREGOING IS A TRUE AND CORRECT RECORD OF THE ABOVE DESCRIBED HOLE AND THAT HE OR SHE WILL FILE THIS WELL RECORD WITH THE STATE ENGINEER AND THE PERMIT HOLDER WITHIN 20 DAYS AFTER COMPLETION OF WELL DRILLING:

SIGNATURE OF DRILLER

12-10-12
DATE

FOR OSE INTERNAL USE

WELL RECORD & LOG (Version 6/9/08)

FILE NUMBER	POD NUMBER	TRN NUMBER
LOCATION 2012 DEC 11 P 4:20		PAGE 2 OF 2

R. T. HICKS CONSULTANTS, LTD.

901 Rio Grande Blvd NW ▲ Suite F-142 ▲ Albuquerque, NM 87104 ▲ 505.266.5004 ▲ Fax: 505.266-0745

February 28, 2013
Revised November 1, 2013

Murchison Oil and Gas, Mogi 9 State Com 1H Rat Hole Evaluation and Brinninstool 4 State 3H Observations

The Mogi 9 State Com #1H well site has an elevation of 3606 and located 1 mile due south of the Brinninstool 4 State 3H site. The Brinninstool 4 State 3H site is 30 feet higher, with an elevation of 3636.3. The Mogi 9 State Com #1H rat hole location is:

- Lower in elevation than the Brinninstool well site,
- Closer to the center of the Bell Lake depression area
- Closer to the closed topographic contour that defines the edge of the ancient collapse feature

Within the eastern portion of the Bell Lake Sink shallow (Ogallala or Alluvium) groundwater is known to be present at an elevation of 3,566 feet (see Table 1 and Figure 1 in the C-144 application). In the western portion of the Sink, groundwater is likely deeper, as the surface elevation of Bell Lake is about 3565 and the lake is dry. Based on this information it is expected that the shallow groundwater, if present at the Brinninstool 4 State 3H site would be approximately 50 to 70 feet below the surface.

On February 27, 2013 Dale Littlejohn witnessed the drilling of the rat hole at the Mogi 9 #1H site. Ready Drill LLC of Monahans, Texas performed the work using a track-mounted 30-inch auger drilling rig as shown in the adjacent photograph.

Mr. Littlejohn arrived at the site at 10:30 am and found the operations shut down (waiting on fuel for the drilling rig) with the auger in the hole at a depth of approximately 70 feet. This provided an excellent opportunity to check for any groundwater that may have accumulated in the bottom of the while the drilling rig was not operational.

At 11:25 am the rig had been re-fueled and the bottom 1 foot was cut, removed, and inspected for possible moisture. The photograph from the 70 to 71-foot depth interval (shown to the right) demonstrates that the soil cuttings were completely dry. Also, a mirror was used to reflect sunlight in to the boring in order to inspect the walls and bottom. There were no indications of water seeps in the walls or an accumulation of water at the total depth.

Over the next 2.5 hours the boring was advanced to a total depth of 120 feet by removing approximately 1 to 1.5 feet of material per trip into the hole. Mr. Littlejohn carefully inspected each auger for the appearance of moisture in the soil prior to it being spun off and removed from the drilling pad. Had the slightest indication of moisture been identified in the soil, the operation would have been suspended to allow for the accumulation of measurable water.

The photograph to the left was taken from the soil recovered at a depth of 98 feet as it is being spun from the auger. This photograph demonstrates the lack of moisture in the cuttings. It is believed that any potential moisture from the bottom or walls of the boring would have been easily identified during the drilling process as each trip into the hole should contact wet soil if it is present at any depth.

During the drilling operations, soil samples were collected and described as shown on the adjacent log. Based on the evaluation of the cuttings it appears that the Ogallala (or alluvium) is present at least seven feet above the Bell Lake well groundwater elevation. The top of the Triassic is identified by the hard purple shale at a depth of 33 feet and extends to the total depth of the boring.

In light of the geology observed from the rat hole samples and the absence of any detectable moisture throughout the drilling operation, it was determined that the additional costs associated with suspending the installation of the conductor pipe for 24 to 72 hours in order to allow the accumulation of potential groundwater was not justified at this site. Had any moisture been observed during drilling, or had porous rocks been present below the groundwater elevation observed in Bell Lake water wells, the installation of conductor pipe would have been suspended.

On April 2, 2013, Randall Hicks and Kristin Pope examined the cuttings from the Brinninstool 3H conductor pipe auger boring. Because the pit lining was occurring at the same time, we could not catch the auger rig while drilling, thus there are no photographs. The drillers reserved samples from the auger boring at 5-foot intervals. Our examination documented that the cuttings to 120 feet were dust/dry. There is no evidence of groundwater as defined by New Mexico Rules/Regulations from ground surface to a depth of 120 feet at the Brinninstool 4 State 3H location.

Appendix D

Design and Construction

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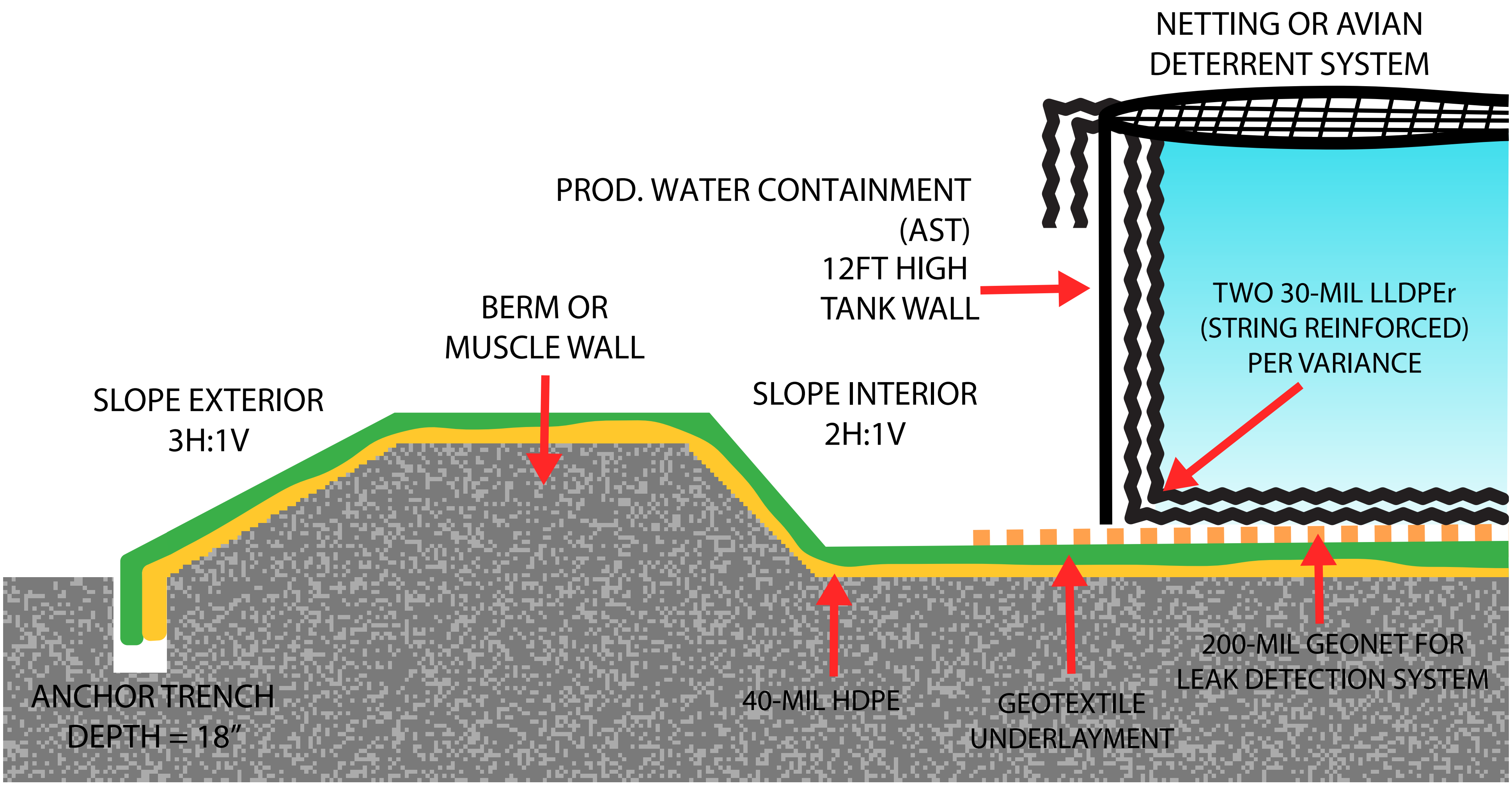
Albuquerque, NM 87104



Not to Scale

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AST Schematic

Tap Rock Resources: MOGI 9 State Com 1H AST

July 2018

General

In this plan, the portion of the Produced Water Re-use Rule that is addressed by certain text is underlined.

Examination of the engineering drawings in Appendix H, the SOP that is Appendix G, the text below and the history of solid performance of these ASTs demonstrates that Select Energy/Rockwater has designed and will construct the recycling containment to ensure the confinement of produced water, to prevent releases and to prevent overtopping due to wave action or rainfall. As the AST is only about 157.5-feet inside diameter, wave action is not a meaningful consideration.

This design and construction plan has been large abstracted from Appendix G of Select Energy/Rockwater's SOPs. However, this Design and Construction Plan provides additional protocols to cause the proposed recycling containments (ASTs) to conform to NMOCD Rules. Therefore, if a conflict exists between the SOP of Appendix G and this plan (Appendix D), Select Energy/Rockwater will adhere to the mandates of this plan.

The Select Energy/Rockwater ASTs are constructed of 12-foot high steel panels and are netted or employs the Mega Blaster Pro avian deterrent system to prevent ingress of migratory birds. OCD has approved a variance under Rule 17 that eliminates the need for Select Energy/Rockwater to fence or enclose a recycling containment in a manner that deters unauthorized wildlife and human access and shall maintain the fences in good repair. The operator shall ensure that all gates associated with the fence are closed and locked when responsible personnel are not onsite.

The customer of Select Energy/Rockwater (the operator) shall post an upright sign no less than 12 inches by 24 inches with lettering not less than two inches in height in conspicuous places surrounding the containment. The operator shall post the sign in a manner and location such that a person can easily read the legend. The sign shall provide the following infom1ation: the operator's name, the location of the site by quarter-quarter or unit letter, section, township and range, and emergency telephone numbers.

Select Energy/Rockwater shall ensure that a recycling containment is screened, netted or otherwise protective of wildlife, including migratory birds. The operator shall on a monthly basis inspect for and, within 30 days of discovery, report the discovery of dead migratory birds or other wildlife to the appropriate wildlife agency and to the division district office in order to facilitate assessment and implementation of measures to prevent incidents from reoccurring.

Site Preparation

Foundation for AST

Preparation of the soils on site is required to form a dependable base for the AST. Preparation of the tank pad is the sole responsibility of Select Energy/Rockwater's AST customer (typically an oil and gas operating company). In general, prior to constructing the containment foundation, the operator will strip and stockpile the topsoil for use as the final cover or fill at the time of closure.

The Select Energy/Rockwater Field Operations Manager will check the status of soil preparation during the pre-project meeting on site. Select Energy/Rockwater personnel will also check the soil preparation using a proof roll test immediately prior to the AST setup.

Select Energy/Rockwater's soil preparation requirements are as follows:

1. Select Energy/Rockwater recommends a minimum soil compaction of 95% compaction.
2. Select Energy/Rockwater recommends soil compaction testing to be conducted via
    a. Standard Proctor Test (American Society for Testing and Materials {ASTM} Standard D698) or Modified Proctor Test (ASTM Standard D1557).
    b. A proof roll test may be used if observed and documented by qualified Select Energy/Rockwater personnel. Attachment 3 of this SOP provides guidance on how to perform a proof roll test and how to interpret the results.
3. Grade AST footprint and 30 feet work area to 0.25 % or 3" feet drop per 100 feet, toward sump location.
4. Site should be graveled prior to tank installation, utilizing gravel size 2B or smaller. (3/4" road grade preferred, or coarse sand with minimum thickness of 4 inches). Do not use crushed rock as sharp edges could puncture the tank liner. After completion of these steps the tank setup can be approved.
5. If 2-3 foot high levees are used to contain the AST, the interior slope of the levee are 2H:1V and the exterior slope is 3H:1V.

Thus, the AST (recycling containment) will have a properly constructed foundation and interior slopes consisting of a firm, unyielding base, smooth and free of rocks, debris, sharp edges or irregularities to prevent the liner's rupture or tear. Geotextile will be placed under the liner where needed to reduce localized stress-strain or protuberances that otherwise may compromise the liner's integrity. If Select Energy/Rockwater constructs the containment in a levee, the inside grade is no steeper than two horizontal feet to one vertical foot (2H: 1 V) and the outside grade no steeper than three horizontal feet to one vertical foot (3H: IV). As the secondary liner covers the levee with the anchor trench outside of the containment, there is for inspection and maintenance of the anchor trench. If Select Energy/Rockwater elects to use a pre-fabricated containment structure, a variance request is included in the registration.

Tank Layout on Foundation

- Check proposed AST site to confirm a 30’ clear work area around the perimeter of the tank is possible to provide access for equipment and laydown area for AST materials and erection equipment.
- Check that the minimum distances to existing wells, power lines, etc. are met.
- Regardless of manufacturer, the minimum footprint should be a circle of at least 24’ greater than that the radius of the tank.
- Establish final location for the suction tube and stairs.
- For a pin tank, the pad should be graded and sloped 0.25% from high side of location to suction side of tank. This will allow for better drainage of tank.
- For a plate tank, the pad needs to be flat.

The transmittal letter identifies the type of foundation to be used for the proposed containment (e.g. sloped or flat) as well as some other features of the particular installation.

AST Tank Setup Preparation

Mark the Foundation for Setup

1. Determine center of tank and mark with paint, then bury preferred non-abrasive item (tennis ball, sand bag, water bottle, etc.) This will be used to find the center of tank after liners have been placed.
2. Measure distance from tank center to existing oil/gas wells to check that the tank meets the minimum distance for the operator
3. Measure and paint a line to mark the circumference of tank for panel placement.
4. Mark the circumference of the liner laid out flat to ensure the liner is properly placed.
5. Determine where tank suction is to be placed (the low side of pad).
    a. For pin tanks, dig 8’ wide x 8’ long x 16” deep sump hole for the suction manifold to set in and taper the edges so there are no sharp corners of the excavation. Remove any sharp stones
    b. If multiple suction manifolds are required, the sumps should have a minimum of 8’ of separation. Attention! In cold weather conditions, the sumps should be dug out as late as possible and should never be left unattended overnight. Barricade any sump pit with appropriate cones or tape if left open when crew is not present or active in the area.
6. When installing certain ASTs, a “Y Trench” can be used both for wind stabilization and for draining the tank. The “Plate Tank Y-Trench Guidance Document” can be found in Attachment 5 of Appendix C (SOP).

The placement of sumps in the foundation and the AST design demonstrates that at a point of discharge into or suction from the recycling containment, the liner is protected from excessive hydrostatic force or mechanical damage and external discharge or suction lines shall not penetrate the liner.

Liner and Leak Detection Materials

The liner and geotextile specifications in Appendix H show that all primary (upper) liners in a recycling containment shall be geomembrane liners composed of an impervious, synthetic material that is resistant to ultraviolet light, petroleum hydrocarbons, salts and acidic and alkaline solutions. All primary liners shall be 45-mil LLDPE string reinforced (minimum). A variance may be requested to use a double-liner system that results in equivalent or better characteristics.

Secondary liners shall be 30-mil LLDPE string reinforced (minimum) or equivalent with a hydraulic conductivity no greater than 1 x 10-9 cm/sec.

Liner compatibility shall meet or exceed the EPA SW-846 method 9090A or subsequent relevant publications.

Install Secondary Liner, Leak Detection System and Secondary Containment

All tanks holding produced water will have a primary (upper) liner and a secondary (lower) liner with a leak detection system appropriate to the site's conditions. The edges of all secondary liners shall be anchored in the bottom of a compacted earth-filled trench. The anchor trench shall be at least 18 inches deep.

The steps to install the secondary liner are:

1. The crew walks the entire tank base area to and pick up any sharp stones or other sharp debris that could damage the liner.
2. If necessary, lay out a geotextile to create a pad between the liner and the earth foundation. In some cases, the geotextile is “bundled” with the liner and will be rolled out together. After unrolling, pull the geotextile and liner to extend it fully using several crew members spaced along the edge.
3. Perform a visual inspection of the liner – repair any defects as necessary.
4. Install a 30-mil LLDPE string reinforced (minimum) secondary liner per the manufacturer’s specifications
    a. to extend over or on any earthen levees for secondary containment and then into the anchor trench (18-inches deep) or
    b. attach the secondary liner to pre-fabricated secondary containment in accordance with the manufacturer’s specifications.
5. Within and extending several feet from the footprint of the AST, place 200-mil geogrid or 10-oz geotextile (see variance request if applicable) and secure to the secondary liner. This geotextile material is permeable and will act as the drainage layer between the primary liner system and the secondary liner. Any leakage from the AST will be obvious as the fluid moves from beneath the AST into the secondary containment.
6. If a Y trench is used (see Appendix G (SOPs), Attachment 5), in the deepest section of the trench (center) place a water sensor (conductivity probe) and a length of rigid tubing (1/2 inch or smaller diameter) above the secondary liner and below the geotextile. The

sensor wire and tubing extends beyond the diameter of the tank to facilitate leak detection and fluid removal (see O&M plan).

Thus, the recycling containment will have a leak detection system between the upper and lower geomembrane liners that shall consist of 200-mil geonet (or a suitable material pursuant to a variance) to facilitate drainage. The leak detection system shall consist of a properly designed drainage and collection and removal system placed above the lower geomembrane liner in depressions and sloped to facilitate the earliest possible leak detection.

The presence of the secondary containment levee or pre-fabricated secondary containment meets the OCD Rule mandate that a recycling containment shall design the containment to prevent run-on of surface water. The containment shall be surrounded by a berm, ditch or other diversion to prevent run-on of surface water,

AST Tank Setup

Install Primary Liner

As with the secondary liner, Select Energy/Rockwater will minimize liner seams and orient them up and down, as much as possible, not across, a slope. Factory welded seams shall be used where possible. Select Energy/Rockwater will employ field seams in geosynthetic material that are thermally seamed. Prior to field seaming, Select Energy/Rockwater shall overlap liners four to six inches and minimize the number of field seams and corners and irregularly shaped areas. There shall be no horizontal seams within five feet of the AST bottom. Qualified personnel shall perform field welding and testing.

Installation set up consistent with the SOP (Appendix G) continues:

A. Place the two 30-mil LLDPE primary liner system aligned to the center of the tank and painted line for the tank walls. The preferred 30 feet area around tank allows the liner to be laid out flat so that fold back can be uniform.
B. Bundling of the liner with the drainage geotextile by the liner supplier is generally not used in New Mexico. If the liner is bundled with the geotextile, roll it out across the diameter of the tank over the geotextile material that extends beyond the AST diameter (described above). Be sure not to use padded vice grips to move liner unless located at edge of liner. Inspect liner and report any damage or bad seams, punctures due to handling, etc. to the Crew Leader
C. Secure liner from wind using sand bags, or if plate tank. If a “Y” trench is used, fill it with water
D. Fold the liner toward inside the painted tank edge line to allow stockpiling of sand and placement tank panel walls.
E. Stockpile sand just inside marked panel perimeter. Place enough sand at spaced locations around the circle to provide for sand approximately 12” deep at tank wall and a 1:1 slope into tank.

Tank Wall Erection

F. Stand the first tank panel in place and keep connected to the hoist mechanism until all the remaining panels have been connected. This will be done using a front-end loader equipped with an engineer-approved attachment specific for this task.
G. Monitor hoist and rigging mechanism of first panel closely to ensure it remains stable, especially during wind and while the other panels are attached.
H. Begin placing the remaining panels in place with the front-end loader and panel rigging frame
I. Personnel secured on man-lift then secure the panels in place with 4 pins each (for pin tanks) or (for plate tanks) with the connecting plates and lug busses, secured with chained cotter pins.
J. To protect the liner, distribute sand with shovels to form 1:1 sand bank against the inside bottom of each panel. Be sure the slope is uniform. Alternatively, roll up excess geo pad (geotextile) into minimum 6” diameter cylinders around the inside of the tank ring to help support the liner at the base of the tank wall as the tank is being filled.
K. Prior to lifting liner into place against inside panel, place metal covering plates over all panel gaps in plate type tank. For pin tanks, check that sand or rolled up geo pad is evenly placed at base of all walls.
L. Prior to covering sump with the geo pad or liner, confirm sump excavation has smooth sides and corners, and that no sharp stones are present.
M. When placing the final panel in the circle, attach this final panel only on left or right side but LEAVE OTHER PANEL SIDE OPEN at this time for access and egress points. (Must have an entry and exit point to the tank at all times.)

Liner Placement and Securing Top With Clips or Clamps

N. After 4 or 5 panels are set, and all liner protection as described above is in place, unfold the liner in sections, toward the base of each panel, making sure the sand or rolled up geo pad will provide padding at the base of the inside of each panel.
O. Crew of 2 inside the tank wall unfolds and pulls the liner toward each panel. Working in small liner sections, this inside crew works with a crew of 2 on a man lift located outside and above each tank panel to pull the liner edge up and over the top of each panel. The man lift crew lifts the liner edge using ropes attached (by the inside crew) to padded vice grips that grip the liner. The man lift crew lifts a small liner section to the top of the panel and folds it over the top of the panel, being sure there is enough slack in the liner inside the panel wall.
P. Once a section of liner is positioned properly (with liner slack inside the tank) and over the top of each panel wall, the man lift crew secures the top of the liner with clips (pin tanks) or clamps (plate tanks). NOTE: A minimum of 5 clips (pin tanks) or 5 clamps (plate tanks) or more are required at the top of each tank panel to secure the liner. Add additional clips and clamps as needed to secure liner.
Q. Both inside and man lift crews continue this process, working around the tank, one or two panels at a time, until the entire liner is in place. NOTE: The crew must allow sufficient slack in the liner at the wall to allow for liner movement during filling and draining.

Stairs, Fill Tubes, and Suction Tubes

I. Install safety stair system, fill tubes, and suction tubes. Ensure that stair system and tubes are appropriately secured to the tank walls according to customer specifications.

II. Upon completion of the stair system installation, the stairs should be secured as per the operating company requirements. At a minimum, these requirements should include access chains with “Authorized Personnel Only” (or equivalent) signage at the bottom of the stairs outside the tank, water rescue equipment on the platform at the top of the stairs, and access chains with “Do Not Enter” signage at the top of the stairs that go inside the tank.

Final Steps, Filling, and Inspection

- Close final panel and secure with pins or plates as needed.
- Trim liner and allow approximately 3’ of liner to hang over edge of tank.
- Secure liner with sufficient clips or clamps and be sure ratchet straps are applied to all tanks.
- Place straps to secure the cut edge of liner on outside of tank.
- Inspect all connections and equipment, confirming at least 5 liner clips or clamps (or more as needed) are in place on top of each panel.
- Have a minimum of 8 inches of water put in the high side of the tank to check for leaks and to hold liner in place.
- Fill tank and monitor.
- If tank remains on site for any period longer than 7 days perform periodic inspections of the tank to ensure everything is in proper working order.
- Every time a tank is fully emptied and refilled, an inspection must be performed.
- Visibly inspect all tank panels and stairs for cracking, dents, burrs on the inside of the panels, chipping paint on welds or sharp edges on panels.
- Look for any cracked or broken valves, damage on pipes and tubes, missing D-Rings, damage to chains or ratchets, and bent clips.
- Pay close attention to hinge plates for chipping paint and cracking.
- Water must NEVER go below 24 inches at the LOWEST level in the tank. (Mark this on the liner as a caution).

Appendix E

Operations and Maintenance

R.T. Hicks Consultants, Ltd.
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Albuquerque, NM 87104

General Specifications

In this plan, the portion of the Produce Water Re-use Rule that is addressed by certain text is underlined. This operations and maintenance plan has been large abstracted from Appendix G (SOPs). However, this plan provides additional protocols to cause the proposed recycling containments (ASTs) to conform to NMOCD Rules. Therefore, if a conflict exists between the SOP of Appendix G and this plan (Appendix E), Select Energy/Rockwater will adhere to the mandates of this plan.

The operator will maintain and operate the recycling containments and facility in accordance with the following plan to contain liquids and maintain the integrity of the liner to prevent contamination of fresh water and protect public health and the environment.

- The operator will use the treated produced water in the containments for drilling, completion (stimulation), producing or processing oil or gas or both. If other uses are planned, the operator will notify the OCD though the submission of a modified C-147.
- For all exploration and production operations that use produced water, the operator will conduct these activities in a manner consistent with hydrogen sulfide gas provisions in 19.15.11 NMAC or NORM provisions in 19.15.35 NMAC, as applicable.
- The operator will address all releases from the recycling and re-use of produced water in accordance with 19.15.29 NMAC.
- The operator will not discharge into or store any hazardous waste in the recycling containments but they may hold fluids such was freshwater, brackish water, recycled and treated water, water generated by oil or gas processing facilities, or other waters that are gathered for well drilling or completion. The recycling facility will not be used for the disposal of produced water. The operator will maintain the containments free of miscellaneous solid waste or debris.
- The operator will verify that no oil is on the surface of the contained fluid. If oil is observed, the oil shall be removed using an absorbent boom or other device and properly disposed at an approved facility. An absorbent boom or other device will be maintained on site.
- The operator will install and use a header and diverter described in the design/construction plan in order to prevent damage to the liner by erosion, fluid jets or impact from installation and removal of hoses or pipes during injection or withdrawal of liquids.
- Pursuant to an approved variance, the operator will maintain at least 2-feet of freeboard in each AST containment. For other containments, the operator will maintain at least 3-feet of freeboard. Under extenuating circumstances, which will be noted on the inspection log as described below, the operator may temporarily exceed the freeboard mandate.

- If the liner develops a leak or if any penetration of the liner occurs above the liquid's surface, then the operator will repair the damage or initiate replacement of the liner within 48 hours of discovery or will seek a variance from the division district office within this time period.
- If visible inspection suggests that the liner developed a leak or if any penetration of the liner occurs below the liquid's surface, then the operator will remove all liquid above the damage or leak line within 48 hours of discovery. The operator will also notify the district division office within this same 48 hours of the discovery and repair the damage or replace the liner.
- In the event of a leak due to a hole in the liner, the following steps will be followed:
    1. If the source of the fluid is uncertain, comparative field tests may need to be performed on both the water in the containment and that which may have been released (e.g. pH, conductance, and chloride).
    2. If the fluid is found to be coming from the containment, determine the location from which the leak is originating.
    3. Mark the point where the water is coming out of the tank.
    4. Locate the puncture or hole in the liner.
    5. Empty the containment to the point of damage in liner.
    6. Clean area of liner that needs to be repaired.
    7. Cut out piece of material (patch or tape) to overlay liner.
    8. Either weld the patch to the injured area in the liner or apply tape over the rupture.
    9. Make sure rupture is completely covered.
    10. Monitor as needed.
- The operator will inspect and remove, as necessary, surface water run-on accumulated in the secondary containment.

Monitoring, Inspections, and Reporting

The containment will contain enough produced water to prevent any shifting of the liner. Weekly inspections shall occur when there is 1-foot depth or more of produced water in the containment. Monthly inspections shall occur when there is less than 1-foot depth of produced water in the containment, as well as when the ASTs are emptied and prior to refilling. An inspection log will be maintained by the operator and will be made available to the division upon request. Inspection may include: freeboard monitoring, leak detection, identifying potential hazards that may have developed, change in site conditions or if the contents of the containment change from the initial use. The last pages of Appendix G contain the "Inspection Form" to be filled out during these routine inspections.

Attachment 4 of Appendix G contains the "AST Visual Inspection Checklist" form to be filled out by Select Energy/Rockwater during periodic inspections. The form provides a list of observations that will enable early detection of uneven tank panel settlement, soil settlement, liner damage, insufficient liner slack, or leaks. The form is reproduced at the end of this section.

The form "Tank Panel Visual Inspection Check Sheet" included in Attachment 6 of Appendix G will be used by Select Energy/Rockwater to inspect individual containment panels and connections titled. Each individual tank panel has a unique identifying number that is used on the sheet. Each panel is checked to identify any abnormal wear or damage.

Monitoring and Inspection Checklist (routine weekly or monthly inspections):

- Visually inspect the liner. If a liner's integrity is compromised, or if any penetration of the liner occurs above or below the water surface, then the operator will notify the appropriate Division district office within 48 hours (phone or email).
- Inspect the system for injection or withdrawal of liquids from the ASTs and document that the design prevents damage to the liner by erosion, fluid jets or impact from installation and removal of hoses or pipes is working appropriately.
- Inspect the water surface for visible oil.
- Measure the freeboard.
- Inspect the secondary containment berm around the ASTs to check for erosion and collection of surface water run-on.
- If H_2S is a documented potential issue with the containment, measure H_2S concentrations on the down-wind side of the facility when produced water is present.
- Inspect the secondary containment for evidence of damage and monitor for leakage.
- Inspect the netting for damage or failure. If netting is jeopardized, repair of the netting shall occur within 48 hours.
- At least monthly, inspect netting (may not be used if Mega Blaster Pro avian deterrent is used) for dead wildlife, including migratory birds. Operator shall report the discovery of a dead animal to the appropriate wildlife agency and to the district within 30 days of discovery. Further prevention measures may be required.

If observed conditions indicate a potential tank failure is imminent, the vicinity will be immediately cleared and the AST will be drained.

Recycling Facility

Form C-147 confirms financial assurance of the recycling facility. The operator of the facility is listed on form C-147.

- If the facility shares the same setting in regard to siting criteria, surface ownership, and location of the containments, registration will be submitted for both the containments and facility using one form C-147.
- The recycling facility serves many wells located on the same lease as the facility or on nearby leases.
- The operator of the facility will submit monthly reports to the division district detailing the total volume of water received for recycling, with the amount of fresh water received

listed separately, and the total volume of water leaving the facility and its disposition using form C-148.

- The facility operator will keep accurate records that identify the sources and disposition of all recycled water. These records shall be made available to the division by request.

Cessation of Operations

If less than 20% of the total fluid capacity is utilized every six months, beginning from the first withdraw, operation of the facility has ceased and the division district office will be notified. The division district may grant an extension not to exceed six months to determine the cessation of operations. The operator will remove all free fluids from the containments within 60 days from the date of operations cessation. An extension may be requested to allow no more than two months for the removal of fluid.

The breakdown of the containments follows the reverse order of the setup steps presented in Section 3.0 of the SOP (Appendix G).

The operator will remove all fluids from the recycling facility within 60 days of cessation of operations. An extension not be exceed 2 months may be granted by the district division for the removal of fluids from the facility.

AST Visual Inspection Checklist

Customer Company Name___________________Pad/Location ________________Date of Inspection__________

Customer Field Rep Name/Phone/Email____

Customer's Water Contact Name/Phone/Email____

Rockwater Job Reference No. _____________Rck Crew Leader_________________ Cell Phone ________________

Tank ID /Stair Number(s)_____________________ Tank Contents: _______________________________________

Tank Panel Visual Inspection Checklist completed and attached? ___________________ (date)___________

- CAUTION – If conditions are observed that could indicate an imminent tank failure, remove yourself and from the area immediately, advise others in the vicinity to do so also, and contact the customer to drain the tank, and the Field Operations Manager to advise of the situation.
- **Periodic Inspection Tasks:**
- Observe soil at base of all panels all around the tank to find any wet or moist areas that may indicate a leak
- Check for any uneven gaps between the panel edges from top of panel to bottom of panel. Uneven gaps between panels should be reported immediately, and noted on a sketch with the panel numbers involved and email or fax to the Field Operations Manager immediately
- Check that no panel bottom has sunk below the soil surface at any location. Tank panel settlement should be reported immediately, and noted on a sketch with the panel numbers involved and email or fax to the Field Operations Manager immediately. NOTE: Panel settlement should not be confused with soil pushed up against the panel bottom. If it is not clear from observing, call the Field Operations Manager.
- Check that the soil around the tank panels and within 10 feet of the tank panel is firm and has not been eroded by stormwater or leaking water
- Observe a vehicle driving near the perimeter of the tank to see if any soil settlement has occurred, note the location on a sketch
- Check contents of tank, advise Field Operations Manager if different than original order (see AST Pre-Project Checklist)
- Any running water on the ground in the vicinity of the tank is suspect and must be traced to its source using a pH test or other means. Take photographs of any running water if safe to do so.
- Check all liner clip (pin tanks) or clamps (plate tanks) are securing liner
- If tank is at low level check that sufficient liner slack is present against panel wall.
- Check all pins and plates, and cotter pins are in place
- Note any rust or corrosion of panels, stairs, or fill/suction tubes
- Note any damage to fill/suction tubes
- Note any liner visible liner damage, or damage to fill or suction tubes

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Customer contact notified of to drain tank? (Date/time)_________________________________

Field Operations Manager notified of any issues (name/date/time) ______________________________

Inspection Completed by:

(Printed name)______________________(signed) ______________________ (date)______

Appendix F

Closure Plan

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Closure Plan

The containments are expected to contain a small volume of solids, the majority of which will be windblown sand and dust with some mineral precipitates from the water.

The operator will notify the division district (phone or email) before initiating closure of the containments and/or facility.

Excavation and Removal Closure Plan – Protocols and Procedures

1. Residual fluids in the containments will be sent to disposal at a division-approved facility.

2. The operator will remove all solid contents and transfer those materials to the following division-approved facility:
   Disposal Facility Name: R360 Permit Number NM 01-0006

3. If possible, geomembrane textiles and liners that exhibit good integrity may be recycled for use as an underliner of tank batteries or other use as approved by OCD via a variance request.

4. Disassemble the recycling containment infrastructure according to manufacturer's recommendations

5. After the disassemble of the containments and removal of the contents and liners, soils beneath the tanks will be tested as follows
   a. Collect a five-point (minimum) composite from beneath the liner to include any obviously stained or wet soils, or any other evidence of impact from the containments for laboratory analyses for the constituents listed in Table I of 19.15.34.14 NMAC.
   b. If any concentration is higher than the parameters listed in Table I, additional delineation may be required and closure activities will not proceed without Division approval.

If all constituents' concentrations are less than or equal to the parameters listed in Table I, then the operator will backfill the facility as necessary using non-waste containing, uncontaminated, earthen material and proceed to reclaim the surface to pre-existing conditions.

Closure Documentation

Within 60 days of closure completion, the operator will submit a closure report (Form C-147) to the District Division, with necessary attachments to document all closure activities are complete, including sampling results and details regarding backfilling and capping as necessary.

In the closure report, the operator will certify that all information in the report and attachments is correct and that the operator has complied with all applicable closure requirements and conditions specified in the closure plan.

Reclamation and Re-vegetation

The operator will reclaim the surface to safe and stable pre-existing conditions that blends with the surrounding undisturbed area. “Pre-existing conditions” may include a caliche well pad that existed prior to the construction of the recycling containment and that supports active oil and gas operations.

Areas not reclaimed as described herein due to their use in production or drilling operations will be stabilized and maintained to minimize dust and erosion.

For all areas disturbed by the closure process that will not be used for production operations or future drilling, the operator will

1. Replace topsoils and subsoils to their original relative positions
2. Grade so as to achieve erosion control, long-term stability and preservation of surface water flow patterns
3. Reseed in the first favorable growing season following closure

Federal, state trust land, or tribal lands may impose alternate reclamation and re-vegetation obligations that provide equal or better protection of fresh water, human health, and the environment. Re-vegetation and reclamation plans imposed by the surface owner will be outlined in communications with the OCD.

The operator will notify the division when the site meets the surface owner’s requirements or exhibits a uniform vegetative cover that reflects a life-form ratio of plus or minus fifty percent (50%) of pre-disturbance levels and a total percent plant cover of at least seventy percent (70%) of pre-disturbance levels, excluding noxious weeds.

The operator will notify the Division when reclamation and re-vegetation is complete.