R. T. HICKS CONSULTANTS, LTD.
901 Rio Grande Blvd NW ▲ Suite F-142 ▲ Albuquerque, NM 87104 ▲ 505.266.5004 ▲ Fax: 505.266-0745

February 17, 2013

RECEIVED
By OCD; Dr. Oberding at 12:21 pm, Feb 19, 2015

Dr. Tomáš Oberding
NMOCD District 1
1625 French Drive
Hobbs, New Mexico 88240
VIA EMAIL

RE: Pulliam Farms 27-P Temporary Pit, Trench Burial Notice
API #30-009-20025-00-00
Unit P, Section 27, T8N, R35E, Curry County

Dr. Oberding:

On behalf of Alta Mesa Services, LP., R. T. Hicks Consultants provides this Trench Burial Closure notice to NMOCD. Closure operations at the above-referenced pit are scheduled to begin Thursday February 19.

While NMOCD did not approve the variance request submitted Jan. 29, 2015. NMOCD did allow Alta Mesa Services LP. two closure choices:

- Dig and haul the entire pit to an OCD approved facility, sample below the current pit and remediate to OCD guides as necessary.
- Trench bury the contents of the pit in a new fresh trench with a new liner that meets OCD guides, and as above, remediate beneath the extant pit.

After evaluating the choices, Alta Mesa has elected to proceed with on-site Trench Burial Closure. Therefore, please find enclosed:

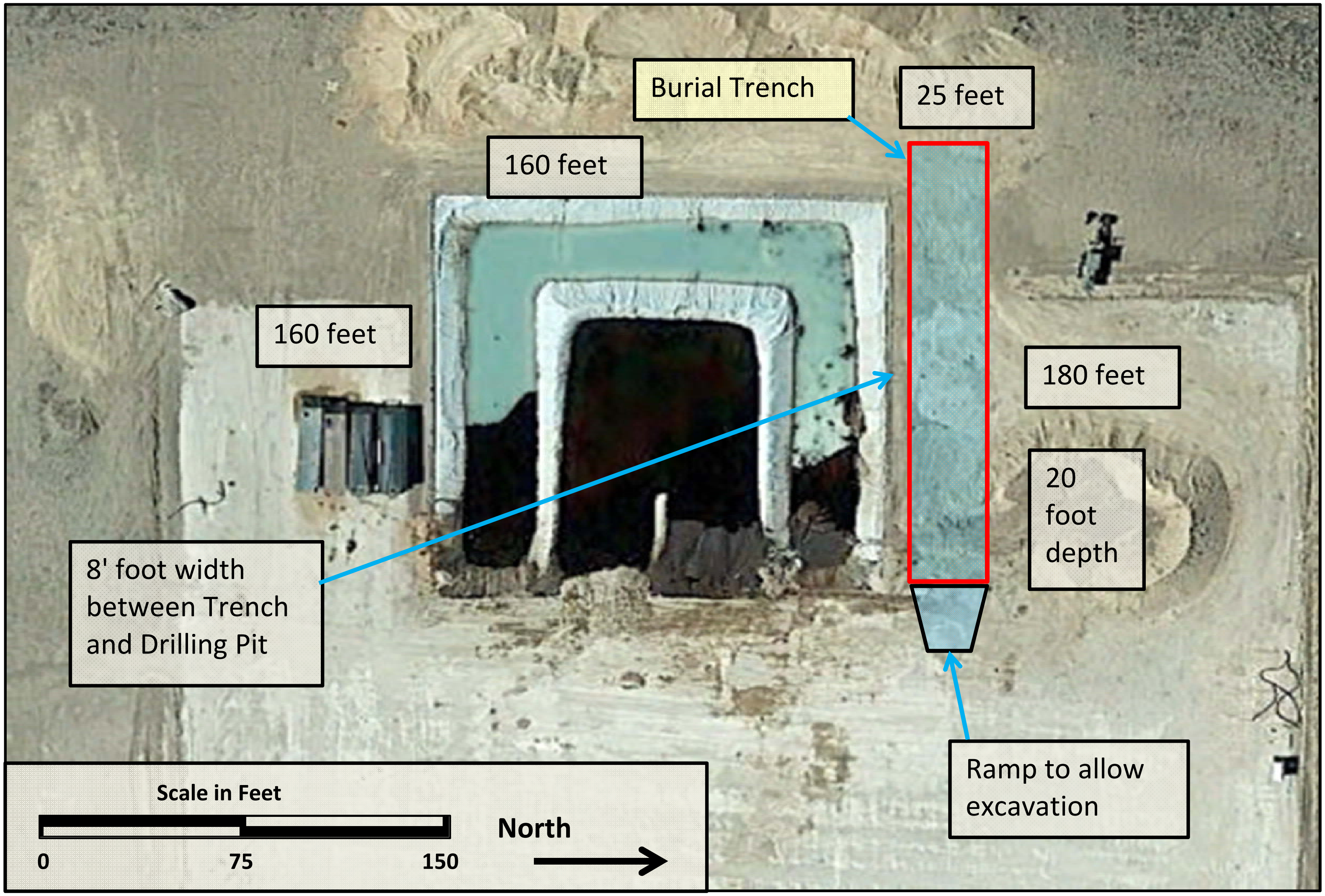
1. Plate 1, which presents a 2014 aerial photograph with a layout of the Trench Burial Design.
2. An updated C-144 referencing
    a. The attached Trench Burial Closure Plan
    b. The variance to allow trench burial of stabilized material that does not meet Table II criteria.

This letter has been sent to the surface owner certified mail, return receipt request and we have notified the surface owner of the closure activities.

Sincerely,
R.T. Hicks Consultants

Randall Hicks
Principal

Copy: Alta Mesa Services, LP
Dale Pulliam



R.T. Hicks Consultants, Ltd 901 Rio Grande Blvd NW Suite F-142 Albuquerque, NM 87104 505-266-5004	**Burial Trench Schematic for Pulliam Farm Pit**	**Plate 1**
	Alta Mesa Services	**Feb. 2015**

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-144
Revised June 6, 2013

For temporary pits, below-grade tanks, and multi-well fluid management pits, submit to the appropriate NMOCD District Office.
For permanent pits submit to the Santa Fe Environmental Bureau office and provide a copy to the appropriate NMOCD District Office.

Pit, Below-Grade Tank, or Proposed Alternative Method Permit or Closure Plan Application

Type of action:
☐ Below grade tank registration
☐ Permit of a pit or proposed alternative method
☐ Closure of a pit, below-grade tank, or proposed alternative method
☒ Modification to an existing permit/or registration
☒ Closure plan only submitted for an existing permitted or non-permitted pit, below-grade tank, or proposed alternative method

Instructions: Please submit one application (Form C-144) per individual pit, below-grade tank or alternative request

Please 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: Alta Mesa Services, LP OGRID #: 295752

Address: 15021 Katy Freeway, Suite 400, Houston, Texas 77094

Facility or well name: Pulliam Farms 27-P 001

API Number: 30-009-20025-00-00 OCD Permit Number: P1-06542

U/L or Qtr/Qtr P Section 27 Township 8N Range 35E County: Curry

Center of Proposed Design: Latitude N 34. 52' 49.11" Longitude W 103. 12' 59.62" W NAD: ☐1927 ☒ 1983

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

2.

☒ **Pit**: Subsection F, G or J of 19.15.17.11 NMAC

Temporary: ☒ Drilling ☐ Workover

☐ Permanent ☐ Emergency ☐ Cavitation ☐ P&A ☐ Multi-Well Fluid Management Low Chloride Drilling Fluid ☐ yes ☒ no

☒ Lined ☐ Unlined Liner type: Thickness 20 mil ☒ LLDPE ☐ HDPE ☐ PVC ☐ Other ____

☒ String-Reinforced

Liner Seams: ☒ Welded ☐ Factory ☐ Other ____ Volume: 23,307 bbl Dimensions: L 160 x W 170 x D 5-9 ft

3.

☐ **Below-grade tank**: Subsection I of 19.15.17.11 NMAC

Volume: ____bbl Type of fluid: ____

Tank Construction material: ____

☐ Secondary containment with leak detection ☐ Visible sidewalls, liner, 6-inch lift and automatic overflow shut-off

☐ Visible sidewalls and liner ☐ Visible sidewalls only ☐ Other ____

Liner type: Thickness ____mil ☐ HDPE ☐ PVC ☐ Other ____

4.

☐ **Alternative Method**:

Submittal of an exception request is required. Exceptions must be submitted to the Santa Fe Environmental Bureau office for consideration of approval.

5.

Fencing: Subsection D of 19.15.17.11 NMAC *(Applies to permanent pits, temporary pits, and below-grade tanks)*

☐ Chain link, six feet in height, two strands of barbed wire at top *(Required if located within 1000 feet of a permanent residence, school, hospital, institution or church)*

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

☐ Alternate. Please specify____

6.

Netting: Subsection E of 19.15.17.11 NMAC *(Applies to permanent pits and permanent open top tanks)*

☐ Screen ☐ Netting ☐ Other___________________________________

☐ Monthly inspections (If netting or screening is not physically feasible)

7.

Signs: Subsection C of 19.15.17.11 NMAC

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

☒ Signed in compliance with 19.15.16.8 NMAC

8.

Variances and Exceptions:

Justifications and/or demonstrations of equivalency are required. Please refer to 19.15.17 NMAC for guidance.

Please check a box if one or more of the following is requested, if not leave blank:

☐ Variance(s): Requests must be submitted to the appropriate division district for consideration of approval.

☐ Exception(s): Requests must be submitted to the Santa Fe Environmental Bureau office for consideration of approval.

9.

Siting Criteria (regarding permitting): 19.15.17.10 NMAC

***Instructions: The applicant must demonstrate compliance for each siting criteria below in the application. Recommendations of acceptable source material are provided below.* Siting criteria does not apply to drying pads or above-grade tanks.**

General siting

Ground water is less than 25 feet below the bottom of a low chloride temporary pit or below-grade tank. - ☒ NM Office of the State Engineer - iWATERS database search; ☒ USGS; ☒ Data obtained from nearby wells	☐ Yes ☒ No ☐ NA
Ground water is less than 50 feet below the bottom of a Temporary pit, permanent pit, or Multi-Well Fluid Management pit . NM Office of the State Engineer - iWATERS database search; USGS; Data obtained from nearby wells **See Figures 1 & 2**	☐ 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. **(Does not apply to below grade tanks) See Figure 5** - Written confirmation or verification from the municipality; Written approval obtained from the municipality	☐ Yes ☒ No
Within the area overlying a subsurface mine. **(Does not apply to below grade tanks) See Figure 7** - Written confirmation or verification or map from the NM EMNRD-Mining and Mineral Division	☐ Yes ☒ No
Within an unstable area. **(Does not apply to below grade tanks) See Figure 8** - Engineering measures incorporated into the design; NM Bureau of Geology & Mineral Resources; USGS; NM Geological Society; Topographic map	☐ Yes ☒ No
Within a 100-year floodplain. **(Does not apply to below grade tanks) See Figure 9** - FEMA map	☐ Yes ☒ No

Below Grade Tanks

Within 100 feet of a continuously flowing watercourse, significant watercourse, lake bed, sinkhole, wetland or playa lake (measured from the ordinary high-water mark). - Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☐ No
Within 200 horizontal feet of a spring or a fresh water well used for public or livestock consumption;. - NM Office of the State Engineer - iWATERS database search; Visual inspection (certification) of the proposed site	☐ Yes ☐ No

Temporary Pit using Low Chloride Drilling Fluid (maximum chloride content 15,000 mg/liter)

Within 100 feet of a continuously flowing watercourse, or any other significant watercourse or within 200 feet of any lakebed, sinkhole, or playa lake (measured from the ordinary high-water mark). (Applies to low chloride temporary pits.) - Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☐ No
Within 300 feet from a occupied 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 -	☐ Yes ☐ No
Within 200 horizontal feet of a spring or a private, domestic fresh water well used by less than five households for domestic or stock watering purposes, or 300feet of any other fresh water well or spring, in existence at the time of the initial application. NM Office of the State Engineer - iWATERS database search; Visual inspection (certification) of the proposed site	☐ Yes ☐ No

Within 100 feet of a wetland. - US Fish and Wildlife Wetland Identification map; Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☐ No
Temporary Pit Non-low chloride drilling fluid	
Within 300 feet of a continuously flowing watercourse, or any other significant watercourse, or within 200 feet of any lakebed, sinkhole, or playa lake (measured from the ordinary high-water mark). Topographic map; Visual inspection (certification) of the proposed site **See Figure 3**	☐ Yes ☒ No
Within 300 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. **See Figure 4**	☐ Yes ☒ No
Within 500 horizontal feet of a spring or a private, domestic fresh water well used by less than five households for domestic or stock watering purposes, or 1000 feet of any other fresh water well or spring, in the existence at the time of the initial application; - NM Office of the State Engineer - iWATERS database search; Visual inspection (certification) of the proposed site **See Figures 1 & 2**	☐ Yes ☒ No
Within 300 feet of a wetland. US Fish and Wildlife Wetland Identification map; Topographic map; Visual inspection (certification) of the proposed site **See Figure 6**	☐ Yes ☒ No
Permanent Pit or Multi-Well Fluid Management Pit	
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). - 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	☐ 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. - NM Office of the State Engineer - iWATERS database search; Visual inspection (certification) of the proposed site	☐ Yes ☐ No
Within 500 feet of a wetland. - US Fish and Wildlife Wetland Identification map; Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☐ No

10.
Temporary Pits, Emergency Pits, and Below-grade Tanks Permit Application Attachment Checklist: Subsection B of 19.15.17.9 NMAC
Instructions: Each of the following items must be attached to the application. Please indicate, by a check mark in the box, that the documents are attached.

☐ Hydrogeologic Report (Below-grade Tanks) - based upon the requirements of Paragraph (4) of Subsection B of 19.15.17.9 NMAC
☒ Hydrogeologic Data (Temporary and Emergency Pits) - based upon the requirements of Paragraph (2) of Subsection B of 19.15.17.9 NMAC
☒ Siting Criteria Compliance Demonstrations - based upon the appropriate requirements of 19.15.17.10 NMAC
☒ Design Plan - based upon the appropriate requirements of 19.15.17.11 NMAC
☒ Operating and Maintenance Plan - based upon the appropriate requirements of 19.15.17.12 NMAC
☒ Closure Plan (Please complete Boxes 14 through 18, if applicable) - based upon the appropriate requirements of Subsection C of 19.15.17.9 NMAC and 19.15.17.13 NMAC

☐ Previously Approved Design (attach copy of design) API Number: ______________________ or Permit Number: ________________________

11.
Multi-Well Fluid Management Pit Checklist: Subsection B of 19.15.17.9 NMAC
Instructions: Each of the following items must be attached to the application. Please indicate, by a check mark in the box, that the documents are attached.

☐ Design Plan - based upon the appropriate requirements of 19.15.17.11 NMAC
☐ Operating and Maintenance Plan - based upon the appropriate requirements of 19.15.17.12 NMAC
☐ A List of wells with approved application for permit to drill associated with the pit.
☐ Closure Plan (Please complete Boxes 14 through 18, if applicable) - based upon the appropriate requirements of Subsection C of 19.15.17.9 NMAC and 19.15.17.13 NMAC
☐ Hydrogeologic Data - based upon the requirements of Paragraph (4) of Subsection B of 19.15.17.9 NMAC
☐ Siting Criteria Compliance Demonstrations - based upon the appropriate requirements of 19.15.17.10 NMAC

☐ Previously Approved Design (attach copy of design) API Number: ______________________ or Permit Number: ________________________

12.

Permanent Pits Permit Application Checklist: Subsection B of 19.15.17.9 NMAC

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

- ☐ Hydrogeologic Report - based upon the requirements of Paragraph (1) of Subsection B of 19.15.17.9 NMAC
- ☐ Siting Criteria Compliance Demonstrations - based upon the appropriate requirements of 19.15.17.10 NMAC
- ☐ Climatological Factors Assessment
- ☐ Certified Engineering Design Plans - based upon the appropriate requirements of 19.15.17.11 NMAC
- ☐ Dike Protection and Structural Integrity Design - based upon the appropriate requirements of 19.15.17.11 NMAC
- ☐ Leak Detection Design - based upon the appropriate requirements of 19.15.17.11 NMAC
- ☐ Liner Specifications and Compatibility Assessment - based upon the appropriate requirements of 19.15.17.11 NMAC
- ☐ Quality Control/Quality Assurance Construction and Installation Plan
- ☐ Operating and Maintenance Plan - based upon the appropriate requirements of 19.15.17.12 NMAC
- ☐ Freeboard and Overtopping Prevention Plan - based upon the appropriate requirements of 19.15.17.11 NMAC
- ☐ Nuisance or Hazardous Odors, including H_2S, Prevention Plan
- ☐ Emergency Response Plan
- ☐ Oil Field Waste Stream Characterization
- ☐ Monitoring and Inspection Plan
- ☐ Erosion Control Plan
- ☐ Closure Plan - based upon the appropriate requirements of Subsection C of 19.15.17.9 NMAC and 19.15.17.13 NMAC

13.

Proposed Closure: 19.15.17.13 NMAC

Instructions: Please complete the applicable boxes, Boxes 14 through 18, in regards to the proposed closure plan.

Type: ☒ Drilling ☐ Workover ☐ Emergency ☐ Cavitation ☐ P&A ☐ Permanent Pit ☐ Below-grade Tank ☐ Multi-well Fluid Management Pit ☐ Alternative

Proposed Closure Method: ☐ Waste Excavation and Removal
☐ Waste Removal (Closed-loop systems only)
☒ On-site Closure Method (Only for temporary pits and closed-loop systems)
☐ In-place Burial ☒ On-site Trench Burial
☐ Alternative Closure Method

14.

Waste Excavation and Removal Closure Plan Checklist: (19.15.17.13 NMAC) ***Instructions: Each of the following items must be attached to the closure plan. Please indicate, by a check mark in the box, that the documents are attached.***

- ☐ Protocols and Procedures - based upon the appropriate requirements of 19.15.17.13 NMAC
- ☐ Confirmation Sampling Plan (if applicable) - based upon the appropriate requirements of Subsection C of 19.15.17.13 NMAC
- ☐ Disposal Facility Name and Permit Number (for liquids, drilling fluids and drill cuttings)
- ☐ Soil Backfill and Cover Design Specifications - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC
- ☐ Re-vegetation Plan - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC
- ☐ Site Reclamation Plan - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC

15.

Siting Criteria (regarding on-site closure methods only): 19.15.17.10 NMAC

Instructions: Each siting criteria requires a demonstration of compliance in the closure plan. Recommendations of acceptable source material are provided below. Requests regarding changes to certain siting criteria require justifications and/or demonstrations of equivalency. Please refer to 19.15.17.10 NMAC for guidance.

Ground water is less than 25 feet below the bottom of the buried waste. - NM Office of the State Engineer - iWATERS database search; USGS; Data obtained from nearby wells	☐ Yes ☒ No ☐ NA
Ground water is between 25-50 feet below the bottom of the buried waste - NM Office of the State Engineer - iWATERS database search; USGS; Data obtained from nearby wells	☐ Yes ☒ No ☐ NA
Ground water is more than 100 feet below the bottom of the buried waste. - NM Office of the State Engineer - iWATERS database search; USGS; Data obtained from nearby wells	☒ Yes ☐ No ☐ NA
Within 100 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). - Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☒ No
Within 300 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	☐ Yes ☒ No
Within 300 horizontal feet of a private, domestic fresh water well or spring used for domestic or stock watering purposes, in existence at the time of initial application. - NM Office of the State Engineer - iWATERS database; Visual inspection (certification) of the proposed site	☐ Yes ☒ No
Written confirmation or verification from the municipality; Written approval obtained from the municipality	☐ Yes ☒ No
Within 300 feet of a wetland. US Fish and Wildlife Wetland Identification map; Topographic map; Visual inspection (certification) of the proposed site	☐ Yes ☒ No
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	☐ Yes ☒ No
Within the area overlying a subsurface mine. - Written confirmation or verification or map from the NM EMNRD-Mining and Mineral Division	☐ Yes ☒ No
Within an unstable area. - Engineering measures incorporated into the design; NM Bureau of Geology & Mineral Resources; USGS; NM Geological Society; Topographic map	☐ Yes ☒ No
Within a 100-year floodplain. - FEMA map	☐ Yes ☒ No

16.
On-Site Closure Plan Checklist: (19.15.17.13 NMAC) ***Instructions: Each of the following items must be attached to the closure plan. Please indicate, by a check mark in the box, that the documents are attached.***

☒ Siting Criteria Compliance Demonstrations - based upon the appropriate requirements of 19.15.17.10 NMAC
☒ Proof of Surface Owner Notice - based upon the appropriate requirements of Subsection E of 19.15.17.13 NMAC
☒ Construction/Design Plan of Burial Trench (if applicable) based upon the appropriate requirements of Subsection K of 19.15.17.11 NMAC
☐ Construction/Design Plan of Temporary Pit (for in-place burial of a drying pad) - based upon the appropriate requirements of 19.15.17.11 NMAC
☒ Protocols and Procedures - based upon the appropriate requirements of 19.15.17.13 NMAC
☒ Confirmation Sampling Plan (if applicable) - based upon the appropriate requirements of 19.15.17.13 NMAC
☒ Waste Material Sampling Plan - based upon the appropriate requirements of 19.15.17.13 NMAC
☐ Disposal Facility Name and Permit Number (for liquids, drilling fluids and drill cuttings or in case on-site closure standards cannot be achieved)
☒ Soil Cover Design - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC
☒ Re-vegetation Plan - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC
☒ Site Reclamation Plan - based upon the appropriate requirements of Subsection H of 19.15.17.13 NMAC

17.
Operator Application Certification:

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

Name (Print): Bridget Helfrich Title: Regulatory Coordinator

Signature: Bridget Helfrich Date: February 17, 2015

e-mail address: bhelfrich@altamesa.net Telephone: (281) 943-1373

18.
OCD Approval: ☐ Permit Application (including closure plan) ☐ Closure Plan (only) ☐ OCD Conditions (see attachment)

OCD Representative Signature: ____________ **Approval Date:** 02/19/2015

Title: Hydrologist **OCD Permit Number:** P1-06542

19.
Closure Report (required within 60 days of closure completion): 19.15.17.13 NMAC
Instructions: Operators are required to obtain an approved closure plan prior to implementing any closure activities and submitting the closure report. The closure report is required to be submitted to the division within 60 days of the completion of the closure activities. Please do not complete this section of the form until an approved closure plan has been obtained and the closure activities have been completed.

☐ **Closure Completion Date:**____________

20.
Closure Method:
☐ Waste Excavation and Removal ☐ On-Site Closure Method ☐ Alternative Closure Method ☐ Waste Removal (Closed-loop systems only)
☐ If different from approved plan, please explain.

21.
Closure Report Attachment Checklist: ***Instructions: Each of the following items must be attached to the closure report. Please indicate, by a check mark in the box, that the documents are attached.***

☐ Proof of Closure Notice (surface owner and division)
☐ Proof of Deed Notice (required for on-site closure for private land only)
☐ Plot Plan (for on-site closures and temporary pits)
☐ Confirmation Sampling Analytical Results (if applicable)
☐ Waste Material Sampling Analytical Results (required for on-site closure)
☐ Disposal Facility Name and Permit Number
☐ Soil Backfilling and Cover Installation
☐ Re-vegetation Application Rates and Seeding Technique
☐ Site Reclamation (Photo Documentation)
On-site Closure Location: Latitude ____________ Longitude ____________ NAD: ☐1927 ☐ 1983

22.

Operator Closure Certification:

I hereby certify that the information and attachments submitted with this closure report is true, accurate and complete to the best of my knowledge and belief. I also certify that the closure complies with all applicable closure requirements and conditions specified in the approved closure plan.

Name (Print): ____ Title: ______________________________________

Signature:____ Date: ____________________________________

e-mail address:____ Telephone: ___________________________________

On SiteTrench Burial Closure Plan

The wastes in the temporary pit are destined for on-site Trench Burial at the drilling location or, if stated in the permit transmittal letter, a nearby site on the same lease.

The operator will not begin closure operations without approval of the closure plan submitted with the permit application.

Siting Criteria Compliance Demonstration
Compliance with siting criteria is described in the site-specific information appended to the C-144.

Proof of Surface Owner Notice
The application package was transmitted to the surface landowner and OCD via email.

Construction/Design Plan of Burial Trench
The design of the burial trench is shown in Plates 1.

In accordance with Burial Trench requirements (19.15.17.11 NMAC) the Trench will be constructed such that the bottom has a firm, unyielding base that is smooth and free of rocks, debris, sharp edges or irregularities to prevent the liner's rupture or tear.

The burial trench will be lined with a geomembrane cover made of 20-mil string reinforced LLDPE liner meeting NMOCD requirements.

1. Liner seams are minimized and oriented up and down and not across a slope
2. Factory welded seams are used where possible
3. Liner seams will be overlapped four to six inches, and the seams will be oriented parallel to the line of maximum slope, i.e., oriented along, not across, the slope, prior to any field seaming
4. The number of welded field seams will be minimized in comers and irregularly shaped areas
5. Only qualified personnel will be used to weld field seams
6. Excessive stress-strain on the liner will be minimized
7. Geotextile will be placed under the liner where needed to reduce localized stress-strain or protuberances that may otherwise compromise the liner's integrity
8. While materials are being place in the Burial Trench, the outer edges of the liner will be secured.

General Protocols and Procedures

- All free liquids from the pit will be recycled or disposed in a manner consistent with OCD Rules.
- The residual drilling mud and cuttings will be stabilized to a capacity sufficient to support the 4-foot thick soil cover.
- The residual pit solids will not be mixed at a ratio greater than 1 part pit solids to 3 parts dry earth material (e.g. subsoil).
- The burial trench will not be closed until the stabilized pit contents pass the paint filter liquids test.

The stabilized waste material within the burial trench will be shaped so that the upper surface is sloped.

The geomembrane cover is to be made of 20-mil string reinforced LLDPE liner or an equivalent cover approved by the district office that is composed of an impervious, synthetic material that is resistant to petroleum hydrocarbons, salts and acidic and alkaline solutions and complies with EPA SW-846 Method 9090A

During placement of the upper geomembrane cover, the operator or qualified contractor will fold the outer edges of the burial trench liner over the top of the stabilized material prior to installation of the geomenbrane cover.

Place the geomembrane cover over the sloping surface of the stabilized waste material in a manner so as to prevent infiltration of water and so that infiltrated water does not collect on the geomembrane cover after the upper soil cover has been placed..

Soil Cover Design

1. Over the sloping, stabilized material and liner, place the **<u>Soil Cover</u>** of:
   a. at least 3-feet of compacted, uncontaminated, non-waste containing earthen fill with chloride concentrations less than 600 mg/kg as analyzed by EPA Method 300.0.
   b. either the background thickness of topsoil or one foot of suitable material to establish vegetation at the site, whichever is greater, over the 3-foot earth material.
2. Contour the cover to
   a. blend with the surrounding topography
   b. prevent erosion of the cover and
   c. prevent ponding over the cover.

Confirmation Sampling Plan

Prior to closure of the temporary pit, a five-point (minimum) composite sample will be obtained from the temporary pit bottom to include any obvious stained or wet material or any material exhibiting other signs of contamination. The sample will be analyzed for the constituents in Table 1 of 19.15.17.13 NMAC (Ground water is more than 100 feet below the bottom of the Temporary Pit at the site).

Reclamation and Re-vegetation Plan

In addition to the area of the in-place burial, the operator will reclaim the surface to a safe and stable condition that blends with the surrounding undisturbed area including:

1. the pit location not used for burial
2. other areas associated with the in-place burial including access roads

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.

As stated above, the soil cover for burial in-place

- A. consists of a minimum of three feet of non-waste containing, uncontaminated, earthen material with chloride concentrations less than 600 mg/kg (or background concentration) as analyzed by EPA Method 300.0 placed over the liner and stabilized solids
- B. is capped by the background thickness of topsoil or 1-foot of suitable material to establish vegetation, whichever is greater
- C. blends into surrounding topography
- D. is graded to prevent ponding and to minimize erosion

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

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

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 surface grading work element of reclamation is complete.

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.

Closure Notice

The operator will notify the surface owner by certified mail, return receipt requested, that the operator plans closure operations at least 72 hours, but not more than one week, prior to any closure operation. The notice will include the well name, API number, and location.

After approval for in-place burial, the operator shall notify the district office verbally and in writing at least 72 hours but not more than one week before any closure operation. Notice will include the operator's name and the location of the temporary pit. The location will include unit letter, section number, township and range. If the location is associated with a well, then the well's name, number and API number will be included.

Should onsite burial be on private land, the operator will file a deed notice including exact location of the burial with the county clerk of the county where the onsite burial is located.

Closure Report

Within 60 days of closure completion, the operator will submit a

i. closure report on form C-144, with necessary attachments
ii. a certification that all information in the report and attachments is correct, that the operator has complied with all applicable closure requirements and conditions specified in the approved closure plan
iii. a plat of the pit location on form C-l05
iv. if burial is in a nearby trench/pit, a separate C-105 showing the exact location

Unless the permit transmittal letter requests an alternative marker to comply with surface landowner specifications, the operator will place at the center of an onsite burial a steel marker that

- is not less than four inches in diameter
- is placed at the bottom of a three-foot deep hole (minimum) that is filled with cement to secure the marker
- is at least four feet above mean ground level
- permanently displays the operator name, lease name, well number, unit letter, section, township and range in welded or stamped legible letters/numbers

Statement Explaining Why the Applicant Seeks a Variance

The prescriptive mandates of the Rule that are the subject of this variance request are the following subsections of 19.15.17

19.15.17.13 CLOSURE AND SITE RECLAMATION REQUIREMENTS:

D (7) If the concentration of any contaminant in the contents, after mixing with soil or non-waste material to a maximum ratio of 3:1, from a temporary pit or drying pad/tank associated with a closed-loop system is higher than constituent concentrations shown in Table II of 19.15.17.13 NMAC, then closure must proceed in accordance with Subsection C of 19.15.17.13 NMAC.

The residual solids in the drilling pit meet the Table II standards for chloride, benzene and total BTEX. The concentration of GRO is relatively low and is not materially different from concentrations observed in other drilling pits that meet the Table II standards after stabilization. While no MRO was detected, DRO is 29, 222 mg/kg. Thus, DRO+GRO is higher than the burial standard of 1,000 mg/kg. The TPH concentration using 8015 (GRO+DRO+MRO) is 35,128 mg/kg which also exceeds the burial standard.

The operator has expended resources and time in an effort to reduce the GRO+DRO+MRO concentration of the pit solids. This time and effort has been partially successful, but not sufficient to meet the closure criteria of Table II for GRO+DRO or TPH (8015 – GRO+DRO+MRO). Excavation and removal of the solids to the nearest surface waste management facility is technically possible and meets the prescription of the Rule. However, we contend that fresh water, public health and the environment are better served by allowing a higher burial standard for this pit via an approved variance.

Demonstration That the Variance Will Provide Equal or Better Protection of Fresh Water, Public Health and the Environment

The two lines of logic that support trench burial of the residual pit solids in accordance with all other mandates of the Rule (i.e. stabilized, relatively dry and beneath a liner and a 4-foot thick soil cover) are:

1. Over time (perhaps decades), natural attenuation processes will effectively reduce the residual petroleum hydrocarbons to below Table II standards.
2. When compared to excavation and removal, on-site burial provides a greater Net Environmental Benefit as described below.

Natural Attenuation Processes

The attached EPA Fact Sheet explains the natural attenuation processes that reduce the mass of buried hydrocarbons. There are numerous peer-reviewed reports that discuss the conditions that favor and inhibit natural attenuation of hydrocarbons. The EPA 2004 publication also provides a good summary (http://www.epa.gov/oust/pubs/tum_ch9.pdf). The rationale presented below draws upon EPA documents as well as other publications.

Sequestration of Hydrocarbons after On-site Burial under NM Pit Rule

At this site, the stabilized, relatively dry drilling waste will be buried more than 100 feet above groundwater and beneath a geotextile liner and a 4-foot soil cover as prescribed by the Pit Rule. These conditions effectively sequester the drilling solids for many decades, preventing hydrocarbon constituents from entering the soil horizon, the atmosphere or groundwater. Natural attenuation of hydrocarbons in the vadose zone over this exceptionally long sequestration timeframe is generally not investigated or discussed in publications.

To estimate the rate of downward moisture migration from the buried waste (beneath the 20-mil LLDPE cap and 4-foot soil cover as prescribed by the Pit Rule) to groundwater we used HYDRUS 1D. As explained in Attachment 1, a realistic, worst-case condition shows a measurable mass of soil moisture (chloride ions) penetrating the groundwater table 125 years after on-site closure of the pit. The center of mass of the downward migrating soil moisture enters groundwater in 205 years – according to the model. Thus, we conclude with a high degree of certainty that many decades occur between the time of solids burial to the time where soil moisture and entrained constituents from the buried waste will reach groundwater.

With respect to the upward migration of soil moisture (and entrained hydrocarbons) from the buried waste to the soil horizon, two mechanisms effectively eliminate this pathway for many decades (probably for many centuries):

- The placement of 20-mil LLDPE over the stabilized solids prevents the upward migration of moisture via capillary flow for the lifespan of the buried liner. Our communications with the Geosynthetic Institute suggest that a 20-mil LLDPE buried liner will hold integrity for about 80 years and then slowly degrade (oxidation/cracks/tears) over a period of about 200 years (a half-life of 100 years at 20 degrees C). This estimate is ½ of the lifespan of HDPE as reported in http://www.geosynthetic-institute.org/papers/paper6.pdf .
- Over the first 80 years after on-site closure, the soil moisture in the buried solids, which is higher than the surrounding vadose zone, will move downward due to gravity. Lateral movement in response to the pressure gradient between the buried solids and the vadose zone will also occur to some extent during this same 80-year period. Thus, the buried solids will dry over time as moisture flows downward (due to gravity and pressure) and laterally (due to pressure alone). When the liner cap begins to degrade around year 80, the soil moisture in the buried solids will be lower than the soil moisture immediately above the liner where the downward migration of infiltrated precipitation meets the impermeable boundary of the liner. Thus, when a fissure in the liner inevitably occurs, the moisture flux is from the soil above the liner toward the underlying, drier drilling solids (gravity flow and capillary flow). Upward wicking of chloride or hydrocarbons will not occur.

We conclude with a high degree of scientific certainty that the buried, stabilized drilling waste will not migrate upward and is isolated from the soil horizon.

Upward migration of hydrocarbon vapors is a concern where volatile hydrocarbon constituents exist. At the location, the concentration of BTEX is very low as is the concentration of GRO. Given the nature of the buried material, the upper liner and the circuitous route such vapors must travel from the buried waste to the surface, we conclude with a high degree of certainty that harmful vapor will not migrate to the surface to any degree that would endanger public health or the environment.

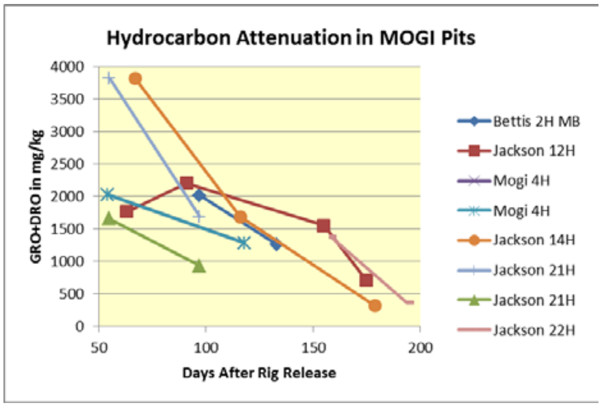
Natural Attenuation of GRO+DRO+MRO in Drilling Pits

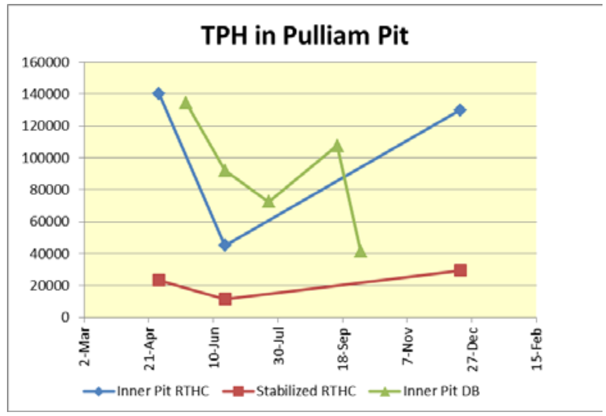
The reduction of hydrocarbon concentration/mass over time is documented in numerous published reports and is consistent with the Second Law of Thermodynamics (entropy). In all of the available publications we examined, the experimental or observational timeframe was days or several years – not decades. Natural degradation rates observed for diesel or crude in soil, including clay soil, range from a 30% reduction in mass/concentration after 10-30 days to 50% after two years[1]. However, these degradation rates were observed in unsaturated soil directly exposed to the atmosphere, not conditions similar to saturated residual drilling solids in a drilling pit or conditions after on-site burial pursuant to the Pit Rule.

In drilling pits, we observe degradation of petroleum hydrocarbons, which is consistent with Thermodynamics and published reports. The charts below show a rate of natural attenuation in drilling pits with relatively low GRO+DRO (Murchison Oil and Gas, Inc. pits) is about 50% in 50 days.

---

[1] See www.ajol.info/index.php/ajb/article/download/97267/8658,
http://nepis.epa.gov/Exe/ZyPDF.cgi/30002379.PDF?Dockey=30002379.PDF,
http://www.epa.gov/oust/pubs/tum_ch9.pdf,





In the Pulliam Pit in northern Curry County, the samples taken by Don Board (MicroBlaze® Representative) from the inner pit show a natural attenuation rate of about 70% in 135 days. The samples collected by RT Hicks Consultants do not display the same relationship. The data from the three RT Hicks Consultants sampling events do not suggest that GRO+DRO is being created in the pit, rather we can conclude with certainty that the RTHC data is consistent with the problems associated with sampling highly heterogeneous media, as observed at other locations and explained by previous submissions and discussions with NMOCD As suggested above, the complexity of sampling heterogeneous solids did not create a problem for the Murchison pits.

Natural Attenuation of GRO+DRO+MRO During and After Pit Closure
During the 7-14 days of the closure process, stabilization with dry earth material and evaporation of entrained fluid will expose the pore spaces and surfaces of the drilling solids to the atmosphere and oxygen. Hydrocarbon vapors will be released during material mixing of the closure process. After burial, soil moisture drainage (unsaturated flow) will open more pore space in the stabilized material. Molecular diffusion and barometric pumping (exchange of soil gas with the atmosphere) will allow some oxygen to be available to the buried drilling solids and a small mass of hydrocarbon vapors may escape (to the atmosphere and adjacent vadose zone). Thus, the conditions for continued removal of hydrocarbons from the stabilized solids are present after burial. However, the rate of hydrocarbon degradation after burial is expected to be much slower than measured values in drilling pits or values reported in the literature for surface piles and tilled soil.

For lower concentration materials, we can assume a conservative biodegradation rate of 50%/year after burial. Thus, the buried drilling solids of the Pulliam Farms 27-P will meet Table II standards in 2020.

Net Environmental Benefit Analysis

The attached document describes the NEBA process as it applies to this site. Below is a brief summary of the findings.

The alternatives considered for a semi-quantitative Net Environmental Benefit Analysis (NEBA) are

A. Dig and haul all drilling solids to a surface waste management facility pursuant to the Pit Rule.
B. In-place burial under an approved variance
C. Trench burial under an approved variance
D. More aggressive surface treatment/landfarming to meet the GRO+DRO burial standards of the Pit Rule with an approved variance followed by on-site burial

The matrix presented below presents the rankings for each alternative considered. Although the total score of Remedy B is about 40% better (lower) than Remedy A, the reader should not interpret this result as suggesting that the remedy provides a 40% greater net environmental benefit. Rather, the more correct interpretation of the results in the matrix are:

- Remedy B provides the highest benefit
- Remedies C and D provide less benefit (the differences are 12% and 26%)
- Remedy A provides the least environmental benefit

	Multiplication Factor - Site Conditions	**Multiplication Factor - Stakeholders**	Remedy A Dig-Haul-Dispose		Remedy B In-Place Closure		Remedy C Trench Burial		Remedy D Surface Treatment	
			Score	Weighted Value	Score	Weighted Value	Score	Weighted Value	Score	Weighted Value
Environmental										
Ground Water	1	3	2	6	2	6	2	6	1	3
Surface Water	0	2		0		0		0		0
Air Quality										
Dust generation	1	1	2	2	1	1	1	1	2	2
Exhaust generation	1	2	2	4	1	2	1	2	2	4
Off gassing	1	1	1	1	1	1	1	1	1	1
Habitat > 5 years										
Restore Vegetation/Forage	3	2	1	6	1	6	1	6	1	6
Restore Original Landforms	1	2	1	2	1	2	1	2	1	2
Dry Land Farming	2	2	1	4	2	8	2	8	1	4
Wildlife	1	2	1	2	1	2	1	2	1	2
Impact on Resources										
Development for Residence	1	1	1	1	2	2	2	2	1	1
Water	3	2	2	12	1	6	1	6	2	12
Cost	1	2	3	6	1	2	2	4	3	6
Human Safety	1	3	4	12	1	3	2	6	3	9
Total Score				**58**		**41**		**46**		**52**

The reader should keep in mind that the attached document is in DRAFT form as final scoring must be subject to consensus between the stakeholders.

Because transport of drilling solids from the site to a landfill only transfers a potential problem from one locality to another, consideration of the environmental factors at the landfill site are appropriate for this benefit analysis.

Ground Water Scoring

Data demonstrate that ground water is present at the site at a depth exceeding 100 feet beneath the pit (see C-144 application). We assigned a factor of 1 to the groundwater scoring matrix due to the documented water table aquifer. We also assigned a stakeholder scoring factor of 3, as groundwater in southeast New Mexico is a highly important commodity.

At many landfill sites, groundwater is also present. While some landfills are lined (e.g. Gandy-Marley), some are not (e.g. R360). Lined or unlined, the large scale of commercial operations and the history of landfills creating groundwater impairment a site multiplication factor of 2 could be used. Because the drilling pit solids from this well represent a very small portion of the material in a landfill, a more appropriate multiplication factor is 1.

Remedies A, B and C received the same rank/score of 1 and a weighted score of 6 because all of the remedies pose the same threat to groundwater quality. Remedy D causes the drilling solids to meet the in-place burial criteria and results in a better ranking: a weighted score of 3.

Surface Water

A surface water body (a playa or an arroyo that may hold water for several days) is not present near the pit (see permit application). This condition creates a multiplication factor for surface water of zero for both the site and stakeholders. At the landfill, we assume that the permit calls for control of runoff from any large, elevated pile. Therefore, this location also receives a site multiplication score of zero. We conclude that the probability of impact to surface water is essentially nil, and this factor does not contribute to ranking of alternatives.

Air Quality

Dust generation

Our evaluation suggests that the footprint of the drilling pit covers less than one acre. Under Remedy A (dig-haul-dispose), we estimate that negligible dust generation would occur due to the excavation. However the transport of about 50 trucks over about 1-mile of dirt road between the landfill and the site would generate some dust. Dust is also generated at the landfill site and during tilling of the solids removed from the pit under Remedy D. We assigned a score of 2 for Remedies A and D. Remedies B and C would generate less dust and received a score of 1.

We believe that dust generated by any remedy will not be significant relative to the dust generated by other oilfield activity in the area, therefore we assigned a site multiplication value of 1 for dust generation. Dust is an annoyance to stakeholders, but something that we live with in the southwest; thus the assigned stakeholder multiplication factor is 1.

Exhaust Generation

The 200 plus-mile round-trip haul distance to a landfill creates a relatively large exhaust impact to Remedy A so we assigned it a score of 2. The periodic transport of machinery to till excavated solids and the act of tilling also generates exhaust, thus Remedy D also received a score of 2. Remedies B and C require only one mobilization to the site to bury the solids and received a score of 1. Because all remedies require movement of the cuttings (to trucks, to the surface or stabilization for burial, only the transport element adds exhaust.

From a stakeholder perspective, air pollution and generation of greenhouse gas appears more important than dust generation at this site; creating a stakeholder multiplication factor of 2. The site multiplication factor is 1 for many of the same reasons discussed above for dust generation.

Off-gassing of Hydrocarbons

We considered the off gassing of hydrocarbons generated by each remedy. In our opinion, tilling (Remedy D), stabilization (Remedies B and C), and loading/offloading and spreading (Remedy A) probably create the same release of gas. Therefore we assigned the same score to all remedies.

While off-gassing may be important to stakeholders (a multiplication score of 2), the typical wind combined with off gassing from all of the other E&P activity cause a site multiplication factor of 1 (not very important).

Habitat Restoration

Restore Native Vegetation/Forage

Over the long-term, reducing the disturbance footprint and transforming the area to natural vegetation (habitat and forage) is important and received a site multiplication factor of 3. With respect to the stakeholder importance, we assigned this criteria a multiplication factor of 3 – we believe all stakeholders desire restoration of the site to as close as practical to the pre-disturbance condition.

Based upon previous experience with pit closures (in-place and trench burial), we are confident that restoration of grasses will occur within 5 years. Therefore, Remedies B and D received a ranking of 1. Under Remedy C, the nature of trench burial can cause saline fluids to accumulate on the bottom liner. This perched brackish water could rise via capillary action into the root zone. Although the probability of this occurring is extremely small, Remedy C received a rank of 2. Remedy A also received a score of 1, as we assume that reclamation of a landfill to include the growth of native grasses over the final surface of the pile.

Restore Original Landforms
Although the volume of pit solids transported to a landfill is very small relative to the size of a landfill (e.g. R360), we assigned a rank of 2 to Remedy A. The original landform in this area will not be restored.

Our experience with pit closures demonstrates that the final grade after solids burial will conform with the nearby landforms. Therefore, Remedies B, C and D received the same score of 1.

Dry Land Farming
At the Pulliam site, dry land farming occurred in the past and may be a consideration in the future to the surface landowner. Therefore, we assigned a site and stakeholder multiplication factor 2.

Removal of the solids to a landfill removes any restriction to farming, resulting in a score of 1. Treatment of the drilling solids followed by on-site burial (without a liner cap via a variance) could result in a ranking of 1. Because such a variance is not in place, Remedy D received a ranking of 2, as did Remedies B and C. The existence of a liner at a depth of 4 feet could create some limitations for dry land farming.

Wildlife
The small area of the pit is not a critical habitat for wildlife and restoration of this small area will have little impact on wildlife. We assigned a site multiplication factor of 1 and a stakeholder multiplication factor of 2. By assuming that all remedies will succeed, all of the remedies are ranked equal 1 for the protection of wildlife, all receive a weighted value of 2.

Human Safety

All remedies require on-site earthwork and some vehicular transport. The safety threat posed by transport is greater than on-site earthwork as this element can involve the public. Remedy A requires the greatest amount of vehicular transport (waste to the landfill) and we assigned it a score of 3. Remedies B and C require only one mobilization and both received a score of 1. Due to the need for multiple mobilizations to the site for tilling, the score/rank for Remedy D is 2

Human safety should be the most important stakeholder factor; a multiplication factor of 3 is assigned. Because nearly all transportation is on two-lane roads, the site multiplication factor is 2.

Impact on Resources

Water

Remedies A and D will use more water than Remedies B and C. The landfill presumably uses water for dust control (although they may use produced water) and on-site treatment of the solids to enhance natural microbial action also requires some water. Therefore Remedies B and C were ranked as 1 and Remedies A and D were assigned a rank of 2.

Because the water use for Remedies A and D are not large, we used a value of 2 for both multiplication factors.

Cost
Cost is the only consideration where the ranking of alternatives is clear. Remedy A is more expensive than Remedy D. Remedy B is the least expensive and Remedy C is probably $10,000 more than Remedy B. The alternatives were ranked according to their respective costs.

Regardless of the selected alternative, cost will be incurred by the operator. So the site multiplication factor is 1. Cost is an important consideration for the operator and is less important to other stakeholders, resulting in a multiplication factor of 2.

United States Environmental Protection Agency
Office of Research and Development Washington, DC 20460
National Risk Management Research Laboratory Ada, OK 74820
EPA/600/F-98/022 May 1999

Monitored Natural Attenuation of Chlorinated Solvents

U.S. EPA REMEDIAL TECHNOLOGY FACT SHEET

Scope of this fact sheet:

This fact sheet explains what "monitored natural attenuation" means when the term is used to describe a potential strategy to remediate a contaminated site. It also describes the various physical, chemical and biological processes of natural attenuation that may occur at a site. This fact sheet is written for an audience with little or no scientific background and is meant to aid Federal, State, and local regulators in educating the public on complex environmental issues. Other informational materials are in preparation and will provide more specific details and scientific depth for the evaluation of monitored natural attenuation as a remedy at specific sites.

What Is Monitored Natural Attenuation?

The term "monitored natural attenuation," as used by the EPA, refers to the reliance on natural processes to achieve site-specific remedial objectives. Where found to be a viable remedy, monitored natural attenuation may be used within the context of a carefully controlled and monitored site cleanup approach. To be considered an acceptable alternative, monitored natural attenuation would be expected to achieve site remedial objectives within a time frame that is reasonable compared to that offered by other more active methods. Monitored natural attenuation is always used in combination with "source control;" that is, removal of the source of the contamination as far as practicable.

Natural attenuation processes include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or ground water. These processes include biodegradation; dispersion; dilution; sorption; volatilization; and chemical or biological stabilization, transformation, or destruction of contaminants.

Spills and leaks of chlorinated solvents such as perchlorethylene (PCE), trichloroethylene (TCE) and trichloroethane (TCA) have caused widespread contamination in the environment. Generally these contaminants are present both in NAPL form (non-aqueous phase liquid; the bulk liquid chlorinated solvent) and also as dissolved contaminants in the ground water. Cleanup of both the NAPL and dissolved contamination in soils and ground water using many common remedial techniques is often expensive and slow. However, under the proper conditions at some sites, natural attenuation can contribute significantly to remediation of dissolved chlorinated solvent contamination and may accomplish site remediation goals at a lower cost than conventional remediation technologies, within a similar time frame. Natural attenuation is not expected to remediate NAPL.

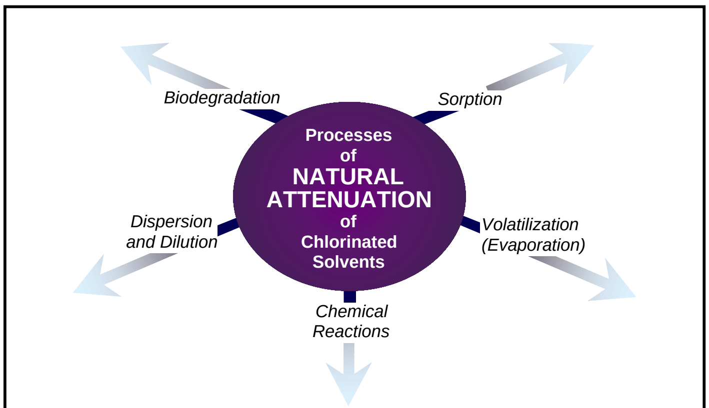


Figure 1. Processes of natural attenuation of chlorinated solvents.

How Does Natural Attenuation Work?

Biodegradation

One of the most important components of natural attenuation is biodegradation—the change in form of compounds carried out by living creatures such as microorganisms. Under the right conditions, microorganisms can cause or assist chemical reactions that change the form of the contaminants so that little or no health risk remains. Biodegradation is important because many chlorinated solvents can be destroyed by biodegradation, microorganisms that are capable of biodegrading contaminants are found almost everywhere, and biodegradation can be very safe and effective. However, most chlorinated solvents biodegrade only under very specific conditions, which are not present at all sites.

Microorganisms are most effective at degrading low to moderate concentrations of contaminants. High concentrations and very low concentrations of contaminants may not be biodegradable. Contaminants in the NAPL phase are not effectively degraded by microorganisms.

As chlorinated solvents biodegrade, the products of the degradation process may or may not be less harmful than the original contaminants. Sometimes chlorinated solvents may degrade to form more toxic compounds, and these toxic compounds may accumulate under certain conditions. Also, under some conditions, the microbial activity involved in degrading the contaminants could cause mobilization of certain materials such as manganese or arsenic which could cause environmental problems. Monitoring for these potential problems is necessary.

Sorption

The soil and sediment particles (sand, silt, clay, organic matter) through which the ground water and dissolved contaminants move can sorb the contaminant molecules onto the particle surfaces, and hold bulk liquids in the pores in and between the particles, thereby slowing or stopping the movement of the contaminants. This process can reduce the likelihood that the contaminants will reach a location (such as a drinking water well or stream) where they would directly affect human or environmental health.

Dispersion and Dilution

As the dissolved contaminants move farther away from the source area, the contaminants are dispersed and diluted to lower and lower concentrations over time. Eventually the contaminant concentrations may be reduced so low that the risk to human and environmental health will be minimal.

Chemical Reactions

Some chlorinated solvents such as TCA can undergo significant degradation by chemical reactions without microbial activity. However, most chlorinated solvents are not significantly degraded by chemical reactions in soil or ground water, though exposure to sunlight can break down many chlorinated solvents. Exposure to sunlight is significant only for chlorinated solvent vapors in the air, or possibly dissolved solvents in surface water or on the soil surface.

Volatilization (Evaporation)

Chlorinated solvents are volatile and readily evaporate into the atmosphere, where air currents disperse the contaminants, reducing the concentration. Also, the solvent vapors may be quickly broken down by sunlight. Vapors in contact with soil microorganisms may be biodegraded. Volatilization from NAPL or ground water to soil gas may be an important exposure pathway in a risk analysis.

Importance of Natural Attenuation Processes

The processes involved in natural attenuation are operating at all contaminated sites, but the contribution of natural attenuation to achieving remediation goals varies in different situations. At some sites natural attenuation may meet all the remedial goals, and at other sites natural attenuation may make little or no contribution. Therefore, before natural attenuation can be selected as a remedial alternative, it is necessary to study each contaminated site carefully to determine how effective natural attenuation is for attaining site remediation goals.

Bulk chlorinated solvents – in the NAPL form, rather than dissolved in water or sorbed on soil particles – are not readily degraded by microorganisms. Also, dispersion, dilution and sorption of the NAPL is slow. Therefore, it is important to determine where this NAPL may be at a polluted site, in order to remove or contain as much of it as possible, because the processes of natural attenuation would not effectively remediate most of this material in a reasonable time

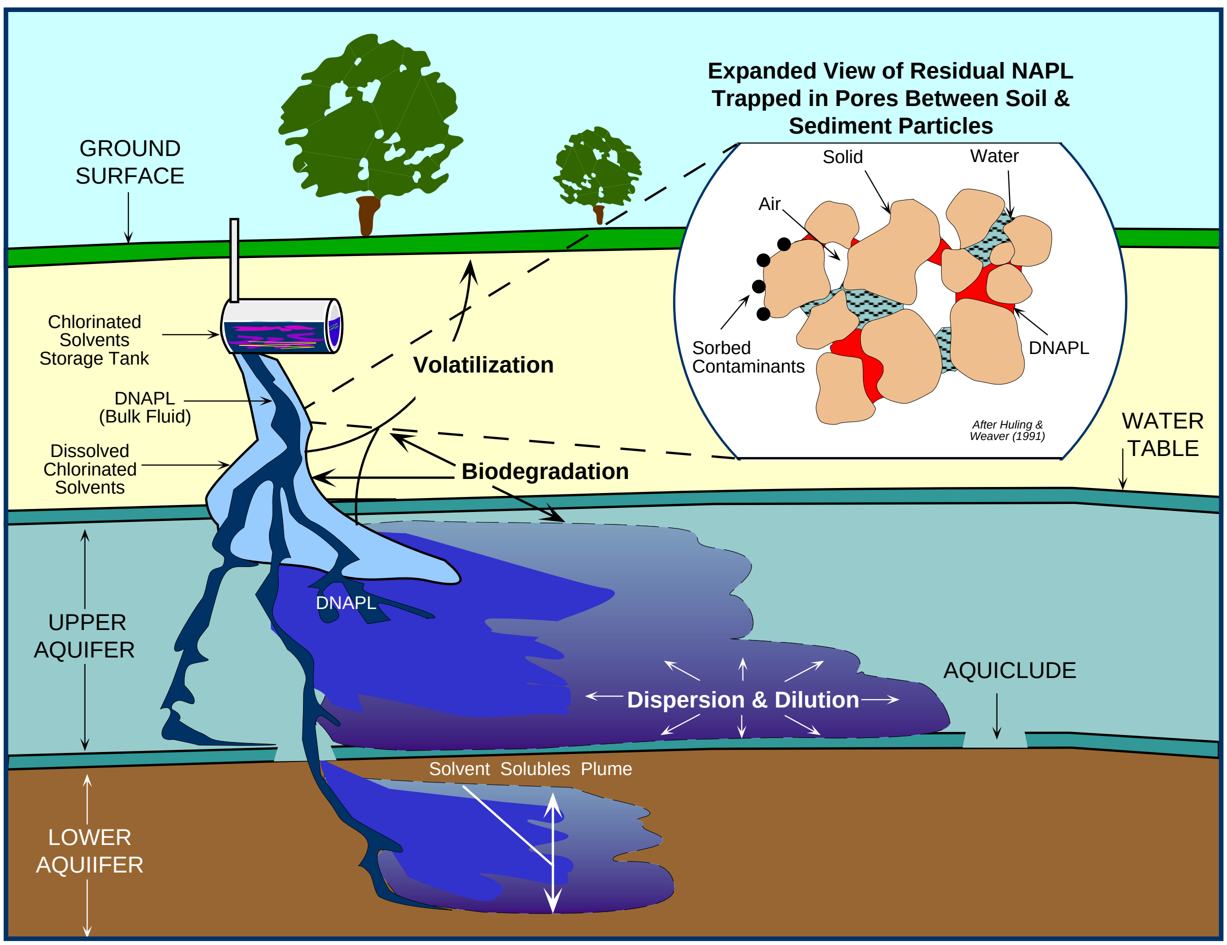


Figure 2. **As the bulk chlorinated solvent moves through the subsurface, some of the liquid may be trapped in the soil or sediment pores (residual saturation); some may evaporate (volatilization); some may become sorbed to the surface of the soil particles (sorption) and some may dissolve in the ground water (dissolved plume). Since bulk chlorinated solvents are more dense than water, the liquid tends to move down below the water table. As the dissolved plume moves, the concentration of the dissolved solvents is lowered by dispersion and dilution effects. Microorganisms may degrade hydrocarbons that are dissolved, volatilized or sorbed.**

frame. Natural attenuation processes are usually of most significance for the remediation of those contaminants dissolved in water, sorbed on soil particles, or in the vapor form.

How Is Natural Attenuation Evaluated?

In order to decide what contribution natural attenuation can make to meeting site remediation goals, very detailed site investigations must be carried out. Generally, the investment in site characterization for determining the applicability of natural attenuation is at least as expensive and time consuming, if not more so, than for any other site remediation technology. However, the long-term costs for natural attenuation (if natural attenuation is able to achieve most of the site remediation goals) may be less than for other remedial technologies.

In order to properly evaluate natural attenuation at a site, it is necessary to know the location and concentration of the contaminants, and how the contaminants move in the environment. Since contaminants commonly move dissolved in water, the movement of ground water at the site must be carefully investigated to determine how the water moves, when it moves and where it moves. The subsurface is often very complex in terms of water movement pathways, and determination of these pathways can be expensive.

Also, evaluation of natural attenuation processes may require a detailed understanding of the site geochemistry, especially where biodegradation processes are involved. The compounds that may be associated with microbial activity, such as oxygen, carbon dioxide, nitrate, sulfate, iron, etc., should be measured in order to gain understanding of what processes the microorganisms are using, how fast these processes are occurring, and what the results of these processes are likely to be. Biodegradation of many chlorinated solvents takes place under very specific conditions, which may not be present at many sites.

Evaluation of natural attenuation usually involves not only the determination of what processes of natural attenuation are occurring, but also the estimation of what the results of these processes will be in the future. Therefore, use of natural attenuation as part of the site remedial plan will necessarily require that a long-term monitoring plan be instituted. The monitoring plan should provide information to allow regulators to decide if natural attenuation is meeting site objectives, and to verify that there are no changes in conditions affecting natural attenuation. A detection system for early warning of impacts on sensitive receptors, such as drinking water wells, streams and wetlands should be provided. Also, plans must be developed for contingency remedial efforts that can be implemented if natural attenuation processes do not fulfill expectations.

Summary

Natural attenuation processes occur to varying degrees in all chlorinated solvent contamination sites, and may contribute significantly to site remedial goals. Biodegradation processes can be particularly important for natural attenuation of some chlorinated solvents, under specific environmental conditions. Chlorinated solvents dissolved in water, sorbed on soil particles or in vapor form are the most readily subject to natural attenuation processes, but bulk chlorinated solvents (NAPLs) are not readily subject to natural attenuation in the short term. The significance of natural attenuation processes at a given site for achieving site remedial goals must be carefully evaluated, and extensive site characterization and monitoring is usually necessary.

Additional Information:

U.S. EPA. *A Citizen's Guide to Natural Attenuation.* EPA 542-F-96-015. October 1996. http://www.epa.gov/swertio1/download/remed/citguide/natural.html.

U.S. EPA. *Commonly Asked Questions Regarding the Use of Natural Attenuation for Chlorinated Solvent Spills at Federal Facilities.* http://www.epa.gov/swerffrr/chlorine.htm (20 May 1999).

U.S. EPA. *Proceedings of the Symposium on Natural Attenuation of Chlorinated Organics in Ground Water.* EPA/540/R-97/504. May 1997. http://www.epa.gov:80/ordntrnt/ORD/WebPubs/natural/natural.pdf.

U.S. EPA. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water.* EPA/600/R-98/128. September 1998. http://www.epa.gov/ada/reports.html.

U.S. EPA. *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites.* OSWER Directive 9200.4-17P, April 21, 1999. http://www.epa.gov:80/ordntrnt/ORD/WebPubs/biorem/D9200417.pdf.

For more information, contact:

Jerry N. Jones or John T. Wilson
R.S. Kerr Environmental Research Center
Subsurface Protection and Remediation Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

Authors:

Daniel F. Pope, Dynamac Corporation
Jerry N. Jones, RSKERC/SPRD/NRMRL/ORD

To simulate the possible effects on ground water chloride concentration from the buried material in the Pulliam Farms P-27, the gravity-driven vertical water flow through the vadose zone is simulated using HYDRUS-1D. The resultant chloride flux to ground water is used as input to a simple ground water mixing model. The output of the mixing model is a predicted chloride concentration in ground water at the down gradient edge of the affected area as would be observed in a monitoring well at this location.

HYDRUS-1D numerically solves the Richard's equation for water flow and the Fickian-based advection-dispersion equation for heat and solute transportation. The HYDRUS-1D flow equation includes a sink term (a term used to specify water leaving the system) to account for transpiration by plants. The solute transport equation considers advective, dispersive transport in the liquid phase, diffusion in the gaseous phase, nonlinear and non-equilibrium sorption, linear equilibrium reactions between the liquid and gaseous phases, zero-order production, and first-order degradation.

The ground water mixing model uses the chloride flux from the vadose zone to ground water provided by HYDRUS-1D and instantaneously mixes this chloride and water with the ground water flux of chloride plus water that enters the mixing cell beneath the subject site. We refer the reader to API Publication 4734, Modeling Study of Produced Water Release Scenarios (Hendrickx and others, 2005) for a general description of the techniques employed for this simulation experiment.

To model the implementation of the closure method, a number of steps are necessary.

- First, the soil profile has to be constructed and an initial soil moisture condition calculated (see below in Hydrus Inputs section).

- Pit closure activities result in there being an impermeable liner placed four-feet below ground surface. This upper four feet of soil consists of a clean fill material (assumed as loam at the surface and loamy sand beneath the surface material). For this model, we have assumed that the liner is impermeable for 50 years and degrades completely over the following 125 years. To model this situation, the soil profile is separated into two models while the liner still exists.

- The upper four-foot soil profile is run for two time intervals to simulate the intact liner (50 years) and then to simulate the degrading liner (an additional 125 years). These two intervals are modeled by using different lower boundary conditions.

- For the first 50-years (an intact liner), the lower boundary condition allows drainage when saturation has occurred above the liner. The moisture is in effect removed from the system. This is equivalent to the moisture draining off to the side of the liner and moving downwards outside the burial pit footprint. Vegetation was also assumed to exist in the soil profile above the liner.

- For the next 125 year time period, the upper four feet of soil were modeled to represent the time period in which the liner degrades by changing the lower boundary condition. It is changed to that of a "free drainage boundary condition", i.e. a cell below the boundary cell is assumed to have the same flux as the cell on the boundary. This output was stored and then modified and used as the input to the buried cuttings and the lower soil. The nature of the modification was to take the lower boundary condition output and assume that the liner begins linearly degrading at 50 years plus one day and is completely gone at Time =175 years (a 125 year degradation period). Hence, at 50 years plus one day, moisture begins to infiltrate into the lower soil profile in a very tiny amount (calculated from the upper four-foot soil profile lower boundary condition). At 62.5 years, the moisture flux to the lower soil profile is half of the upper soil profile boundary condition output (50% liner degradation); and at 125 years, all of the moisture flux from the upper four foot soil profile enters the lower soil profile (100% liner degradation)

- The soil profile beneath the liner is constructed of four feet of cuttings (saturated sandy clay). This material was placed on top of the original soil profile minus its upper-eight feet. It is assumed that in the closure process, the drilling pit liner was functionally destroyed. To the extent that parts of the drilling pit liner remain intact, the model exaggerates impacts to ground water.

- This lower soil profile was run for 50 years with a no-flow upper boundary condition to represent the intact burial liner installed at closure. It was then run for an additional 125 years using the modified output from the upper four-foot soil profile to simulate the degrading liner. As a note, for this 125 year time interval, no evapotranspiration was allowed to simulate conditions four-feet below ground surface.

- After the 175 year time period, the soil profiles were rejoined and run as one model now that the liner no longer existed.

A description of the model input parameters are listed below and are synopsized in Table 2.

HYDRUS 1-D INPUTS

Soil Profile - The HYDRUS 1-D soil profile was chosen to be conservative of ground water quality by choice of materials having hydraulic conductivities greater than or equal to those observed from nearby borings logged by R.T. Hicks Consultants.

Dispersion lengths - Standard practice calls for employing a dispersion length that is 10% of the model length and was used in this simulation.

Climate – Weather data used in calculation of the initial condition and the predictive modeling was from the Pearl, New Mexico weather station, about 120 miles south of the area. This station is the closest station to the area for which the necessary HYDRUS-1D input file exists. Climate on the eastern plains of New Mexico is similar enough that this was considered an acceptable choice. The weather data spans the 46. 5 year period from July, 1946 to December, 1992,

HYDRUS-1D can also employ a uniform yearly infiltration rate that will obviously smooth the temporal variations. Because the atmospheric data are of high quality, we have elected to allow HYDRUS-1D to predict the deep percolation rate and the resultant variable flux to ground water. This choice results in higher predicted peak chloride concentrations in ground water due to temporally variable high fluxes from the vadose zone than would be predicted by an averaged infiltration rate. As such, this choice is conservative of ground water quality.

Soil Moisture - Because soils are relatively dry in this climate and vadose zone hydraulic conductivity varies with moisture content, it is important that simulations are started with representative soil moisture content. Commonly, the calculation of soil moisture content begins with using professional judgment as an initial input and then running sufficient years of weather data through the model to establish a "steady state" moisture content.

For this simulation, a number of initial conditions were calculated. First, a soil profile from the ground to the water table was given 46.5 years (1 cycle) of the weather data. This was considered sufficient to establish an initial moisture condition as no large changes in soil moisture content were observed after about 12.5 years. Portions of this vadose zone moisture content profile were used as the initial condition for subsequent simulations as appropriate.

Initial Chloride Profile – Within the vadose zone soil profile, the mass of chloride was simulated by placement of a four-foot thick layer of sandy clay placed 4 feet below ground level. This layer was modeled as having an average soil moisture content of saturation (0.38) with a chloride concentration of 10,000 mg/L. Because chloride is a conservative tracer (i.e. this ion neither mineralizes, volatilizes nor degrades over time), the chloride concentration within the modeling can be multiplied by a scaling factor to simulate other concentrations. Calculation of this scaling factor is discussed below.

At this site, the December 18 composite soil samples had an averaged chloride concentration of 21,200 mg/kg. This material mixed with clean fill at a ratio of 1:3 has a concentration of 5,509 mg/kg. We assume that the cuttings were saturated (0.38 moisture content) and that the clean fill dirt was relatively dry (0.10 moisture content). As such the stabilized cuttings have an average volumetric moisture content of 0.17. Calculation of the soil moisture chloride concentration (using a dry bulk density of 1500 kg/m^3) yields 55,590 mg/L.

Keeping in mind that the cuttings are assumed as saturated in the model, a chloride mass equal to that in the stabilized cuttings has to be installed in the model. Calculation of this chloride mass for the one dimensional model also requires an average depth of stabilized cuttings. From discussion with the contractor and pit dimensions, we take this dimension as 4.5-feet. The chloride mass within the stabilized cuttings is given by:

Chl Mass = cuttings thickness * thickness proportion that is water * Chl conc. of water
= 4.5 feet * 0.17 * 55,590 mg/L
= 42,526 feet-mg/L

We require that:

Chl Mass in Model = Chl Mass Stabilized Cuttings
Height_model * moisture content * C = 42,526 feet- mg/L
4 feet*0.38 * C = 42,526 feet-mg/L
C = 27,978 mg/L

As mentioned above, the model is constructed with a concentration of 10,000 mg/L. The model's output was scaled by a factor of 2.8 to yield an equivalent mass to that contained within the stabilized cuttings. Within the model, the cuttings are assumed as saturated. The additional moisture results in a higher hydraulic conductivity for this section of the soil profile. As such, this assumption is conservative of ground water quality.

MIXING MODEL INPUTS

As described in API Publication 4734, the ground water mixing model takes the background chloride concentration in ground water multiplied by the ground water flux to calculate the total mass of ground water chloride entering the ground water mixing cell, which lies below the area of interest. The chloride and water flux from HYDRUS-1D is added to the ground water chloride mass and flux to create a final chloride concentration in ground water at an imaginary monitoring well located at the down gradient edge of the mixing cell (the edge of the burial site).

Influence Distance - The influence distance is defined as the maximal length of the release parallel to groundwater flow direction. To be conservative of ground water quality, we used the maximum diameter of the pits, 220 feet was parallel to ground water flow.

Background Chloride Concentration – A 75.0 mg/L chloride concentration was used as the concentration of chloride in ground water based on common conditions in SE New Mexico.

Hydraulic Conductivity - R.T. Hicks Consultants believes that the hydraulic conductivity of the saturated zone at the release site is similar to that observed for the Ogallala Aquifer elsewhere in southeastern New Mexico. McAda (1984) simulated water level declines using a two-dimensional digital model and employed hydraulic conductivity values of 10-170 feet/day within Lea County. More recently, Musharrafieh and Chudnoff (1999) employed values for hydraulic conductivity primarily between 21 and 100 ft/day, for their simulation. According to Freeze and Cherry (1979), these values correspond to clean sand, which agrees with nearby lithologic descriptions of the saturated zone. To be conservative of ground water quality at this site, the hydraulic conductivity of the saturated zone is assumed as 20 feet/day.

Groundwater Gradient - Hydraulic gradient is taken as approximately parallel to the surface topography. Using USGS data, this was calculated as about 0.008. The resulting ground water fluxes are about 0.16 feet/day.

Aquifer Thickness – An aquifer thickness of 40 feet was employed for the monitoring well in the mixing model.

For all variables for which field data did not exist, assumptions conservative of ground water quality were made. A summary of the input parameters and a description of the source information used in the HYDRUS-1D model for this application are provided in Table 1 below.

Table 1: Input Data for Simulation Experiment

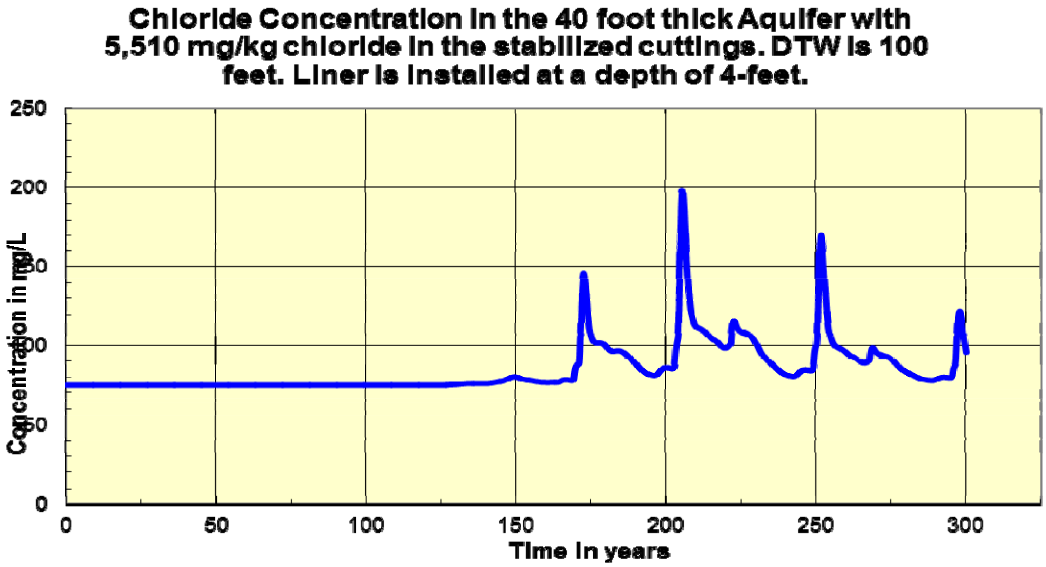
Input Parameter	Source
Vadose Zone Thickness - 100 feet	Conservative Assumption
Vadose Zone Texture	Well Logs From Nearby Sites
Dispersion Length - 10% of model length	Standard Modeling Practice
Climate	46.5 years of Pearl N.M., Weather Station Data
Soil Moisture	HYDRUS-1D initial condition simulation
Initial soil chloride concentration profile	Four-feet of stabilized cuttings are assumed to have a uniform concentration of 21200 mg/kg based upon composite samples
Length of possible impact parallel to ground water flow - 220 feet	Maximum Possible Pit Dimension
Background Chloride in Ground Water - 75 ppm	Common result for SE New Mexico
Ground Water Flux - 0.16 feet/day	Calculated from published data
Aquifer Thickness - 40-feet	From nearby wells

RESULTS AND CONCLUSIONS OF MODELING

Shown in Figure 1 is predicted chloride concentration in a simulated monitoring well at the down–gradient edge of the burial pit. Assumptions include:

1) The burial liner remains intact for 50 years.
2) The burial liner begins degradation at 50 years. It degrades completely in a linear fashion over a 125 year period.
3) A monitoring well penetrates the full saturated thickness of the aquifer (40 feet), and is placed at the down gradient edge of the burial site.
4) The hydraulic conductivity of the aquifer is 50 feet/day
5) Water samples from this fully-penetrating well represent the water quality of the entire aquifer with higher quality water entering the well from the base of the aquifer

Figure 1



As can be seen, no effect can be seen in ground water for about 125 years, 70 years after the liner begins degrading and about 50 years before it has completely degraded. Peak concentration in the well is about 198 mg/L more than 200 years from now.The cyclic nature of the output is due to the repetition of the weather input file. A number of El Nino event years in the 1980's are resposible for the 'high peaks' in chloride concentration. Using this data is conservative of ground water quality.

As can be seen no exceedance of New Mexico WQQC standards is predicted. The model is constructed to be conservative of ground water quality by use of inputs that:

- exagerrate vadose zone flux to ground water and
- minimize ground water flux

for all variables for which field data does not exist.