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Closure Plan Design Report

Samson BD-04 Reserve Pit
Samson Investment Company

R.T. HICKS CONSULTANTS, LTD.

901 RIO GRANDE BLVD. NW, SUITE F-142, ALBUQUERQUE, NM 87104

August 2006

Closure Plan Design Document

SAMSON BD-04 RESERVE PIT

Prepared for:

Samson Investment Company
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Tulsa, OK 74103

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901 RIO GRANDE, SUITE F-142, ALBUQUERQUE, NM, 87104

1.0 CLOSURE PLAN DESIGN DOCUMENT FOR PITS, BELOW GRADE TANKS & ACCIDENTAL RELEASES

Data and modeling demonstrate that, in the absence of a vadose zone remedy at the BD-04 site, the residual chloride beneath the former pit represents a threat to ground water quality. The data and analysis generated by our characterization activities coupled with long-term testing data available through Sandia National Laboratories allow us to conclude that placement of a monolithic evapotranspiration (ET) infiltration barrier will effectively protect fresh water, public health, and the environment. Because the materials on site allow the creation of a capillary break between the residual chloride and the proposed monolithic ET barrier, we have elected to incorporate this design modification.

The ET barrier will minimize the downward and upward migration of soluble salts such that the rate of vertical migration, down or up, has no material impact on ground water quality or soil productivity. Patch seeding for the vegetative cover will be placed at a time of year recommended by a range specialist.

As described below, monolithic evapotranspiration barriers are routinely employed as the final covers for hazardous and radioactive waste landfills. Sandia National Laboratories (SNL) compared the efficacy of the monolithic barrier to other landfill cover designs and concluded that this system can work very well in arid and semi-arid environments, such as the Permian Basin of southeast New Mexico. The design modification of a capillary break, while not absolutely necessary, can improve the efficacy of the cover. Our unsaturated zone modeling of this proposed remedy is consistent with the findings of SNL.

1.0 PROPOSED INFILTRATION BARRIER DESIGN & CONSTRUCTION PROTOCOLS

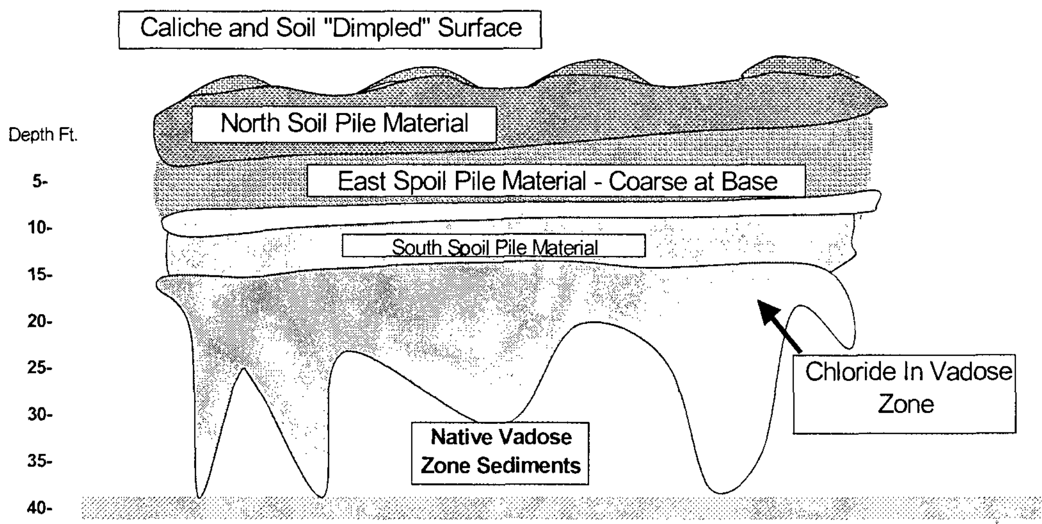


Figure 1: Final Closure Design

Figure 1 shows the design of the Monolithic ET cover for the BD-04 site. As shown, Samson will first place the material from the south spoil pile into the former pit and create a 5% surface slope to the east. The overlying infiltration barrier design calls for the following elements:

1 Screen or segregate about ½ of the material in the eastern spoil pile into coarse and fine-grained fractions.

2. Over the replaced material from the southern spoil pile, place 2-to 4-feet of coarse-grained material. This layer should also slope about 5% to the east.

3. Over the coarse-grained layer, place the un-screened remainder of the eastern spoil pile, again retaining a 5% surface slope to the east.

4. Over the well-graded material from the eastern spoil pile, place the fine-grained fraction from the screening/segregation process described above.

5. A 5% grade at the surface will prevent excess accumulation of precipitation over the ET barrier and shed excess water away from the former pit area. The slope requirement will result in a small mound over the former pit area.

6. The material from the northern soil pile is placed to create a topsoil dressing with variable thickness and "dimples" that will allow for concentration of small volumes of precipitation in areas of soil about 1-foot thick. As represented in Figure 2, these dimpled areas, may be about 20 feet square and spaced 20 feet apart. In the center of each dimpled depression is a 5-10 foot square area of 1-foot thick exposed soil planted with warm- and cold-weather grasses and forbs.

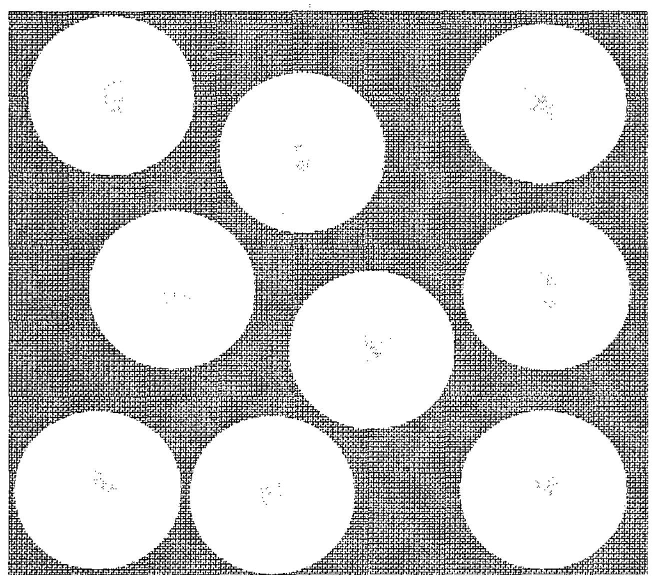


Figure 2: Plan View of Dimpled, Patch-Seeding Restoration

7. A very thin (about 1-inch) layer of coarse-caliche remaining from the screening/segregation process is placed between the dimpled/seeded areas where the topsoil dressing may be only 4- to 6-inches thick and within the dimpled areas where the thicker, seeded soil is not exposed. The gravel will create a cover/mulch that is more resistant to wind or water erosion and will reduce evaporation of infiltrated precipitation. These soil areas that are overlain by the thin caliche layer will not be seeded except as occurs naturally due to surrounding vegetation. Over time, vegetation from the established colonies within the dimples will spread over the site and wind-blown sand and dirt will fill the voids of the caliche cover.

8. A qualified person who is versed in construction earthwork, oilfield activities and environmental protection will supervise all aspects of the implementation of the proposed vadose zone remedy and act as a supervisor of completed work. This individual will:

    - Oversee topsoil surface placement, then survey the site to meet the design criteria of the 5% grade and the supervisor will retain the records of this survey.

    - Select areas for seeded "dimples" and direct the placement of topsoil and gravel mulch.

    - Direct the patch seeding seeding effort.

    - Prepare a report that provides the documentation of appropriate construction of the remedy and submit the report to NMOCD as part of the surface final restoration of the disposal facility.

We recommend that Samson request final closure for this injection well site after the former pit area and the entire well pad is re-vegetated to 70% of the ground cover observed in adjacent areas unaffected by oilfield activities. We also recommend eight quarters of ground water monitoring to verify that the ET Barrier was correctly constructed.

2.0 BACKGROUND DATA AND PROOF OF CONCEPT

The researched performance criteria of numerous landfill closure designs included examination of the following documents, all of which are available through the Internet:

- www.sandia.gov/caps provides a synopsis of landfill liner cover performance for the proposed designs
- www.sandia.gov/caps/designs.htm#landfill1 describes the various landfill cover designs tested by SNL
- cluin.org/products/altcovers/usersearch/lf_list.cfm provides links to performance monitoring of similar sites
- www.sandia.gov/caps/alternative_covers.pdf is the Sandia National Laboratory Report that fully describes the landfill cover evaluation project
- www.epa.gove/superfun/new/evapo.pdf provides useful links and data
- www.beg.utexas.edu/staffinfo/pdf/scanlon_vadosezj.pdf provides more case studies of ET cover performance

From this literature, we identified several alternatives that we believed could be feasible for the closure of pits, below grade tanks, and sites where accidental releases created a subsurface mass of constituents of concern. These alternatives are:

1. RCRA Subtitle C Barrier - with minor modification
2. Capillary ET (Evapotraspiration) Barrier
3. Monolithic ET Barrier

The SNL website references provide a brief description of each barrier design (see Appendix A).

3.0 PROOF OF DESIGN

The references listed above represent years (and sometimes decades) of field monitoring and simulation modeling, and clearly demonstrate the efficacy of these designs. The EPA Fact Sheet provides a recent summary of the monitoring data including the three barrier systems that we considered for the vadose zone remedy. Below is a data table from the Fact Sheet that presents the measured infiltration rates below these cover systems (Table 1).

Table 1: Comparison of Percolation Rates of Several Landfill Cover Designs (EPA Fact Sheet)

	1997 (May 1 - Dec 31)		1998		1999		2000		2001		2002 (Jan 1 - Jun 25)	
	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)	Precip. (mm)	Perc. (mm)
Monolithic ET	267.00	0.08	291.98	0.22	225.23	0.01	299.92	0.00	254.01	0.00	144.32	0.00
Capillary barrier ET	267.00	0.54	291.98	0.41	225.23	0.00	299.92	0.00	254.01	0.00	144.32	0.00
Anisotropic (layered capillary barrier) ET	267.00	0.05	291.98	0.07	225.23	0.14	299.92	0.00	254.01	0.00	144.32	0.00
Geosynthetic clay liner	267.00	0.51	291.98	0.19	225.23	2.15	299.92	0.00	254.01	0.02	144.32	0.00
Subtitle C	267.00	0.04	291.98	0.15	225.23	0.02	299.92	0.00	254.01	0.00	144.32	0.00
Subtitle D	267.00	3.56	291.98	2.48	225.23	1.56	299.92	0.00	254.01	0.00	144.32	0.74

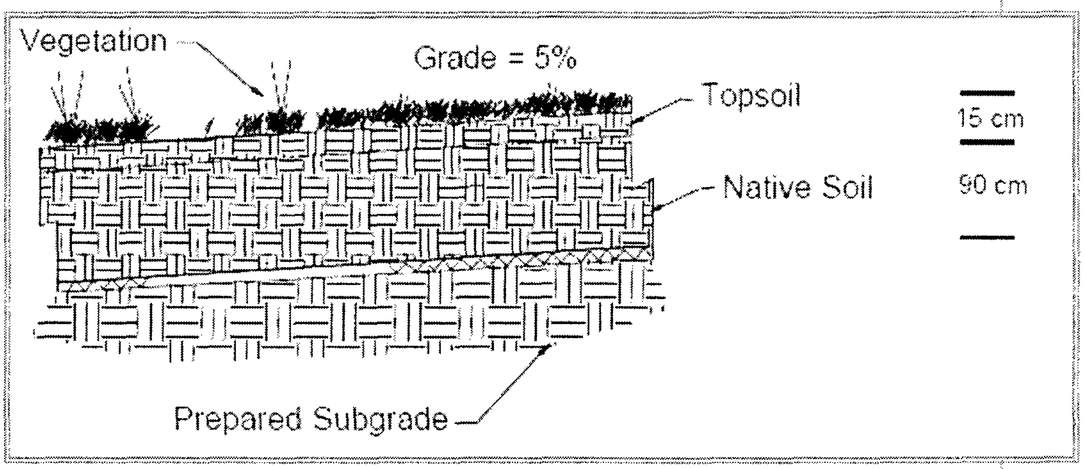
The systems that performed best during the first year after installation were the Subtitle C Cover (0.04 mm/year), the Monolithic ET barrier (0.08 mm/year) and the Capillary Barrier (0.54 mm/year). All three of the infiltration barrier systems under consideration performed equally well four years after installation and did not measure any infiltration. The efficacy of these three systems being equal, we considered other factors such as ease of installation and potential traffic to the site in making our recommendation:

The Capillary Barrier can be more difficult to install than other considered systems under oilfield conditions. Although this design performs no better than the Subtitle C or Monolithic design, we considered this option because the coarse-grained material required to install this design is on-site. A capillary break is a proven technology to prevent salts from upward migration from the waste to the root zone - a factor that was not important in the SNL study and was not fully considered.

The Subtitle C Barrier performs best during the first year of operation and we strongly considered this design. Because the clay-rich drilling fluids were removed from the site, no nearby clay is available to meet the design criteria of a 60 cm compacted clay layer. Importation of clay to the site would create significant truck traffic, dust and diesel exhaust. The environmental gain relative to other designs is only a short-term and may be offset by the environmental impact of the traffic.

The Monolithic ET Barrier is easy to install and performs well as a landfill cover. This design became our preferred alternative. The design of the Monolithic ET Barrier from the SNL website (see also Appendix A) is presented in Figure 3.

Figure 3 - Design of Monolithic ET Barrier from Sandia National Laboratory Report SAND2000-2427



4.0 SIMULATION MODELING OF A MONOLITHIC ET BARRIER

To predict the effect of the proposed monolithic ET Barrier, we used HYDRUS-1D and a ground water mixing model with site-specific data. Appendix B describes the input data and assumptions employed in this site-specific modeling.

Figures 4a and 4b show a HYDRUS-1D simulation of the impact to ground water quality assuming installation of the proposed monolithic/capillary barrier remedy at time = 0. Both figures employ the same input data as that described in the companion Investigation Report. Figure 4b expands the scale to show predicted ground water concentrations, with the barrier in place, relative to actual ground water data. Figure 4 assumes the vadose zone chloride concentration profile as delineated by the field investigation (Figure 5) and the lithology represented in Figure 1.

Figure 4a: Chloride Concentration in the Aquifer, BD-4 Site with Evapotranspiration Barrier Installed

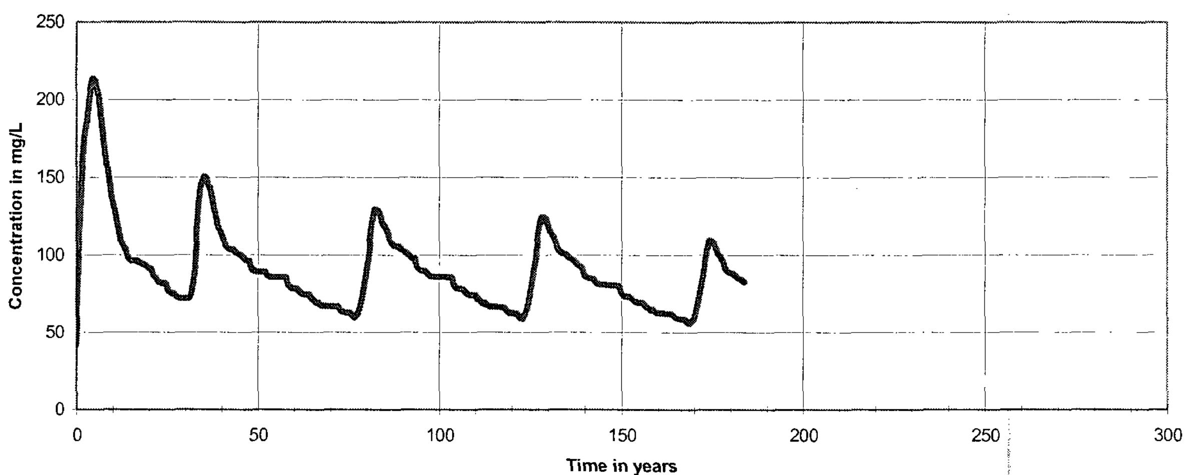
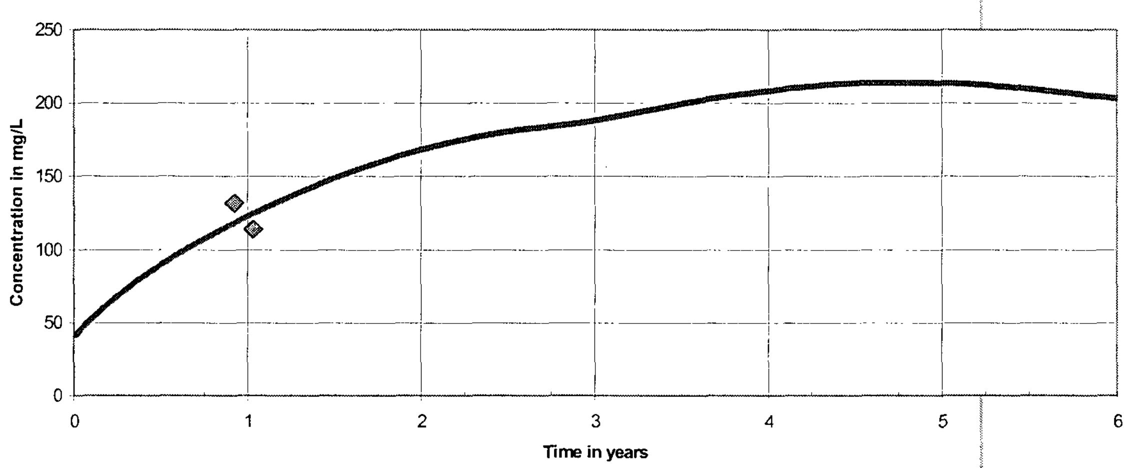


Figure 4b: Predicted Chloride Concentration in the Aquifer, BD-4 Site with Evapotranspiration Barrier Installed at Year 0 - Diamonds Represent Ground Water Samples in May and August 2006



Peak chloride concentration in ground water occurs about 5 years after installation of the ET barrier and is less than 215 mg/L (see Figure 4b). As a result of installation of the ET barrier, vadose zone water flux to ground water is reduced about an order of magnitude less than the flux at the currently un-vegetated pit site (Figure 6). Note that the rate of recharge to the aquifer for both scenarios is exactly the same until about year two. After year two, flux to the aquifer without the barrier increases due to greater infiltration at the un-vegetated surface. The conclusion we can draw from this graph is quite simple, the ET barrier should be installed as soon as possible.

Figure 5: Chloride Profile of the Proposed Remedy, BD 4 Site

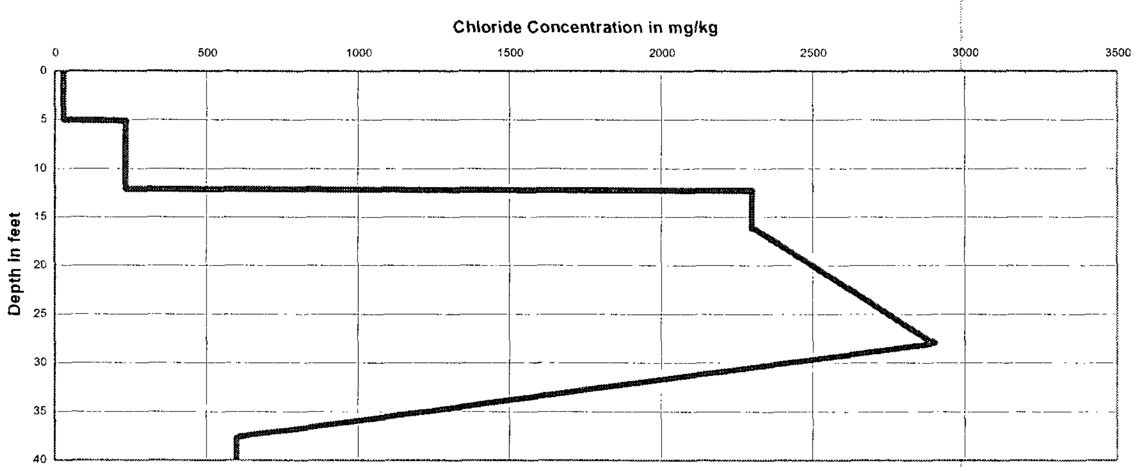


Figure 6: Vadose Zone Water Flux to Ground Water at the BD-4 Site

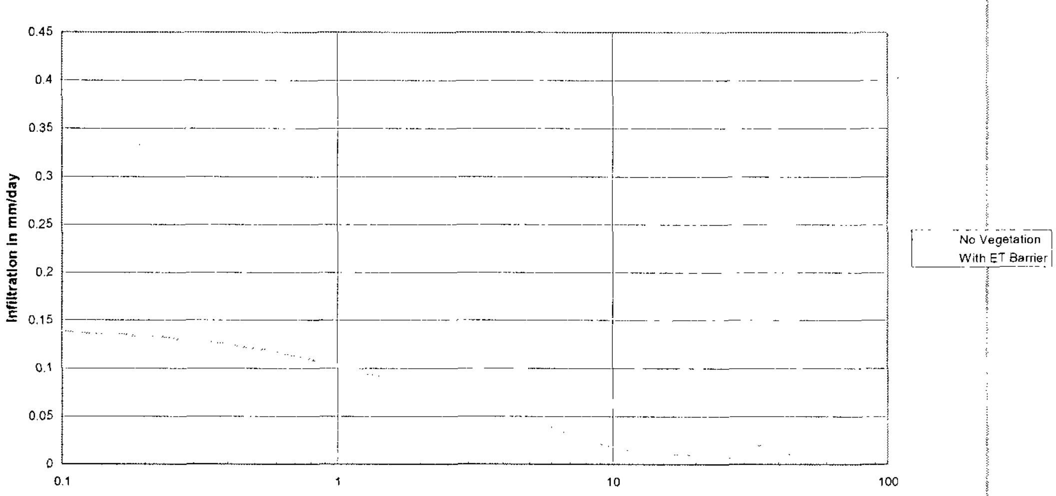
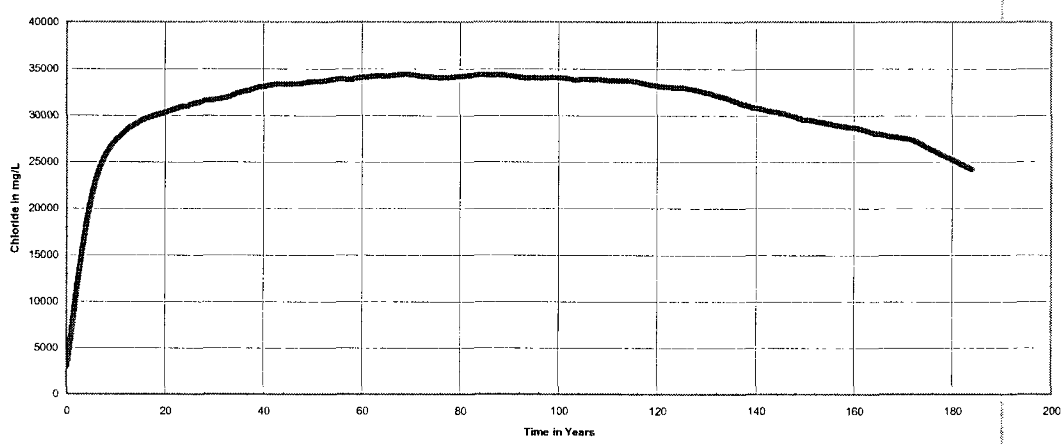


Figure 7: Chloride Concentration of Vadose Zone Water at the Ground Water Interface, BD-4 Site with Installed Evapotranspiration Barrier



As stated above, with the ET cover in place, the vadose zone chloride flux to ground water peaks at about year five (see Figure 4a) as a result of reduction of vadose zone water flux by about an order of magnitude. However, peak chloride concentration (34,400 mg/L) of the vadose zone water enters ground water between years 68 and 86 (Figure 7). From this graph we can conclude that the chloride center of mass in the vadose zone profile (2,900 mg/kg at 28 feet bgs) enters ground water at this later time step. Because of the reduced vadose zone water flux, between years 68 and 86, the maximum chloride concentration in ground water is about 125 mg/L (year 84 in Figure 4a)

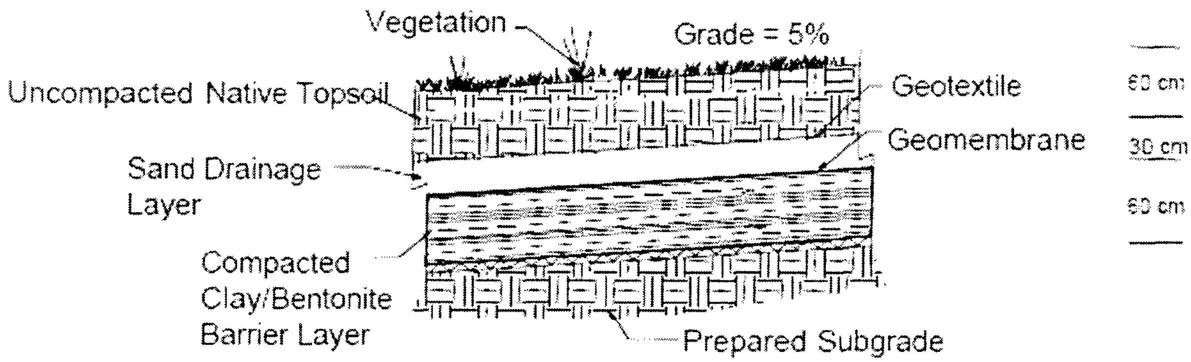
The simulation shows that the monolithic ET barrier permanently and immediately protects fresh water, public health and the environment. We believe that the monolithic/capillary ET barrier remedy effectively meets all mandates of the Oil and Gas Act. A two-year ground water monitoring program will serve to verify the predictions presented herein. The efficacy of the ET Barrier design, however, has been verified by decades of monitoring at various sites throughout the US.

APPENDIX A

Landfill 3 (RCRA Subtitle C)
Compacted Clay Cover designed and constructed in accordance with minimum regulatory requirements for closure of hazardous and mixed waste landfills. These regulations are somewhat vague. To overcome this vagueness, the Environmental Protection Agency (EPA) recommended a cover profile for the RCRA Subtitle 'C' final cover design profile described below, from bottom layer to top layer:

1. A composite barrier layer consisting of a minimum 60-cm thick layer of compacted natural or amended soil with a maximum saturated hydraulic conductivity of 1 x 10-7 cm/sec in intimate contact with a minimum 40-mil geomembrane overlying this soil layer.The function of this composite barrier layer is to limit downward moisture movement.
2. A drainage layer consisting of a minimum 30-cm thick sand layer having a minimum saturated hydraulic conductivity of 1 x 10-2 cm/sec, or a layer of geosynthetic material having the same characteristics;
3. A top vegetation/soil layer consisting of a minimum 60-cm of soil graded at a slope between 3 and 5 percent with vegetation or an armored top surface.

The installed Compacted Clay Cover is 1.5 m thick which basically matches the recommended EPA design described above. The profile for this cover consists of three layers. See figure below.



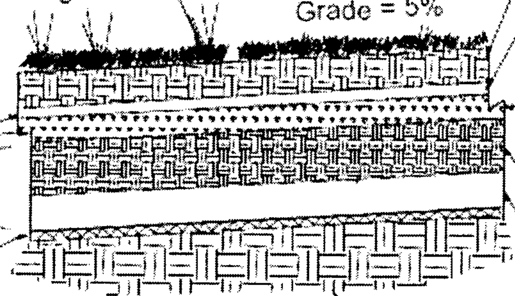
Profile of Baseline Test Cover 2 (Landfill 3)

The bottom layer is a 60 cm thick compacted soil barrier layer. The native soil required amendment to meet the saturated hydraulic conductivity requirement (maximum of 1 x 10-7 cm/sec) for this barrier layer. Laboratory tests determined that a mixture of 6% by weight of sodium bentonite with the native soil compacted 'wet of optimum' to a minimum of 98% of maximum dry density would be adequate.

A 40 mil linear low density polyethylene (LLDPE) geomembrane was placed directly on the compacted soil barrier layer to create a composite barrier layer. The purpose of this composite barrier layer is to create an impermeable barrier that blocks the infiltration of water. Eight 1-cm2 defects (puncture holes) were purposely and randomly placed in this geomembrane to be representative of a geomembrane installation with average quality control conditions (Dwyer et al. 1998).

Welding Seams of Geomembrane Panels

Landfill 5 (Capillary Barrier)
This cover system consists of four primary layers from bottom to top: (1) a lower drainage layer; (2) a barrier soil layer; (3) an upper drainage layer; and (4) a topsoil layer. The barrier soil layer and lower drainage layer comprise the capillary barrier. The lower drainage layer is composed of 30 cm of washed concrete sand. See figure below.



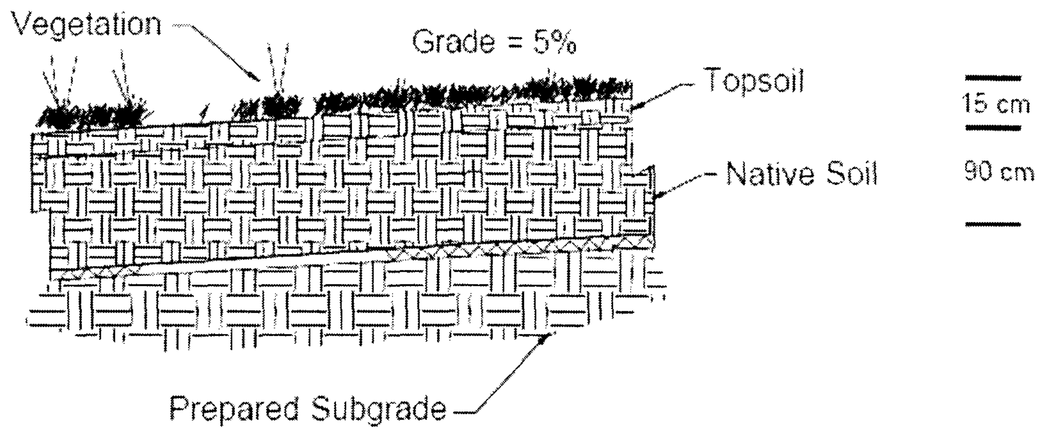
Profile of Alternative Test Cover 3 (Landfill 5)

The 45 cm barrier soil layer was installed directly on the sand. The upper drainage layers were placed over the barrier soil layer. This upper drainage layer consists of two materials containing 22 cm of clean pea gravel and 15 cm of washed concrete sand. Finally, a 30 cm thick layer of topsoil was placed on the sand.

Capillary Barrier Installation

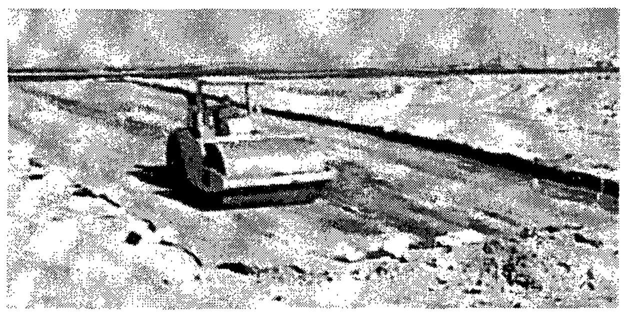
Landfill 6 (Evapotranspiration)
The ET Cover consists of a single, vegetated soil layer constructed to represent an

optimum mix of soil texture, soil thickness, and vegetation cover. The installed test cover is a 105 cm thick monolithic soil cover. The bottom 90 cm of native soil was compacted while the top 15 cm of topsoil was loosely placed. The soil allows for water storage, which combined with the vegetation, is designed to optimize evapotranspiration. See figure below.



Profile of Alternative Cover 4 (Landfill 6)

A thin gravel veneer (2 to 4 cm) was placed on the surface after the cover was seeded. The objective of the gravel veneer was to enhance the vegetation establishment and minimize erosion.



Compacting Soil in ET Cover

APPENDIX B

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.

A description of the model input parameters are listed below.

Soil Profile - Information for the soil profile (or vadose zone thickness and texture) is based upon the boring logs from the two borings made adjacent to the site for installation of the monitoring wells. Depth to water measurements from the monitoring wells provide a vadose zone thickness of 40 feet at the site.

Dispersion lengths - Conservative dispersion lengths were employed. Standard practice calls for employing a dispersion length that is 10% of the model length.

Climate - Weather data used in the predictive modeling was from the Pearl Weather Station (46 years of data), approximately 46 miles south-southeast of the BD-4 site. This data was used instead of weather data from Tatum, New Mexico (15 miles east-southeast of the site) as neither weather data source is at the site and the climates are quite similar. The Pearl Weather Station precipitation data was modified to reflect the higher annual precipitation at Tatum (about 16%).

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 and nearby to the site, 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 peak chloride concentrations in ground water due to temporally variable high fluxes from the vadose zone. As such, this choice is conservative and will not under-predict impairment to ground water quality.

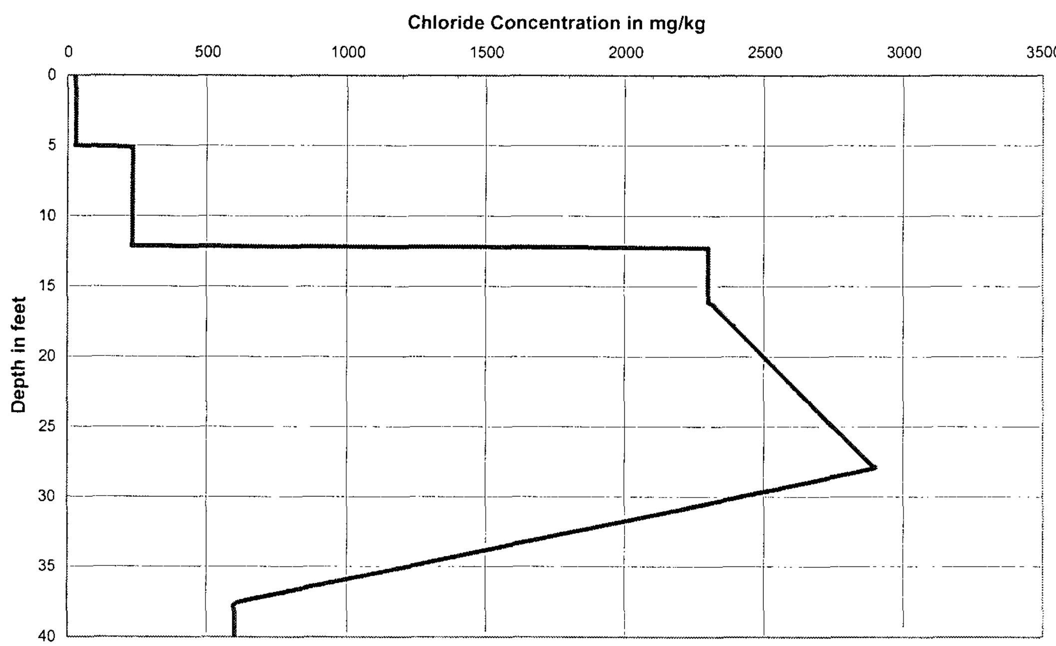
Soil Moisture - Because soils are relatively dry in this climate and vadose zone hydraulic conductivity varies with moisture content, it is important that simulation experiments of different remedial strategies begin with an initial "steady state" soil moisture content. The calculation of soil moisture 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. Because only minimal changes in the HYDRUS-1D soil moisture content profile occurred after year 55 of the initial condition calculation, 92 years (2 cycles of the 46 years of weather data) was considered more than sufficient to establish the initial moisture condition. All simulations of chloride movement used soil profiles hydrated in this manner.

Initial Chloride Profile – Field chloride soil concentrations (mg/kg) from the excavation and the stockpiled materials included:

1) nine samples from the stockpile on the east side of the excavation with an average chloride concentration of 235 mg/kg,
2) five samples from the stockpile on the south side of the excavation and a five point composite sample from the floor of the current excavation (16 to 20 feet below ground surface (bgs) with an average chloride concentration of 2300 mg/kg,
3) seven samples taken from six trenches excavated eight to ten feet below the floor of the current excavation with an average chloride concentration of 2900 mg/kg.

The chloride concentrations were installed to simulate the remedy (see Figure 1). First, the floor of the current excavation was set with the averaged concentration of materials from the south stockpile (2300 mg/kg). The deeper trench samples provided an average chloride concentration of 2905 mg/kg at a depth of about 28 feet bgs. From this depth, chloride concentrations were assumed to decline with depth to a constant concentration (600 mg/kg). This constant concentration was chosen such that chloride concentration in ground water at a time of two years was greater than or equal to 131 mg/L, the observed value in MW-1.

Figure 1: Chloride Profile of the Proposed Remedy, BD 4 Site



The remedy is assumed to consist of the emplacement of the south side stockpile materials in the excavation from approximately 16 feet to 12 feet bgs with an averaged chloride concentration of 2300 mg/kg from field samples. On top of this is emplaced the east side stockpile from about 12 feet to 5 feet bgs with an averaged chloride concentration of 235 mg/kg obtained from field samples. Above this is placed a coarse grained material from 5 feet to 3.5 feet bgs; and finally, 3.5 feet of silt loam is placed on top of the coarse grained material. The uppermost material is assumed to contain a chloride concentration of 30 mg/kg.

Integration of the chloride contained within the profile yielded a chloride load of 27.3 kg/m^2. The averaged soil concentration values (mg/kg) were linearly interpolated to correspond to the HYDRUS 1-D soil profile nodes. Using the volumetric moisture content from the HYDRUS 1-D initial condition and a default dry bulk soil density of 1390 kg/m^3, soil water moisture concentrations (mg/L) were calculated for the HYDRUS 1-D soil profile nodes. These chloride concentrations were installed in the HYDRUS-1D model.

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 release site).

Influence Distance - The influence distance is defined as the maximal length of the release parallel to groundwater flow direction. From USGS well data (1996), direction of flow is about parallel to the northeast-southwest sides of the 110 feet by 115 feet pit. Therefore, an influence distance of 120 feet was used.

Background Chloride Concentration – from regional data and the monitoring wells, a value of 40 mg/L chloride for ground water was used at this location.

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 throughout the general area. McAda (1984) simulated water level declines using a two-dimensional digital model and employed hydraulic conductivity values of 51-75 feet/day (1.9 E-4 to 2.8 E-4 m/s) in the area. More recently, Musharrafieh and Chudnoff (1999) employed values for hydraulic conductivity within this area of interest between 41 and 60 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. For the BD-4 site, the saturated hydraulic conductivity of the uppermost saturated zone is assumed as 50 feet/day.

Groundwater Gradient - From USGS well data (1996) ground water flows southeast in the area under a hydraulic gradient of approximately 0.0029 ft/ft. The resulting ground water flux is 4.4 cm/day.

Aquifer Thickness - A restricted aquifer thickness of 15 feet was employed in the mixing model as this is the aquifer thickness penetrated by MW-1 and Mw-2 on the site.

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: Modeling Inputs for the D-20 Site	
Input Parameter	**Source**
Vadose Zone Thickness - 40 feet	From monitoring wells on the site
Vadose Zone Texture	Boring Logs and professional judgment
Dispersion Length - 10% or less of model length	Professional judgment
Climate	Modified Pearl, N.M. Weather Station data
Soil Moisture	HYDRUS-1D initial condition simulation
Initial soil chloride concentration profile	From 22 samples within site
Length of release parallel to ground water flow - 120 feet	From calculated ground water flow direction
Background Chloride in Ground Water - 40 ppm	Regional and Site Data
Ground Water Flux – 4.4 cm/day	Calculated from regional data
Aquifer Thickness - 15-feet	Aquifer thickness penetrated by on-site wells

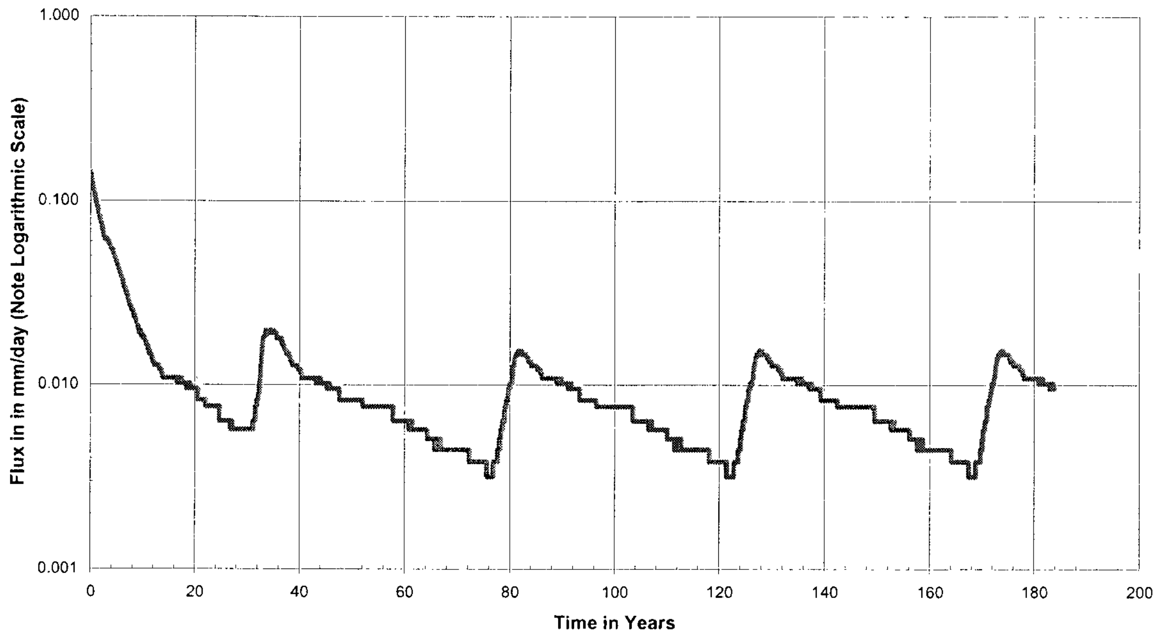
Vegetation was allowed at the site within the upper 3.5 feet of imported loam.

Model of the BD-4 Site with an Installed Infiltration Barrier

The proposed remedy of the BD-4 site was modeled with a site specific HYDRUS-1D model. The model was begun with a 40 foot thick soil profile constructed and hydrated as discussed above. The initial chloride profile was also installed as above.

The remedy modeled featured an ET barrier with 3.5 feet of silt loam above 1.5 feet of coarse grained sand to reduce upwards wicking of chloride into the root zone (0-3.5 feet bgs). This modification allows vegetation to be established immediately. With established vegetation, the vadose zone water flux to ground water is reduced by about an order of magnitude (see Figure 2).

Figure 2: Vadose Zone Water Flux into the Aquifer, BD4 Site with Installed Evapotranspiration Barrier



The resultant chloride concentration in ground water peaks at a time of about 4.8 years at 214 mg/L and declines there after (see Figure 3). Peak chloride concentration in vadose zone water entering ground water is about 34,400 mg/L during the time interval from 68 years to 86 years after installation of the proposed remedy (see Figure 4).

Figure 3: Chloride Concentration in the Aquifer, BD-4 Site with Evapotranspiration Barrier Installed

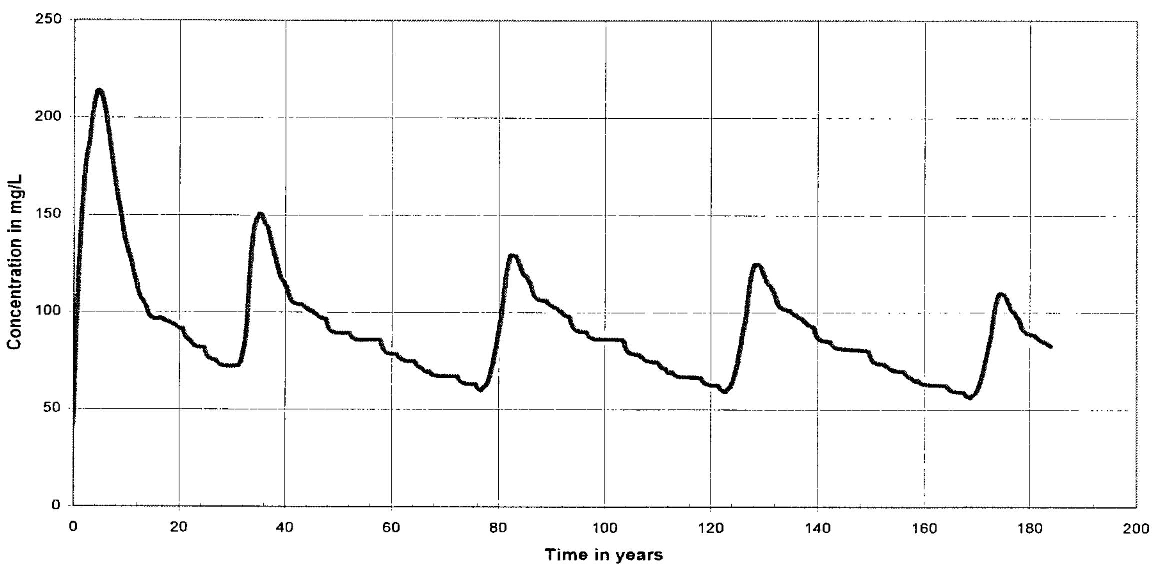


Figure 4: Chloride Concentration of Vadose Zone Water at the Ground Water Interface, BD-4 Site with Installed Evapotranspiration Barrier