AP - 59

VADOSE ZONE WORK PLAN

DATE:
10-09-06

October 9, 2006

AP-59
Vadose Zo[ne]
Work Plan
10-9-06

Stage 2 Abatement Plan Vadose Zone Remedy

for F-35 and G-35 SWD Facility Sites

R.T. Hicks Consultants, LTD

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2006 NOV 17 AM 10 14

November 15, 2006

Wayne Price
NMOCD Environmental Bureau Chief
1220 South St. Francis Drive
Santa Fe, New Mexico 87505
Via E-mail

RE: F-35 SWD & G-35 SWD, T17S, R35E; NMOCD Case #: 1R0330 & 1R0332

Dear Mr. Price,

R.T. Hicks Consultants is pleased to deliver our Stage 2 Abatement Plan Vadose Zone Remedy report for F-35 and G-35 SWD Facilities.

If you have questions or comments regarding the remedy, please contact Kristin Pope.

Sincerely,
R.T. Hicks Consultants, Ltd.

Randall T. Hicks

Randall Hicks
Principal

Copy: Rice Operating Company

Landfill	Layer	Porosity			Field Capacity (vol/vol)			Wilting Point (vol/vol)			Ksat (cm/sec)			Initial MC (vol/vol)		LAI			Cumulative Percolation (mm)			
		4(1)	5(2)	6(3)	4(1)	5(2)	6(3)	4(1)	5(2)	6(3)	4(1)	5(2)	6(3)	5(2)	6(3)	4(1)	5(2)	6(3)	4(1)	5(2)	6(3)	Field
Subtitle D Cover	Topsoil	0.44	0.45	0.45	0.11	0.16	0.1	0.05	0.09	0.04	1.70E-03	1.00E-03	9.08E-04	0.19	0.14	1.2	1.5	1.5	280.46	88.42	160.34	8.34
	Barrier Soil	0.42	0.37	0.37	0.31	0.19	0.18	0.18	0.1	0.08	1.90E-05	1.23E-06	1.20E-05	0.37	0.14							
Subtitle C Cover	Topsoil	0.44	0.45	0.45	0.11	0.16	0.13	0.05	0.09	0.06	1.70E-03	1.00E-03	1.15E-03	0.19	0.14	1.2	1.5	1.5	1.24	0.18	0.20	0.21
	Sand	0.42	0.37	0.37	0.05	0.03	0.03	0.02	0.02	0.02	1.00E-02	1.82E-02	1.82E-02	0.12	0.12							
	Barrier Soil	0.43	0.37	0.37	0.42	0.19	0.19	0.37	0.1	0.1	1.00E-07	9.70E-07	9.70E-07	0.37	0.37							
GCL Cover	Topsoil	0.44	0.45	0.45	0.11	0.16	0.13	0.05	0.09	0.06	1.70E-03	1.00E-03	1.17E-03	0.20	0.14	1.2	1.5	1.5	0.05	0.11	0.12	2.87
	Sand	0.42	0.37	0.37	0.05	0.03	0.03	0.02	0.02	0.02	1.00E-02	1.82E-02	1.82E-02	0.15	0.15							
Capillary Barrier	Topsoil	0.44	0.45	0.45	0.11	0.16	0.13	0.05	0.09	0.06	1.70E-03	1.00E-03	1.15E-03	0.19	0.10	1.2	0.5	0.5	44.07	219.41	132.76	0.95
	Compacted Soil	0.42	0.41	0.41	0.31	0.18	0.1	0.18	0.09	0.06	1.90E-05	4.00E-04	5.15E-04	0.41	0.10							
	Sand	0.42	0.37	0.37	0.05	0.03	0.03	0.02	0.02	0.02	1.00E-02	1.62E-02	1.62E-02	0.09	0.09							
	Gravel	0.4	0.37	0.37	0.03	0.03	0.03	0.01	0.03	0.03	3.00E-01	4.42E+00	4.42E+00	0.03	0.03							
Anisotropic Barrier	Topsoil	0.44	0.45	0.45	0.11	0.16	0.16	0.05	0.09	0.07	1.70E-03	1.00E-03	1.06E-04	0.22	0.06	1.2	1.4	1.4	271.87	40.54	74.85	0.26
	Compacted Soil	0.42	0.41	0.41	0.31	0.18	0.12	0.18	0.09	0.05	1.90E-05	4.00E-04	4.47E-04	0.22	0.06							
	Sand	0.42	0.37	0.37	0.05	0.03	0.03	0.02	0.02	0.02	1.00E-02	1.62E-02	1.82E-02	0.09	0.09							
	Gravel	0.4	0.37	0.37	0.03	0.03	0.03	0.01	0.03	0.03	3.00E-01	4.42E+00	4.42E+00	0.03	0.03							
ET Cover	Topsoil	0.44	0.45	0.45	0.11	0.16	0.12	0.05	0.09	0.05	1.70E-03	1.00E-03	1.20E-03	0.19	0.12	1.2	1.8	1.8	279.38	36.48	1.33E-03	0.30
	Compacted Soil	0.42	0.37	0.37	0.31	0.19	0.16	0.18	0.1	0.07	1.90E-05	4.34E-05	4.70E-05	0.15	0.12							

(1) Design input parameters for HELP and HELP simulations as described in Chapter 4.
(2) Initial soil conditions input parameters for HELP and HELP simulations as described in Chapter 5.
(3) Final soils conditions input parameters for HELP and HELP simulations as described in Chapter 6.
(4) No specific initial moisture content used for forward simulations described in chapter 4. Default values for input parameters for HELP combined with prior modeled years used.

Table 7.2. HELP Input Parameters and Results with Field Results

1.0 Introduction

This submission fulfils the commitment stated in Section 9.1 of the Stage 1&2 Abatement Plan. We refer the reader to the December 31, 2005 Abatement Plan for additional information regarding the location, operational history and local hydrogeology. Specifically, Section 9.1 of the Abatement Plan stated that ROC would:

1. Submit simulation experiments and a recommended vadose zone remedy within 60 days of NMOCD approval of this abatement plan.
2. If NMOCD allows only a vadose zone remedy to sequester constituents of concern through the installation of an infiltration barrier, ROC will implement the remedy within 90 days of NMOCD approval.
3. If NMOCD allows the vadose zone flushing, ROC will incorporate this remedy into the ground water remedy.

The simulation experiments and evaluation of field data show that vadose zone flushing as suggested in number 3 above could yield unpredictable results. Therefore, this plan proposes installation of an evapotranspiration (ET) infiltration barrier.

Data and modeling demonstrate that in the absence of a vadose zone remedy, residual chloride beneath the pits, below-grade tanks and accidental releases can represent a threat to ground water quality. However, data and analysis generated by characterization activities coupled with long-term testing data available through Sandia National Laboratories (SNL) show that placement of a evapotranspiration (ET) infiltration barrier will effectively protect fresh water, public health, and the environment from residual constituents of concern in the vadose zone.

An 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 placed at a time of year recommended by a range specialist is a key component of successful re-vegetation in environments where precipitation is sporadic.

As described in this document, evapotranspiration barriers are routinely employed as the final covers for hazardous and radioactive waste landfills. Sandia National Laboratories (SNL) compared the efficacy of the ET barriers to other landfill cover designs and concluded that this system can work very well in arid and semi-arid environments, such as New Mexico. For many sites, including this one, modifications to the landfill cover designs evaluated by SNL, while not absolutely necessary, can improve the efficacy. Unsaturated zone modeling using site-specific data for numerous sites has been consistent with the findings in the SNL report (Appendix A).

The purpose of an ET Barrier is not to permanently isolate these constituents in the vadose zone, although that may be the ultimate result. The purpose of the barrier is to minimize the downward and upward migration of soluble salts such that the rate of migration, in either direction, has no material impact on ground water quality or soil productivity.

2.0 PROPOSED INFILTRATION BARRIER DESIGN AND CONSTRUCTION PROTOCOLS FOR THE F-35 AND G-35 SITES

The design for the F-35 and G-35 tanks and emergency pit is a modified Monolithic ET Barrier that is very similar to the Anisotropic ET Infiltration Barrier identified as Test Cover 3 in the SNL Report (SAND 2000-2427) in Appendix A. Figure 10 of that report showing the ET Soil Cover design is reproduced below as Figure 1 of this report.

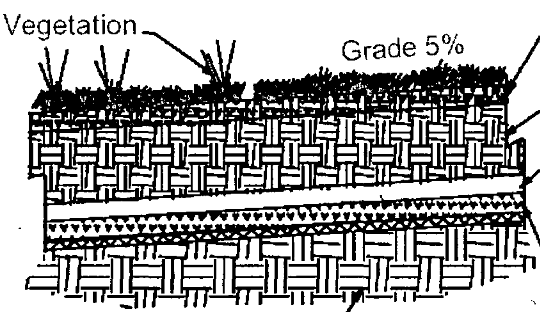

Figure 1: ET Soil Cover Design from SNL Report SAND 2000-2427.

Simulation modeling at other sites shows that chloride and other soluble salts can migrate upward from a depth of about 4 feet. To eliminate the potential of such upward migration and subsequent impact to the vegetation cover, the design calls for the installation of a coarse grain (caliche gravel) layer above the chloride impacted material. Figure 2 shows the design of the Anisotropic ET Barrier cover for the tanks and emergency pit. The design for the F-35 and G-35 sites differ from the SNL tested design by increasing the thickness of the coarse-grained drainage layers and the fine-grained moisture storage layers as shown below in order to achieve a reasonable surface grade because the excavation at each site is about 6-feet deep.

SNL-Tested Design Thickness (inches)	F-35 and G-35 Design Thickness (inches)	ET Layer Material
6	6	Topsoil/Caliche Gravel
24	30	Native Soil Layer
6	12	Fine Sand interface
6	18	Pea Gravel Caliche Sub Layer
42	66	Total Thickness

As shown in Figure 2, ROC will first place any material from the spoil pile into the former pit that tests greater than 1,000 mg/kg chloride (high chloride material in Figure 2). The excavation will be expanded as necessary to allow the proposed infiltration barrier to extend 2-5 feet beyond the zone of impacted vadose zone. The top surface of spoil pile material and clean fill from the excavation walls will be graded to create a 5% surface slope.

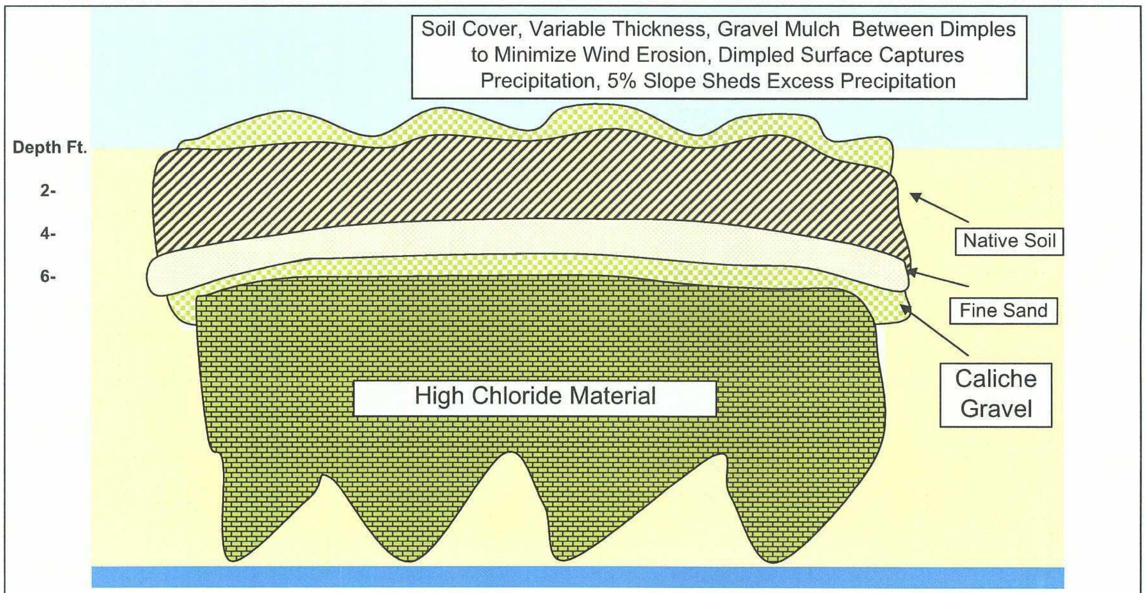

Figure 2: Anisotropic ET cover for the F-35 and G-35 sites.

Field conditions will determine the specifics of the design and "as- built" drawings will be maintained that confirm compliance with the design concept described herein. The top surface of the ET Barrier will be formed to create a 5% surface slope. The underlying infiltration barrier design calls for the following elements, modified as necessary to accommodate field conditions:

1. After placement of any material from the spoils pile that exceed 1,000 mg/kg chloride into the excavation, expand the excavation and place the side wall material in the pit.
2. Over this fill, place about 1.5-feet of coarse-grained caliche derived from the closure of the pad. ROC may elect to wash the caliche with fresh water to open the pore space of the gravel and remove any entrained fine-grained sand.
3. Over the coarse-grained layer, place about 1foot of fine sand (less than 1,000 mg/kg chloride). The top of the fine sand surface should mimic the 5% surface slope.
4. Over the fine sand, place the 30 inches of fine-grained native material, retaining the retaining the 5% grade which, when covered by the topsoil layer will prevent excess accumulation of precipitation over the ET barrier and shed excess water away from the former pit and tank area. The slope requirement may result in a small mound over the former pit area.
5. At the ground surface create the topsoil dressing with variable thickness and "dimples" that will allow for concentration of small volumes of precipitation in areas of soil about 1foot thick. As represented in Figure 3, 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 1foot thick exposed soil planted with warm and cold weather grasses and forbs.

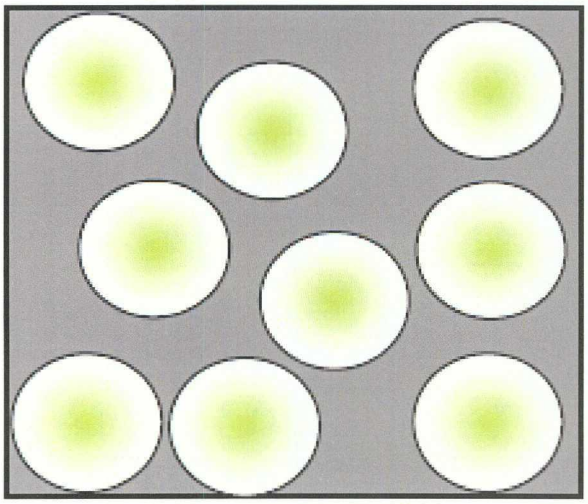

Figure 3: Plan of Dimpled, Patch Seeding Surface Restoration

6. A very thin (about 1-inch) layer of coarse-caliche remaining from the pad restoration program is placed between the dimpled/seeded areas where the topsoil dressing may be slightly thinner and within the dimpled areas where the thicker, seeded soil is not exposed. The gravel will create a cover/mulch that is 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.
7. For the remainder of the site area, the ground surface should be restored and re-seeded using the protocol outlined in steps 5 and 6 above.
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 site restoration. This individual will:

   - Oversee topsoil surface placement, then survey the infiltration barrier to ensure that the barrier meets the design criteria of the 5% grade and retain the records of this survey.
   - Select areas for seeded "dimples" and direct the placement of topsoil and gravel mulch.
   - Direct the patch 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.

After completion of the construction described above, ROC will submit a final closure report for the former SWD facilities.

▼ 3.0 BACKGROUND DATA AND PROOF OF CONCEPT

We researched the 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

Appendix A presents the analysis of alternatives as well as several of the documents referenced above. We urge the reader to examine the pages from the SNL website, which follow the alternatives analysis presented in Appendix A. Table 1 compares the various ET Barrier systems and shows that all systems reduce the percolation rate to near zero and will therefore be effective is mitigating the flux of chloride from the vadose zone to ground water.

	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

Table 1: Comparison of Various ET Barriers from EPA Fact Sheet (see Appendix A)

▼ 4.0 SIMULATION MODELING OF A ANISOTROPIC ET BARRIER

To predict the effect of the proposed Anisotropic ET Barrier at the F-35 and G-35 sites, we used HYDRUS-1D and a ground water mixing model with site-specific data. Appendix B presents the results and describes the input data and assumptions employed in this site-specific modeling.

Proposed Stage 2 Abatement Plan Vadose Zone Remedy

A complete evaluation of existing data on the vadose zone and the most recent chemical trends from ground water sampling allows us to conclude that closure of the former tank and pit sites with modified anisotropic evapotranspiration (ET) infiltration barrier will:

- Protect fresh water, public health and the environment
- Comply with the Oil and Gas Act and NMOCD Rule 19 and
- Provide a reasonable relationship between the cost of the remedy and the environmental benefit

Appendix A contains information relating to ET Barriers, including the anisotropic ET barrier

Background Data to Support Vadose Zone Remedy

Figure 4 plots chloride concentration (mg/kg) v. depth for the borings of G-35-MW-1 and F-35-MW-1. These wells are directly adjacent to the former tanks and provide representative data of the deeper vadose zone. Our previous modeling work at sites throughout Lea County allow us to conclude that concentrations similar to those shown in Figure 4 in the deep vadose zone will not represent a threat to ground water quality if the recharge rate is minimized by cessation of additional leakage and the installation of an ET infiltration barrier.

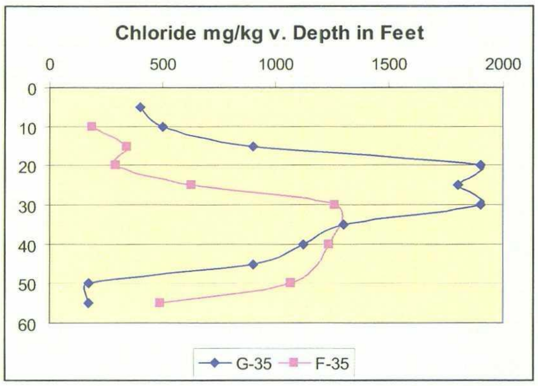

Figure 4: Chloride Concentration Profiles at the F-35 and G-35 Sites.

The chemical trend of ground water analyses at F-35 support our conclusion that cessation of ongoing brine leakage at a site reduces the chloride impact to ground water quality. This trend is evidence that the flux of chloride from the vadose zone to ground water is declining relative to the flow of ground water. The placement of an ET infiltration barrier over the area will reduce the vadose zone chloride flux (i.e. the recharge rate) to near zero and cause additional improvement in ground water quality.

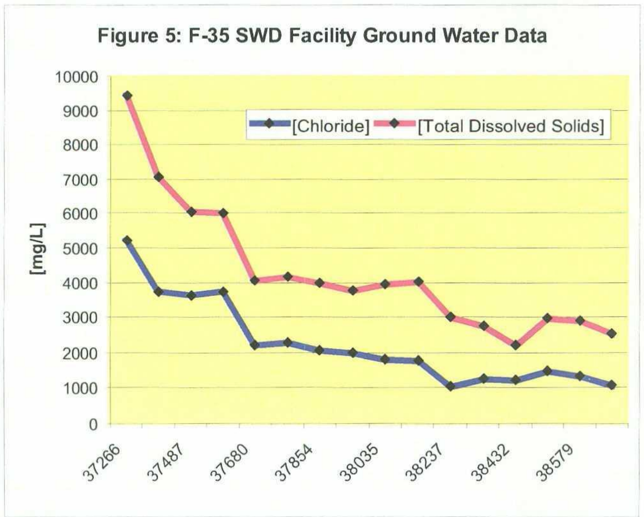

Figure 5: Analytical Results from the F-35 Monitoring Well.

Simulation modeling of an ET barrier at the F-35 site (Figure 6) is explained in more detail in Appendix B. In Figure 6, the ET Barrier is installed at time zero. Because the model begins transport of residual chloride from the vadose zone to ground water also at time zero, chloride concentration in the aquifer increases from time=0 until the effect the ET Barrier causes a reduction in the recharge rate to ground water. For the "wet" initial condition, chloride drains for about 10 months until drainage begins to slow as a result of the ET Barrier. For the moist initial condition, vadose zone drainage continues for nearly 18 months until the lower infiltration rate due to the ET Barrier (installed at time=0) reduces the chloride flux to the aquifer and ground water chloride concentrations decrease as a result.

Under "moist" vadose zone conditions, chloride will continue to drain and cause ground water to exceed the WQCC chloride standard for about 15 years. More rapid drainage under wet conditions results in compliance with WQCC standards after about 3.5 years, in the absence of a pump-and-use ground water remedy. Ground water monitoring, not model predictions will testify to the efficacy of the ET Barrier and the time frame required for completion of the proposed remedy.

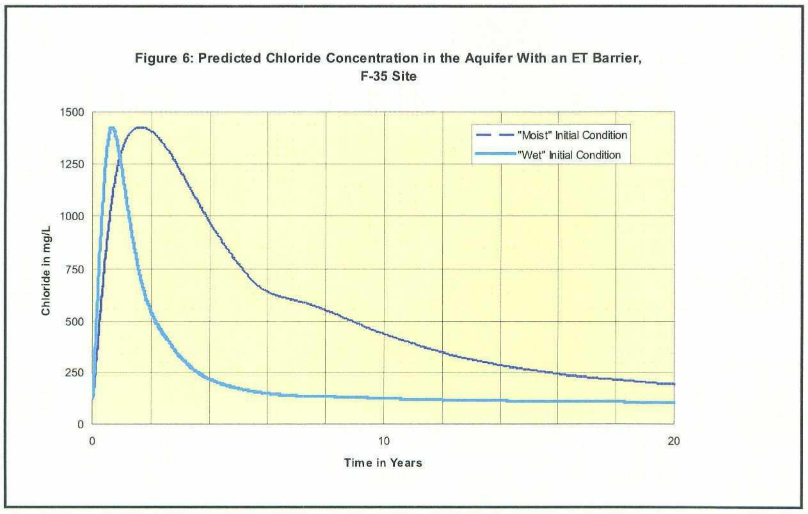

Figure 6: Predicted Chloride Concentration in the Aquifer With an ET Barrier, F35 Site.

At G-35-MW-1, the ground water chemical trend does not follow the same pattern as that of F-35 and is difficult to interpret (see Figure 7). However, recent data from newly-installed monitoring wells demonstrate that the chloride concentration in the monitor well MW-1 samples originates in the vadose zone, not an up gradient source.

Predictions from the HYDRUS-1D modeling at the G-35 do not correspond well with the observed ground water data. Data from this site are insufficient to generate a reasonable fate and transport model for constituents in the vadose zone. Nevertheless, many years of data collection demonstrate that placement of an ET barrier at G-35 will reduce the recharge rate and chloride flux to near zero.

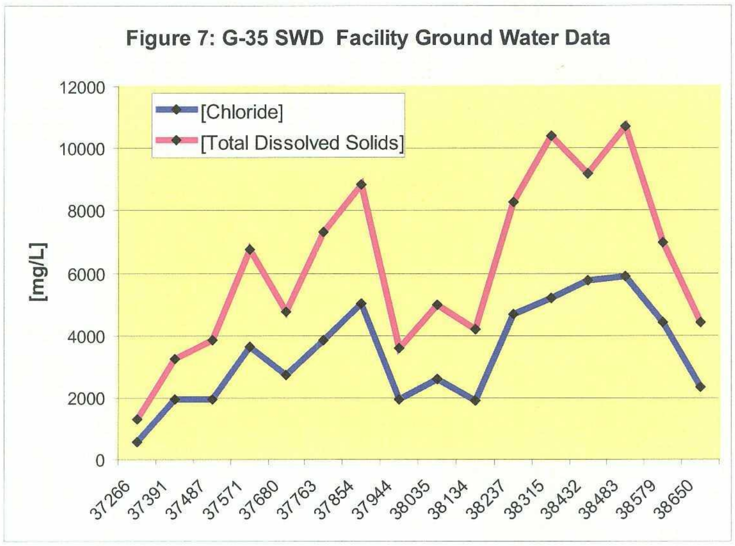

Figure 7: Analytical Results from the G-35 Monitoring Well.

The research presented in Appendix A supports our modeling simulations and our conclusion that an appropriately designed ET infiltration barrier is an effective remedy for release sites such as the F-35 and G-35 tanks and pits.

Installation of an Anisotropic ET barrier permanently and immediately protects fresh water, public health and the environment. We believe that the anisotropic ET barrier remedy effectively meets all mandates of the Oil and Gas Act. Except for verification that the installation of the barriers is consistent with the design presented herein, we propose no on-going monitoring of the vadose zone. The efficacy of the ET Barrier design has been verified by decades of monitoring at various sites throughout the US (see Appendix A and other references). Ground water monitoring is sufficient to measure the sucess of the ET Barriers.

Appendix A

Evaluation of Vadose Zone Remedy Alternatives

The references listed in the main body of the report and included in this appendix present years (and sometimes decades) of field monitoring and exhaustive simulation modeling of ET infiltration barriers. These peer-reviewed and public domain government reports clearly demonstrate the efficacy of the ET infiltration barrier designs considered for this site. The EPA Fact Sheet provides a recent summary of the monitoring data including the 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). This table is included in the body of the report as well as below.

	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

Table 1: Summary of Percolation Data for ET Barriers (EPA Fact Sheet)

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 Anisotropic Barrier (0.05 mm/year). All infiltration barrier systems performed equally well four years after installation (2001 data) and did not measure any infiltration. The long-term efficacy of these barrier systems being essentially equal, we considered other factors such as ease of installation and potential traffic to the site in making our recommendation. The evaluation of the three alternatives is presented below.

The Capillary Barrier and Anisotropic 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. Because no nearby clay is available to meet the design criteria of a 60 cm compacted clay layer, we do not recommend this design. 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 and public safety risks caused by the increase in truck traffic required to implement this design.

The Monolithic ET Barrier is easy to install and performs well as a landfill cover. This design is typically our preferred alternative and was employed at the D-20 Reserve Pit near Eunice. To prevent any upward migration of salt to the soil horizon, the monolithic barrier must be at least 4-feet thick. This thickness requirement cannot be met at all sites. At the F-35 and G-35 sites, sufficient borrow material may not be available nearby and meeting this thickness requirement could be problematic. The selected alternative allows a thinner ET cover.

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The rest of Appendix A is available on the enclosed cd.

Appendix B

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After cessation of operations at the F-35 and G-35 sites, the redwood tanks were removed and the area below them was excavated to an approximate depth of ten feet. Borings for monitoring wells were advanced adjacent to the excavations. As such, the borings do not penetrate the vadose zone immediately below the former junction boxes. To characterize the sites, samples were collected at depths during the borings and the monitoring wells were installed. More than four years of ground water monitoring events together with the vadose zone chloride concentration data demonstrates that chloride from the sites has entered ground water in sufficient mass to cause exceedance of the WQCC ground water standard.

To model the effect of the vadose zone remedy's impact on ground water output from HYDRUS-1D is used as input to a ground water mixing model. Vadose zone chloride concentration is scaled to allow calibration of the model to the monitoring well chloride concentration data.

HYDRUS-1D numerically solves the Richard's equation for vadose zone 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.

HYDRUS INPUTS:

Soil Profile - Information for the soil profile (or vadose zone thickness and texture) is based upon the boring logs from the 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 50 feet at the site.

Dispersion lengths - Conservative dispersion lengths of less than 6% of the model length 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), which is less than 10 miles south-southeast of the F-35 and G-35 sites.

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.

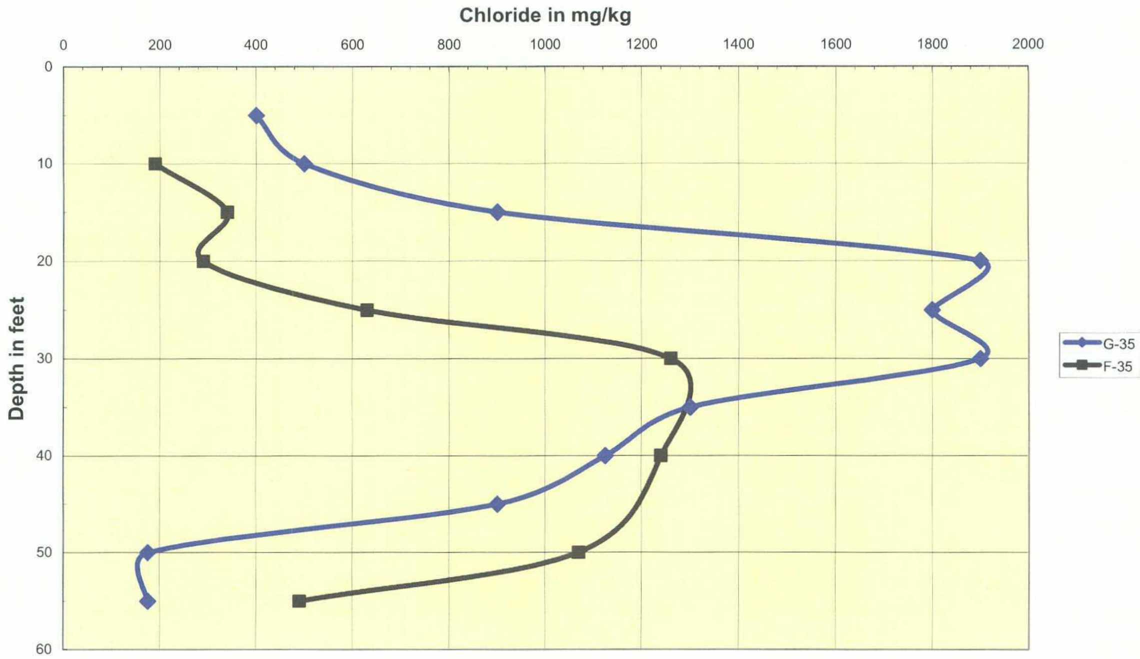
Soil Moisture - Because soils are relatively dry in this climate and vadose zone hydraulic conductivity varies with moisture content, it is important that simulation experiments of different remedial strategies begin with a representative soil moisture content. Commonly, the calculation of soil moisture 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 these sites, only minimal changes in the HYDRUS-1D soil moisture content profile occurred after year 25 of the initial condition calculation, 92 years (2 cycles of the 46 years of weather data) was considered more than sufficient to establish an initial moisture condition. This vadose zone moisture content profile was the basis for subsequent initial condition simulations.

Because the sites were active until about four years ago, this "steady state" vadose zone moisture content profile was considered to be too "dry" to represent the current site for modeling purposes. Therefore to generate additional soil moisture content profiles, a model was constructed featuring approximately seven additional 25 cm precipitation events a year for 30 years. This length of time was chosen as it is sufficiently long to generate a "wetter" soil profile. At the end of the 30 year time interval, the model was run an additional 16 years without additional precipitation added to the atmospheric input file to simulate vadose zone moisture content with cessation of operations. This time length was chosen as to be long enough to confirm "drying" of the soil profile.

From this data, a "wet" soil moisture content profile was taken at a time about 100 days after cessation of additional precipitation. A second "moist" moisture content profile was taken at a time of about two years after cessation of additional precipitation. The "dry" soil moisture content profile is as described in the first paragraph of this subject.

Initial Chloride Profile – Field chloride soil concentrations (mg/kg) from samples obtained during the boring of the F-35 and G-35 monitoring wells are shown in Figure 1. Within the vadose zone, soil pore water movement is predominantly vertical. Relatively small amounts of lateral movement occur through diffusion and dispersion. Because the monitoring well (and soil sampling) locations are at the edge of the sites, the chloride concentration data in Figure 1 probably underestimates chloride concentrations immediately below the former tanks and pit. It is thought that chloride concentration data from the lower vadose zone (25 feet to 50 feet bgs) is more accurate.

Figure 1: Chloride Concentration at Depth for F-35 and G-35



Integration of the chloride contained within the profile yielded a chloride load of 27.6 kg/m^2 at F-35 and 37.9 kg/m^2 at G-35. The 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 conditions and a default dry bulk soil density of 1,390 kg/m^3, soil water moisture concentrations (mg/L) were calculated for the HYDRUS 1-D soil profile nodes. These chloride concentrations were initially installed in the HYDRUS-1D model. Because chloride is conservative, the chloride load is scalable and can be adjusted to permit calibration with ground water quality data.

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).

MIXING MODEL INPUTS:

Influence Distance - The influence distance is defined as the maximal length of the release parallel to ground water flow direction. From the dimensions of the tank and reserve pits, an influence distance of 100 feet was used.

Background Chloride Concentration – from regional data, a value of 100 mg/L chloride for ground water was used at this location to be conservative of ground water quality. Some data suggests that 50 mg/L is more accurate.

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 21 and 40 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 F-35 and G-35 sites, the saturated hydraulic conductivity of the uppermost saturated zone is assumed as 40 feet/day.

Ground water Gradient - From USGS well data (1996), ground water flows southeast in the area under a hydraulic gradient of approximately 0.0036 ft/ft. The resulting ground water flux is 3.7 cm/day.

Aquifer Thickness - A restricted aquifer thickness of 10 feet was employed in the mixing model as a conservative measure to cause over-estimation of chloride concentration in an imaginary receptor well.

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 F-35 and G-35 Sites

Input Parameter	Source
Vadose Zone Thickness - 50 feet	From monitoring wells on the sites
Vadose Zone Texture	Boring Logs and professional judgment
Dispersion Length - 6% or less of model length	Professional judgment
Climate	Pearl, N.M. Weather Station data
Soil Moisture	HYDRUS-1D initial condition simulation
Initial soil chloride concentration profile	From Monitoring Well Boring samples within site
Length of release parallel to ground water flow - 100 feet	From site dimensions
Background Chloride in Ground Water - 100 ppm	Regional Data
Ground Water Flux – 3.6 cm/day	Calculated from regional data
Aquifer Thickness - 10-feet	Aquifer thickness penetrated by on-site wells

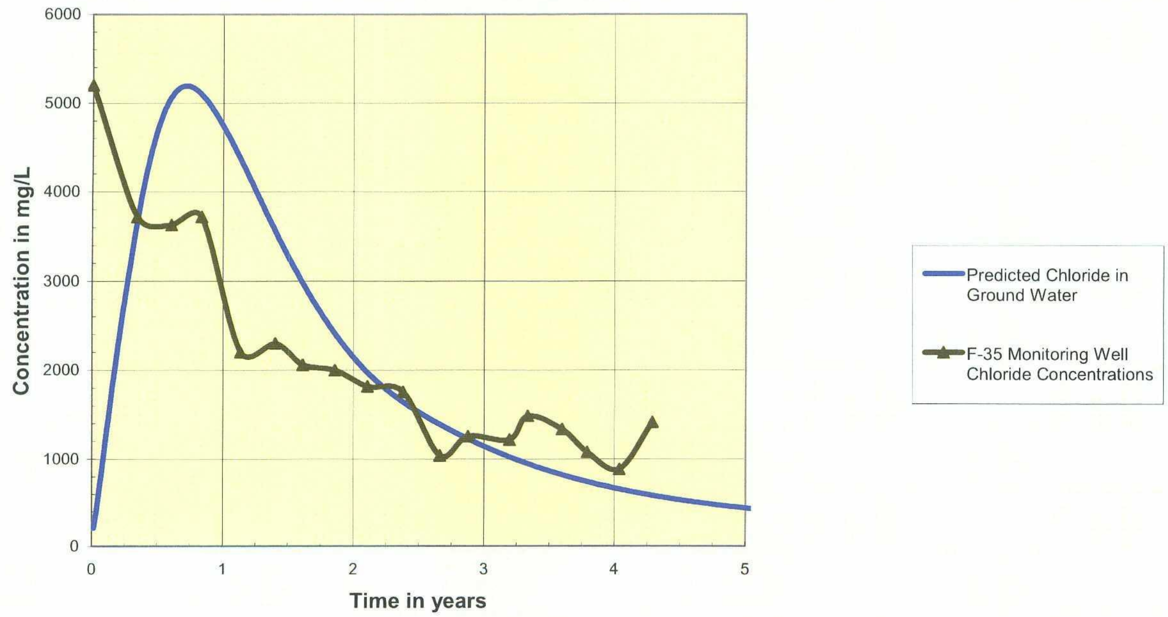
Model Calibration to the F-35 Site

Modeling of the F-35 site used a 50-foot thick vadose zone soil profile constructed and hydrated with the "wet" vadose zone moisture content as discussed in the **Soil Moisture** section above. This choice of soil moisture content is most representative of site conditions at that time. Chloride concentrations were those obtained from the samples obtained during installation of the F-35 monitoring well. The concentrations were installed as detailed above in the **Initial Chloride Profile** section.

The model was run for five years with the results shown in Figure 2. Plotted with the model's predicted chloride concentration in the aquifer are the results of the sampling events of the F-35 well.

To calibrate the model, the chloride concentration output from the HYDRUS-1D model was multiplied by a concentration factor to match early peak chloride concentration with observed chloride concentrations in the F-35 monitoring well (5,200 mg/L in Jan., 2002). This calibration method simply adjusts the chloride load in the vadose zone to permit matching the response in the aquifer. The mixing

Figure 2: Predicted Chloride Concentration and Measured Chloride Concentration in the Aquifer, F-35 Site



model input requires a constant chloride concentration input for ground water. There is a time delay as the model numerically reaches an "equilibrium" between ground water chloride concentration and vadose zone water chloride concentration (from time 0.0 to about time 0.75 years).

From examination of the HYDRUS-1D output files, the peak chloride concentration within the initial soil chloride concentration profile passes to ground water at a time of about 2.1 years.

As can be seen in Figure 2, the model over predicts chloride concentration in ground water for the first 2.1 years. After this time, chloride concentrations are under predicted by the model. However, chloride entering ground water after this time originated from the upper vadose zone. Compared to observed ground water data, it is concluded that this initial chloride concentration profile under represents chloride in the upper vadose zone.

Because the model over predicts chloride concentration in ground water through the time in which the peak concentration of chloride passes into ground water (chloride from the lower vadose zone), it is considered conservative of ground water quality. In the absence of any remedy, the model predicts that chloride will exceed the ground water standard of 250 mg/L for about 7.5 years.

Model of the Remedy for the F-35 Site

The remedy modeled for the site 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.

In order to model the installation of the remedy, the chloride concentration profile constructed from the monitoring well boring samples was installed. This was run with different initial soil moisture contents because this information is not known.

- For Simulation 1, the "dry" initial moisture content soil profile was employed. The predictions using this profile required physically impossible assumptions to match ground water data and this scenario was eliminated.
- For Simulation 2, a "moist" initial moisture content soil profile taken at a time approximately 2 years after cessation of additional precipitation events was used.
- For simulation 3, the "wet" moisture content soil profile was employed.

The "moist" and "wet" soil profile scenarios were chosen to bracket predicted outcomes of the vadose zone remedy at this site.

In all cases, the concentration factor within the mixing model was adjusted to match the early peak chloride concentration of the model to the F-35 monitoring well data (approximately 1,420 mg/L) of March, 2006. This adjustment was made in order to be most representative of installation of the remedy at the current time.

Given a vadose zone chloride concentration profile based upon mass of chloride per mass of soil, it is assumed that all chloride resides within the soil water for a given depth interval. Given identical mass chloride concentration data, a "wet" soil profile will therefore contain pore water with a lower chloride concentration than a "dry" soil profile.

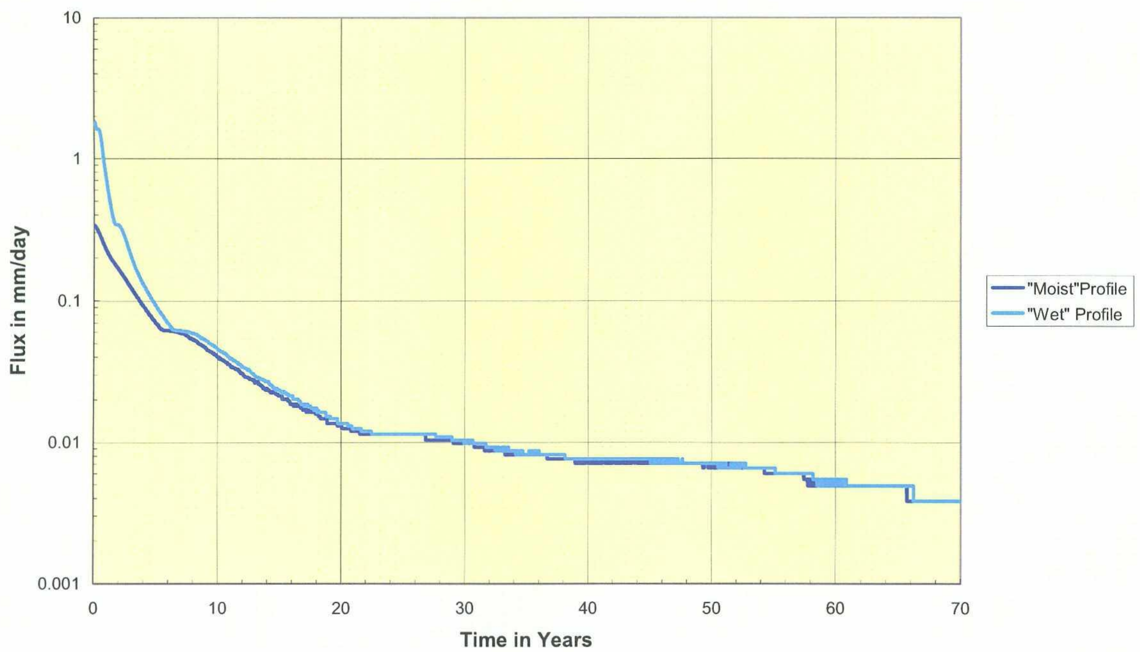
A "wet" soil profile will feature higher hydraulic conductivities than a "drier" soil profile. Therefore, a given chloride concentration profile will move through the vadose zone and enter ground water in less time given a "wet" soil profile than a "drier" soil profile.

In order to match the "wet" soil profile to existing ground water data, a concentration factor less than 1.0 (0.37) was necessary while the "moist" soil profile required a concentration factor greater than 1.0 (1.84). This is a reflection of the higher chloride flux of the "wet" soil profile.

This can also be seen in Figure 4 wherein the area under the curves represents total chloride in the mixing zone of the model. Clearly, there exists less area underneath the "wet" profile curve than the "moist" profile representing a smaller chloride mass entering ground water. In the case of the "wet" profile, the smaller area represents the fact that much of the chloride mass has already entered ground water due to the higher hydraulic conductivities of the "wet" profile. This adjustment of the concentration factor implies that differing masses of chloride reside within the vadose zone depending upon moisture content.

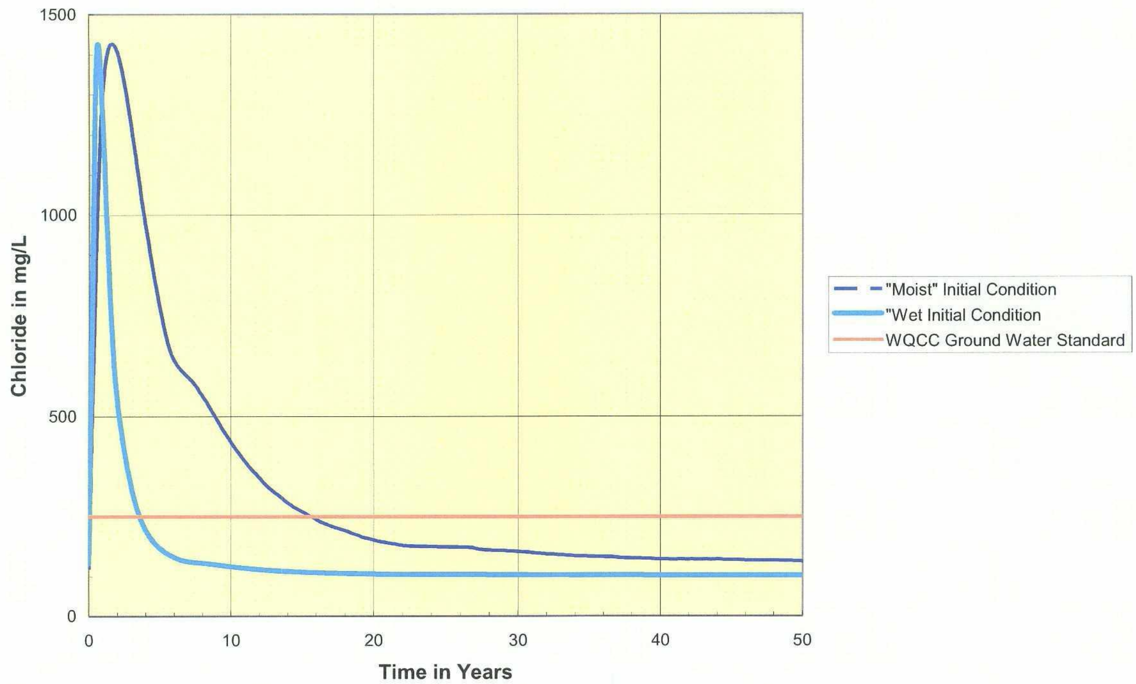
As can be seen in Figure 3, in all cases, the vadose zone flux to ground water is reduced by at least one order of magnitude.

Figure 3: Predicted Vadose Zone Water Flux to Ground Water with an ET Barrier , F-35 site



Resultant chloride concentrations in a monitoring well at the down gradient edge of the mixing zone are shown in Figure 4. Predicted chloride concentration in ground water decreases to less than 250 mg/L in all simulations. The time that this occurs at varies from less than four years after installation of the ET barrier for the "wet" moisture content to about 16 years for the "moist" moisture content. The drier soil moisture content profile causes lower hydraulic conductivities. Therefore the "moist" lower vadose zone takes longer to pass the chloride to ground water than the "wet" vadose zone moisture content profile. These simulations all assume no other remedy beyond installation of the ET barrier occurs.

Figure 4: Predicted Chloride Concentration in the Aquifer With an ET Barrier, F-35 Site



As the actual vadose zone soil moisture content is unknown, it is not possible to refine the estimates of the modeling. Installing the ET barrier together with the additional point-source treatment program will lower the time estimates at which ground water below the F-35 site will meet the WQCC ground water standard.

Model Calibration to the G-35 Site

Modeling of the G-35 site used a 50-foot thick vadose zone soil profile constructed and hydrated as discussed above for the F-35 site. Chloride concentrations were from the samples obtained during installation of the monitoring well at the G-35 site, and were installed as detailed above.

An attempt was made to calibrate the G-35 model in the same manner as the F-35 model. An examination of the output demonstrates that there exist additional chloride fluxes to ground water from within the vadose zone at the site. Available data is insufficient to create a more robust model that might correlate with the observed chloride concentrations at the G-35 monitoring well.

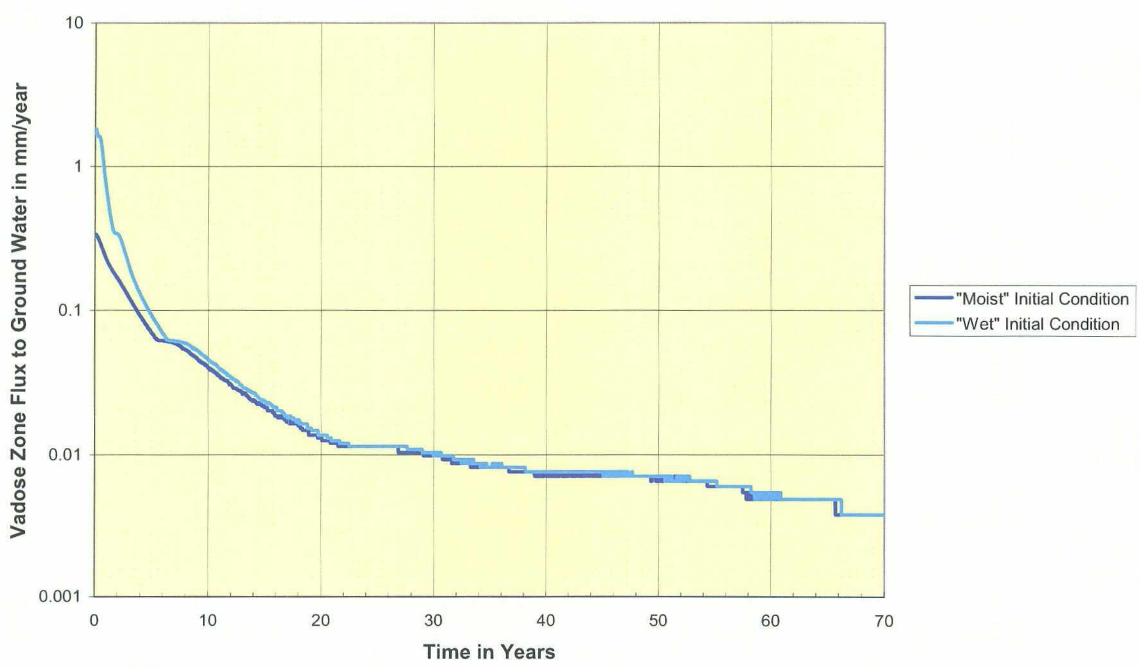
Model of the Remedy for the G-35 Site

Despite the inability of the model to predict observed chloride concentrations in the aquifer, the results from the vadose zone remedy modeling of the F-35 site suggest that the model can provide a qualitative prediction of an installed remedy at the G-35 site. The chosen remedy for the site is an ET barrier identical to that modeled for the F-35 site discussed above.

In order to model the installation of the remedy, the chloride concentration profile constructed from the monitoring well boring samples was installed. This was run with different initial soil moisture contents in the same fashion as for the F-35 site. As for the F-35 site, the concentration factor within the mixing model was adjusted to match the early peak chloride concentration of the model to the G-35 monitoring well data (approximately 1,540 mg/L) of March, 2006. Again, this adjustment is made in order to be most representative of installation of the remedy at the current time.

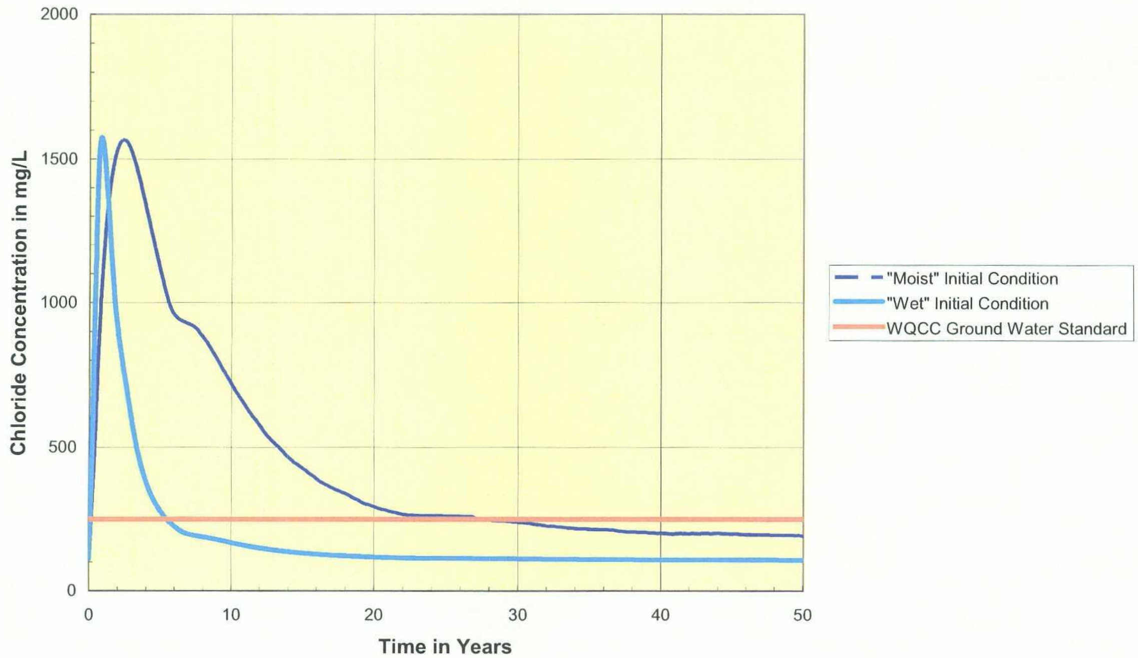
As can be seen in Figure 5, the vadose zone flux to ground water is reduced by at least one order of magnitude with installation of an ET barrier. This reduction occurs within a time interval of 4 years to about 10 years depending upon the initial moisture content of the vadose zone.

Figure 5: Predicted Infiltration Rate to Ground Water with Installed ET Barrier, G-35 Site



Resultant chloride concentrations in a monitoring well at the down gradient edge of the mixing zone are shown in Figure 6. Using the chloride concentration profile obtained from boring of the G-35 monitoring well, results in reduction of chloride concentration in ground water to less than 250 mg/L. The time that this occurs varies from less than six years after installation of the ET barrier for the "wet" moisture content to about 28 years for the "moist" moisture content. Because available data does not explain observed chloride concentrations in ground water, these time estimates are not considered accurate. The resultant chloride concentrations are considered an indicator of the efficacy of the ET barrier.

Figure 6: Predicted Chloride Concentrations in the Aquifer with an Installed ET Barrier at the G-35 Site



These simulations all assume no other remedy beyond installation of the ET barrier occurs. Installing the ET barrier together with the additional point-source treatment program will shorten the time interval at which ground water below the G-35 site will meet the WQCC ground water standard. Currently, however, ground water quality is suitable for livestock.