Modeling Study of Produced Water Release Scenarios

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PREPARED UNDER CONTRACT BY:

Jan M. H. Hendrickx, Department of Earth & Environmental Science
New Mexico Tech, Socorro, New Mexico

Graciela Rodriguez, R.T. Hicks Consultants, Ltd., Albuquerque, New Mexico

Randall T. Hicks, R.T. Hicks Consultants, Ltd., Albuquerque, New Mexico

Jirka Simunek, Professor and Hydrologist, Department of Environmental Sciences, University of California Riverside, Riverside, California

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Evan Sedlock, ChevronTexaco Energy Technology Company; PWIG Chairman

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Mickey Carter, ConocoPhillips Corporation
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EXECUTIVE SUMMARY

Project Goals

This document provides a scientific basis for operators, regulators and landowners to determine if assessment or remediation of produced water releases will provide a meaningful environmental benefit.

The two principal research objectives of this study are (i) the identification of produced water release scenarios that have a potential to cause ground water quality impairment in homogeneous subsurface geologic profiles, and (ii) the prediction of chloride movement through the vadose zone[1] for different release scenarios. Secondary objectives of the study included evaluation of the effect of heterogeneity on the migration of chloride through the vadose zone, the impact of repeat releases and the effect on ground water quality of surface soil restoration by revegetation and soil leaching.

This modeling study deals with sudden produced water releases of 100 to 10,000 barrels that infiltrate into the soil within a period of 1 day (sand soil) to 30 days (clay soil). Depending on the environmental conditions, the chloride molecules in the produced water may or may not reach the ground water. However, if produced water remains in the root zone, impacts to plants and soil fertility are possible.

Release Scenarios Deemed Unlikely To Cause Ground Water Quality Impairment

Numerical and analytical model simulation results suggest that large spills (100 and 10,000 barrels) will not cause unacceptable impairment of ground water quality if the depth of soil penetration is small (i.e. the release spreads over a large area) and the depth to ground water exceeds 3 meters. However, the results predict that most large produced water releases that occur over thin (< 3 meters), sandy vadose zones have the potential to cause unacceptable impairment of ground water quality. Although no simulations were performed for small releases (< 100 barrels), the results from this study can be used to infer that small releases that spread over the land are unlikely to cause unacceptable impairment to ground water quality when the depth to ground water exceeds 3 m.

Release scenarios where a high-chloride-concentration produced water collects (e.g., within an unlined bermed area or a topographic depression) above a thin vadose zone are more likely to cause ground water impairment relative to releases with contrasting characteristics (e.g.; a low-chloride-concentration-produced water and a release that spreads in a thin layer over the land surface). Other release scenario characteristics (e.g., climate and depth to ground water) have relatively less impact on the maximum chloride concentration observed in a nearby downgradient monitoring well.

The Rate of Migration and Distribution of Chloride in the Vadose Zone

In addition to evaluating scenarios that have the potential to impair ground water quality, this study examined the time required for chloride to migrate through the vadose zone into ground

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[1] The vadose zone, also known as the unsaturated zone, lies between the ground surface and the water table.

water. An understanding of the temporal behavior of a chloride release is useful for timing remedial responses.

The modeling results show that chloride molecules from a produced water release will eventually migrate from the ground surface to ground water as long as there is a net downward flux to the water table. However, because the downward flux of chloride to ground water is often very small, close to zero in arid climates, the migration of chloride to ground water does not necessarily create material impairment of ground water quality. Simulated releases to a thin vadose zone in a humid climate with coarse textured soils result in the earlier arrival of the maximum concentration at an adjacent down-gradient monitoring well relative to a release with contrasting characteristics (e.g., a thick clay vadose zone, in an arid climate). Key release-scenario characteristics that have an impact on the *time* it takes for the maximum chloride concentration to be observed in the well are climate, soil type and depth to ground water.

The Impact Of Heterogeneity

Homogeneous vadose zone soil profiles are rare in nature. Therefore several scenarios with contrasting climate settings were analyzed to determine how clay layers intermixed with sand will affect chloride movement in the vadose zone and the subsequent impact on chloride concentration in ground water. Chloride concentrations simulated for a monitoring well down gradient of the release for the heterogeneous profiles decrease with increasing clay layer thickness in the vadose zone. The modeling results show that the increase in total thickness of clay layers in a profile slows down the chloride movement and results in lower concentrations in an adjacent down gradient monitoring well. Results of the heterogeneous profile simulations performed show that for vadose zones thicker than 3 m, chloride concentrations rarely exceeded 1000 mg/L at the simulated adjacent well.

The Impact of Repeat Releases

Repeat releases are an issue at some sites. Simulations were performed to determine the maximum chloride concentrations in a down gradient adjacent monitoring well as a result of three repeated releases taking place, at 1-year and 5-year time intervals, respectively. If releases are one year apart or less, the effect is a proportional increase in the chloride load. This means higher chloride concentrations in ground water than observed in a single release event. If releases occur at a time interval that is sufficient for the center of mass to reach ground water before the next release or at a time interval sufficiently large to prevent the multiple releases to merge, then repeated releases do not increase the chloride load and the maximum concentration in ground water is similar to a single release event.

The Effects of Soil Flushing

A produced water release may stunt or kill vegetation. While the agricultural industry routinely applies excess irrigation water to remove salt from the root zone, this practice is not used in some oilfields because of perceived increased threat to ground water quality. Flushing soil with water to remove chloride can be an effective alternative to soil restoration by excavation, disposal, and soil importation. Soil flushing was simulated to determine if this action would exacerbate degradation of ground water quality due to produced water releases. On the contrary, simulations show that the application of water to flush chloride below the root zone results in chloride dilution that improves the quality of ground water when compared to the no flushing alternative. Therefore, if the model predicts that a release would not impair ground water quality, then soil flushing at this site will not cause degradation as a result of the addition of water.

The Effect of Revegetation

A limited number of simulations designed to examine the affect of re-establishing a plant cover produced some preliminary results. For humid climates, scenarios that included a plant cover produce lower maximum chloride concentrations in an adjacent down-gradient monitoring well than otherwise similar scenarios without plant cover. Simulations for arid climates produce mixed results that cannot be adequately explained within the scope of the project. The small number of simulations performed for the analysis of plant cover do not allow for definitive conclusions at this time; however, re-establishment of plants after soil restoration appears to have other benefits (e.g., preventing soil erosion) that justify the practice.

The combined effect of irrigation and subsequent revegetation was not specifically examined. However one may speculate that the irrigation-induced shortening of the time for the maximum concentration to reach the nearby down-gradient monitoring well may be offset after revegetation.

TECHNICAL HIGHLIGHTS

Release Scenarios Deemed Unlikely To Cause Ground Water Quality Impairment

The sensitivity analysis performed in this study provides an overview of the likelihood of groundwater impairment for large release volumes (100 bbls and 10,000 bbls). Assuming homogeneous unsaturated zone soil profiles, the results of over 1000 modeled release scenarios reveal that 49% of single-event releases do not cause impairment of ground water above drinking water standards for chloride (250 mg/L) in a monitoring well that is adjacent to the edge of the release. In 70% of these scenarios, chloride concentrations in ground water do not exceed 1000 mg/L. Although these numbers give no information about the fate of chloride from a specific produced water release, they do indicate that a release does not necessarily cause ground water impairment. Tables TH-1 show the distribution of the maximum chloride concentrations in a well that is down gradient of a release during the course of the sensitivity study.

Table TH-1a—Distribution of the maximum chloride concentrations simulated in a down gradient monitoring well (Background chloride concentration assumed to equal zero)

Maximum Concentration (ppm)	Frequency		Cumulative Frequency	
	Number	%	Number	%
< 250	501	49	501	49
250 – 500	120	12	621	61
500 – 750	73	7	694	68
750 – 1000	25	2	719	70
> 1000	305	30	1024	100

Table TH-1b—Distributions of the maximum chloride concentrations for brine concentrations of 10,000 and 100,000 ppm after spills of 100 and 10,000 barrels simulated in a down gradient monitoring well
(Background chloride concentration assumed to equal zero)

	Brine Concentration															
	10,000 (ppm)								100,000 (ppm)							
	Barrels								Barrels							
	100		10,000		100		10,000		100		10,000		100		10,000	
	Frequency				Cumulative Frequency				Frequency				Cumulative Frequency			
Maximum Concentration (ppm)	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
< 250	187	73	161	63	187	73	161	63	87	34	66	26	87	34	66	26
250 – 500	21	8	27	11	208	81	188	73	35	14	37	14	122	48	103	40
500 – 750	15	6	20	8	223	87	208	81	20	8	17	7	142	55	120	47
750 – 1000	4	2	5	2	227	89	213	83	8	3	8	3	150	59	128	50
> 1000	29	11	43	17	256	100	256	100	106	41	128	50	256	100	256	100

A sensitivity analysis with over 2000 scenarios simulated shows that the initial depth of the produced water (spill height) and the chloride concentration of the brine has the greatest affect on ground water quality predictions. These two factors were combined into a single factor: chloride loading, or “Release Chloride Mass” (g/m^2) – a parameter that can be measured in the field or calculated with known release characteristics. The second most important factor is aquifer thickness, which basically determines the volume of ground water available for dilution of the chloride seepage (flux) from the vadose zone to the aquifer. Other factors certainly influence the predictions as well, but accurate prediction of possible ground water impairment is impossible without a reasonable knowledge of chloride loading and aquifer thickness.

Factors influencing chloride migration are introduced in Chapter 2. Sensitivity analysis of factors determining chloride fate are covered in detail in Chapter 4. A guide to understanding the role of key produced water release and chloride fate factors is presented in Chapter 11.

The Rate of Migration and Distribution of Chloride in the Vadose Zone

In addition to evaluating which scenarios have the potential to impair ground water quality, this study examined the time required for chloride to migrate through the vadose zone into ground water. The modeling results suggest that chloride molecules will migrate from the ground surface to ground water as long as there is a net downward flux to the water table. However, because the flux of chloride to ground water is often very small, especially in arid climates, the migration of chloride to ground water does not necessarily create material impairment of ground water quality.

Model predictions of the *time* required for the maximum chloride concentration to reach an adjacent well were used to measure the sensitivity of each factor to the movement of chloride through the vadose zone. Results indicated that climate, vadose zone texture, and ground water depth exerted the most control on this prediction. Other factors were relatively unimportant in the prediction of the time of transport.

The vertical distribution of chloride in the vadose zone after a release was simulated for two representative climates: Hobbs, New Mexico (arid climate) and Shreveport, Louisiana (humid climate). The movement of chloride during the first 5 weeks after a release did not depend on climate, but rather on the particular weather conditions (e.g., rainfall events) after the hypothetical release. Review of 96 scenarios modeled showed that the center of mass (of chloride) after 5 weeks of transport was sometimes deeper in Hobbs and sometimes deeper in Shreveport, despite the fact that other input parameters were held constant. The depth of penetration depended strongly on weather conditions and, more importantly, on the soil texture.

The modeling shows that chloride migration during the first 5 weeks after a release accounts for 70% of the chloride migration observed after 50 weeks. On average, the center of mass is predicted to move about 1 m in the arid climate and 3 m in the humid climate. The average penetration depth for the center of mass for clay, clay loam, sandy loam and sand are about 0.2, 0.3, 2.0, and 5.0 m respectively.

For many scenarios, chloride migration from the ground surface to a 30-m deep aquifer requires decades and, in the arid climate, sometimes centuries. The migration of chloride over time in 22 different scenarios was examined. As expected, the maximum predicted concentration of chloride decreases with the depth of penetration: the center of mass attenuates with vertical transport. In a humid climate the observed attenuation is faster than in the arid climate. The climatic conditions do not influence the amount of attenuation, only the time frame necessary for the attenuation to take place.

Arrival time of the maximum chloride concentration is discussed in detail in Chapter 4, section 4.4.2. The initial and long-term distribution of chloride is covered in Chapters 5 and 7, respectively.

The Impact Of Heterogeneity

Homogeneous vadose zone soil profiles are rare in nature. Therefore, 384 selected heterogeneous scenarios were simulated to evaluate the importance of clay layers. Modeling confirmed what many would consider intuitive: increasing the total thickness of clay layers decrease the maximum chloride concentration at the adjacent down- gradient monitoring well and increases the time for the maximum chloride concentration to be observed. Tables TH-2a – b provide the distribution of maximum chloride concentrations for all the heterogeneous simulations conducted during the course of the study. Table TH-2a shows that 53% of the cases did not result in chloride concentrations above 250 ppm, and that the chloride concentration in ground water exceeded 1,000 ppm in 13 cases, or only 3% of all simulations. These results are better than those in Tables TH-1a – b because there are no 3 m deep profiles included in the heterogeneous profiles, and clay layers were present in each profile. (The 3 m profiles were assumed to be vulnerable in real world situations regardless of the presence of clay layers.) Because heterogeneous conditions are more common in nature than homogeneous conditions, the statistics associated with heterogeneous conditions may be more representative of conditions commonly observed in the field. Details of the heterogeneous profile simulations are presented in Chapter 6. Appendix A presents all results of the simulations for the homogeneous and heterogeneous profiles.

Table TH-2a—Distribution of the maximum chloride concentrations detected in a down gradient monitoring well for all 384 heterogeneous profiles simulated These profiles were 10, 20, and 30 m deep

Maximum Concentration (ppm)	Frequency		Cumulative Frequency	
	Number	%	Number	%
< 250	202	53	202	53
250 – 500	104	27	306	80
500 – 750	46	12	352	92
750 – 1000	19	5	371	97
> 1000	13	3	384	100

Table TH-2b—Distribution of the maximum chloride concentrations for brine concentration 100,000 ppm after spills of 100 and 10,000 barrels at Hobbs and Shreveport detected in a down gradient monitoring well for 384 scenarios in heterogeneous profiles. These profiles were 10, 20, and 30 m deep

	Hobbs, brine 100,000 ppm								Shreveport, brine 100,000 ppm							
	Barrels								Barrels							
	100		10,000		100		10,000		100		10,000		100		10,000	
	Frequency				Cumulative Frequency				Frequency				Cumulative Frequency			
Maximum Concentration (ppm)	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
< 250	67	70	41	43	67	70	41	43	55	57	39	41	55	57	39	41
250 – 500	15	16	33	34	82	85	74	77	24	25	32	33	79	82	71	74
500 – 750	8	8	13	14	90	94	87	91	11	11	14	15	90	94	85	89
750 – 1000	3	3	5	5	93	97	92	96	4	4	7	7	94	98	92	96
> 1000	3	3	4	4	96	100	96	100	2	2	4	4	96	100	96	100

The Impact of Repeat Releases

Repeat releases are an issue at some sites. In this study, repeat releases were simulated using 5 different vadose zone profiles and different depths to ground water. If releases are 1 year apart or less, the effect is a proportional increase in the chloride load. This means higher chloride concentrations in ground water than observed in a single release event. If releases occur at a time interval that is sufficient for the center of mass to reach ground water prior to the next release or at a time interval sufficiently large to prevent the multiple releases to merge, then repeated releases do not increase the chloride load and the maximum concentration in ground water is similar to a single release event. Chapter 8 presents the results of the repeat release simulations.

The Effects of Soil Flushing

Soil flushing can be an effective alternative to soil restoration by excavation, disposal, and soil importation. Natural soil leaching occurs in the humid climate and a soil flushing program is typically used in lower permeability soils. In the arid climate, previous simulations demonstrated that the center of mass remained near the ground surface for decades. Therefore, soil leaching was simulated for the arid climate only. Although only 8 scenarios were modeled, soil restoration by leaching actually improved the ground water quality in 7 of the 8 cases. For the remaining scenario, predicted ground water quality was 295 ppm chloride with a soil leaching program and 291 ppm under the no-action alternative. Modeling of this topic is presented in Chapter 9.

The Effect of Revegetation

Some arid climate experts believe that recharge of ground water does not occur in flat areas where vegetation is present, maintaining that the plants quickly use any precipitation that would cause downward movement of soil water. The effect of vegetation was simulated in this study by assuming that warm and cold weather grass would re-vegetate a spill area in a humid climate after chloride in soil decreased to about 500 ppm. In the arid climate, the evergreen Four Wing Salt Bush was used as the volunteer species under these same conditions. Vegetation reduced the chloride flux to ground water in the humid climate. In the arid climate, model simulations predicted a lower chloride concentration in ground water in 10 of 17 sand-profile scenarios. For the seven arid climate scenarios where modeling predicted a higher chloride concentration in ground water, the increases were less than 30%. More work is required to fully understand these results. The examination of the effects of revegetation is presented in Chapter 10.

Model Verification

The model HYDRUS used in this study was verified for predicting chloride movement in the vadose zone by comparing site-specific modeling results to a limited number of well-characterized exploration and production field sites. Chapter 12 summarizes the field observations and model verification.

1. 0 Introduction

1.1 Project Overview

1.1.1 Research Objective

The American Petroleum Institute (API) retained *R.T. Hicks Consultants, Ltd.* (*Hicks Consultants*) to numerically model a range of representative produced water release scenarios. The project's objectives were (1) identification of release scenarios that have a potential to cause unacceptable ground water quality impairment, and (2) prediction of chloride movement through the vadose zone for the different release scenarios. Chloride was selected for the modeling exercise because it is the most common anion in produced water. Further, chloride can cause damage to the productive capacity of soil, and its concentration in ground water often defines the remedy required for an affected aquifer.

Due to the complexity inherent in nature, any model used to simulate potential outcomes of different produced water release scenarios is limited. Nonetheless, with careful attention to relevant details, a proper model can provide an acceptable forecast of chloride ion behavior after a produced water release. The numerical model HYDRUS-1D was used to simulate the transport of chloride from the land surface through the vadose zone to ground water. The predictions from HYDRUS-1D were input into a simple ground water mixing model to calculate the degree of ground water quality impairment. The findings in this report can provide the basis for a series of tools that can assist a producer, regulator, or landowner in determining if a particular release requires subsurface characterization and/or ground water remediation.

1.1.2 Project Organization

Table 1-1 shows how the project was separated into four primary tasks, tasks 1 – 4; and five supplemental tasks, tasks 1a – 3a and tasks 5 and 6.

Task 1, a sensitivity analysis, identified environmental and release factors (e.g., climate, release volume, etc.) that were most important in affecting the distribution of chloride in the vadose zone and the probability that a release would cause ground water quality impairment. Tasks 2 and 3 determined the depth of chloride infiltration and the vertical distribution of chloride over time as a function of climate. Task 4 explored the impact of the repeated releases as a function of the climate and the elapsed time between the releases. Tasks 1a, 2a, and 3a consider how vadose zone heterogeneity affects model predictions. Task 5 explored soil leaching as a technique to restore the soil impaired by produced water without compromising ground water quality. Task 6 explored the effect of vegetation on produced water movement since many spill sites become vegetated after some time.

1.1.3 Scope of Modeling

A series of simulation experiments were conducted to evaluate how different produced water release and environmental characteristics (model inputs or factors) affect the fate of chloride in the subsurface (model outputs or responses). Model inputs include the hydrological and geological characteristics of the vadose zone and of the aquifer, climate, and characteristics of the release. A total of 11 factors were identified:

1. Texture of the vadose zone (e.g. sand, clay, etc.),

2. Depth to ground water,
3. Natural water content in the vadose zone,
4. Dispersion length of chloride in the vadose zone,
5. Climate,
6. Chloride concentration of the produced water release,
7. Volume of the produced water release,
8. Initial depth of produced water on the land surface (e.g., ponded within a berm or dispersed over a large area),
9. Ground water flux of the aquifer,
10. Background chloride content in the aquifer, and
11. Saturated thickness of the aquifer.

Model outputs from HYDRUS-1D are:

- The maximum chloride concentration entering the aquifer from the vadose zone, and
- The arrival time of the maximum chloride concentration at the aquifer.

Model outputs from the groundwater mixing model are:

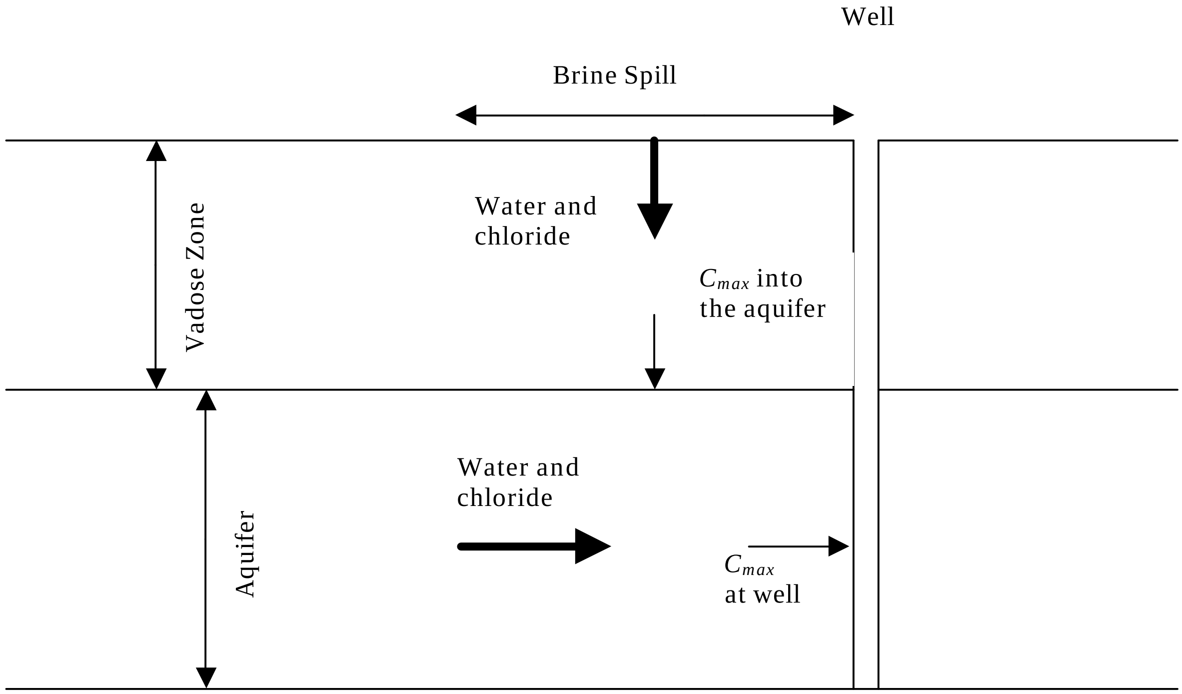
- The maximum chloride concentration measured at a monitoring well at the down gradient edge of the surface produced water release, and
- The arrival time of the maximum chloride concentration at a monitoring well at the down gradient edge of the surface produced water release.

Table 1-1—Project Organization

Task	Homogeneous Profiles	Task	Heterogeneous Profiles
1	Sensitivity analysis	1a	Sensitivity analysis
2	Initial depth of impact		
3	Vertical redistribution over time	3a	Vertical redistribution over time
4	Repeated releases	4a	Repeated releases
5	Soil restoration by leaching		
6	Effect of vegetation		

Figure 1.1 depicts the input parameters and model outputs.

Figure 1.1—Schematic of chloride movement from brine spill through the vadose zone towards monitoring well



1.2 Background

1.2.1 Fulfilling an Industry Need

Ground water is a major source of water for municipalities and is used for agriculture, mining, and manufacturing. Regulatory agencies charged with protection of ground water place the burden of mitigating the effects of accidental releases or engineered discharges on industry as the discharger. To demonstrate whether a release will cause unacceptable impairment, these agencies usually rely on guidance documents or relatively conservative assumptions to assess the effects of a release on ground water quality. However, they do not have the work force to perform independent tests of assumptions or conclusions in spill reports or permit documents. Few guidance documents exist presently and a technically robust guidance document that addresses produced water releases does not exist. In the absence of such a document, surface landowners and regulators often use very conservative assumptions in the review of release incidents.

This document describes chloride movement in the vadose zone and potential ground water quality impairment from produced water releases. Single releases of 10 barrels or less typically do not result in soil or groundwater impacts that require anything more than a minimal response action. Larger releases of produced water (such as the 100-bbl releases studied herein) can cause damage to the productive capacity of soil. A cost-effective method of soil restoration for larger produced water releases is in-place chemical amendment and soil flushing (Carty et al., 1977). However, the regulatory sensitivity regarding protection of ground water has caused limitation of this technique because of its requirement of significant water application. Carty et al., (1977) offers little guidance relating to protection of ground water quality. This report provides information on potential effect on ground water quality caused by soil flushing.

1.2.2 Potential Impacts of a Release

Loss of Soil Productive Capacity

Productive capacity is the ability of the soil to support vegetation such as range land grass, irrigated crops or turf. Two types of soil damage can occur because of a produced water release. The first is a loss of soil permeability due to the high sodium concentrations in the produced water, and related to the first is the immediate death or severe stress of vegetation. Sodium ions in produced water replace natural calcium ions in clay minerals, causing swelling of the clay and a loss of soil permeability complicating soil restoration because it causes retention of chloride and sodium in the root zone. The loss of soil permeability will also cause a long-term deterioration of the original soil productivity.

Ground Water Impairment

The secondary drinking water standards for TDS and chloride are 500 mg/L and 250 mg/L, respectively. A produced water release can degrade ground water quality by elevating total dissolved solids (TDS) and chloride concentrations above these standards. Elevated ground water TDS and chloride concentrations higher than 5,000 mg/l and 2,500 mg/l respectively may render ground water unfit for domestic, livestock, or agricultural use. Runyan and Bader (1995) state that salinities [TDS] measuring between 5000 – 6999 mg/L are marginal quality for beef cattle, sheep, swine, and horses and should not be used for pregnant or lactating animals. Salinities above 5000 mg/L are not suitable for poultry

1.2.3 Common Soil Restoration Programs

Commonly accepted alternatives for soil restoration include: (1) passive or natural remediation, (2) *in-situ* chemical amendment remediation, and (3) mechanical remediation (Carty et al., 1997, API Publication 4663, *Remediation of Salt-Affected Soils at Oil and Gas Production Facilities*). Below is a brief description of each alternative.

1. Passive Remediation

Passive remediation uses little human intervention to restore soil. Instead, it relies on natural processes such as precipitation and chemical diffusion to dilute and mitigate the effects of a produced water release.

2. *In-Situ* Chemical Amendment Remediation

The agricultural industry has used this technique extensively to restore the productive capacity of soils. The approach uses chemical amendments, such as gypsum, calcium nitrate, calcite, acidified water, and surfactants, to improve soil drainage damaged by excess sodium in the soil. In addition to these chemicals, water is added to flush the built-up salts beyond the root zone and mulch (e.g. hay) is added to improve soil permeability.

3. Mechanical Restoration

This technique involves the permanent removal of soil that has been contaminated and its replacement with clean soil. This technique is often the most expensive remediation alternative because large machinery is necessary to remove and replace contaminated soils. This method has a high success rate when the soils are completely removed, but the addition of clean soil poses some risks for erosion and the introduction of non-native plants.

1.2.4 Restoration of Chloride in Ground Water

High chloride concentrations in ground water caused by produced water releases are typically addressed in one of three ways: natural attenuation, pumping and disposal/use, or a pump-and-treat system.

1. Natural Attenuation

Chloride attenuation consists of dilution and dispersion in the aquifer. This technique can require years or decades to meet EPA Secondary Drinking Water Standards and is widely used where high chloride concentrations in ground water pose little risk to human health or the environment.

2. Pumping and Disposal/Use

Landowners, regulators or other stakeholders may desire a more active remedy to halt the movement and spread of high TDS and chloride at some locations. In oilfields with injection wells, disposal water can be cost effectively pumped and disposed of using systems already in place. However, unlike natural attenuation or a pump-and-treat systems (described below), this method permanently removes water from the aquifer, depleting the resource. Therefore, some operators employ water from affected aquifers for dust suppression, chilling fluids, and other uses.

3. Pump-and-treat Techniques

These techniques provide containment of high TDS and chloride ground water, and preserve water resources. Unlike hydrocarbons, microorganisms in ground water do not metabolize TDS and chloride. Therefore, ground water restoration requires often expensive mechanical or chemical treatment systems (such as reverse osmosis). The cost of pump-and-treat methodology is often 10-100 times more expensive than natural attenuation or pumping and disposal/use.

2.0 FACTORS INFLUENCING THE MIGRATION OF CHLORIDE

Chloride migration is controlled by a combination of factors related to the vadose zone, the aquifer, and the produced water release. As discussed earlier, 11 factors controlling chloride migration were analyzed. This chapter discusses how these factors affect the movement of the chloride through the vadose zone and in the aquifer.

2.1 Vadose Zone Factors

2.1.1 Vadose Zone Texture

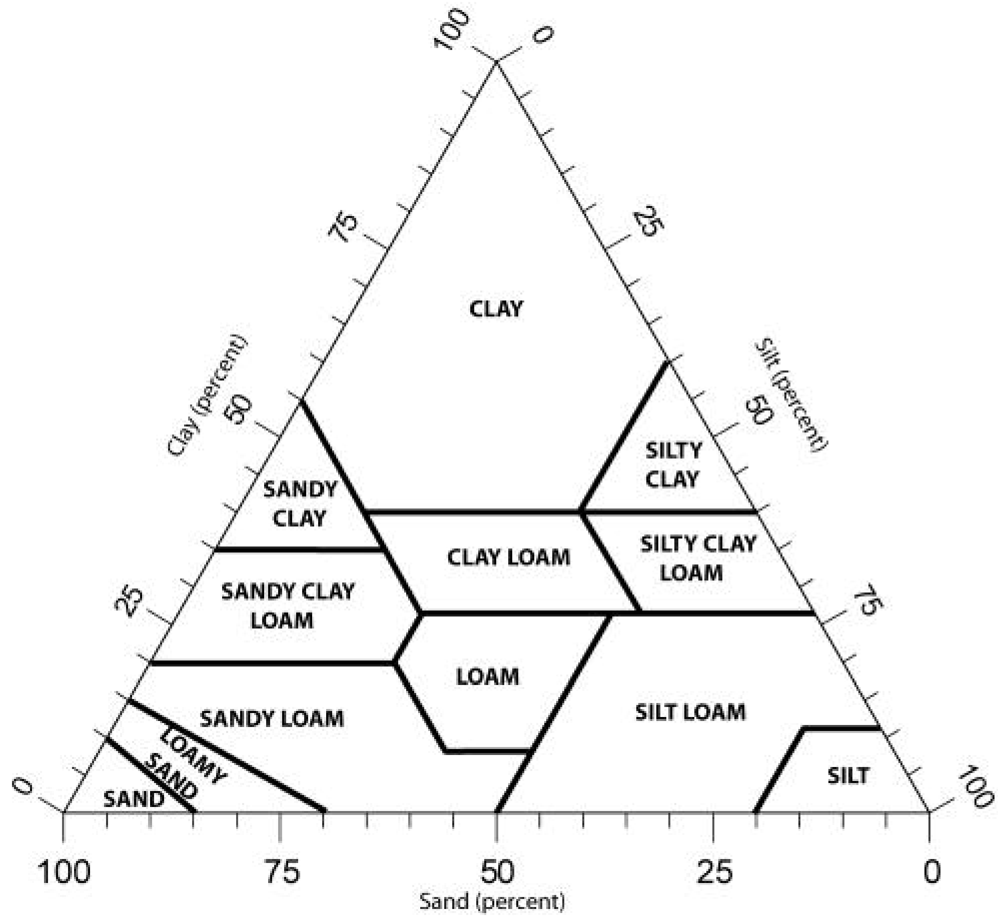
The proportion of sand, silt, and clay in a soil or sediment defines its texture (see Figure 2.1). Texture affects the flow of water and the transport of dissolved chloride in two ways. First, the texture determines the nature of the interconnected open pores of the soil or sediment. Clean gravel generally exhibits large, well-connected pore spaces while silty-clay has smaller pores with poorer connectivity but a higher porosity. As a result, the saturated hydraulic conductivity of gravel is higher than the saturated hydraulic conductivity of silty-clay. In the unsaturated zone, however, the ability of a soil or sediment to transmit chloride depends on how much of the available pore space is filled with water. In a nearly dry soil or sediment, capillary forces hold the water (and chloride) in place, preventing down ward (or upward) movement. As the moisture content of a soil or sediment increases, more pores become interconnected with water and the soil water pressure becomes less negative, increasing the ability of the unit to transmit water and chloride. In other words, the unsaturated hydraulic conductivity of a soil or sediment increases with increasing moisture content. In the vadose zone, fine-grained layers containing silt and clay generally have relatively higher moisture content than adjacent gravel. The higher moister content translates into higher unsaturated hydraulic conductivity. Therefore, a silty clay can often transmit water more quickly than drier coarse-grained units containing sand and gravel. A vadose zone composed of layers of fine-grained and coarse-grained units will often transmit water more slowly than a homogeneous, fine-grained profile.

2.1.2 Water Content in the Vadose Zone

The soil moisture content is the volumetric fraction of water in a soil or sediment. Climate and soil texture influence soil moisture contents. Wetter, more humid environments result in higher moisture contents. Fine-grained and heterogeneous soils retain water better than coarse-grained, more homogeneous soils. Therefore, the more heterogeneous and finer grained the material, the greater the water content.

The water content of a soil or sediment strongly affects its ability to transmit fluids because the hydraulic conductivity increases with increasing water content. The hydraulic conductivity of a sandy soil with water content of 20% can be 1,000 times greater than the same soil in an arid climate where water content is only 5%. Although a brine may migrate much faster in a wet soil profile, the natural water in the soil also dilutes the produced water and provides some mitigation of its effects on ground water quality.

Figure 2.1—Soil texture triangle used by the U.S Department of Agriculture.



2.1.3 Dispersion Length of Chloride in the Vadose Zone

The dispersion length describes the amount of mixing a solute, such as chloride, will undergo in the vadose zone. Dispersion causes dilution of solute concentrations through mixing with ambient vadose water or ground water in a longitudinal direction parallel to water flow, as well as in a transverse direction perpendicular to water flow. Systems with larger dispersion lengths produce greater mixing. Soil and aquifer heterogeneity tend to increase dispersion.

The dispersion length is very difficult to measure in the field. Researchers and field personnel rely on professional judgment and published values (from laboratory or field experiments) to arrive at the dispersion length for a particular site.

2.1.4 Depth to Ground Water or Vadose Zone Thickness

The vadose zone is the region between the land surface and ground water table, and its thickness is defined by the depth to the ground water table. The vadose zone (also referred to as the unsaturated zone) includes the capillary fringe (pore space completely filled with water, under negative soil water pressure) and the overlying soil and sediment where the pore space is partially filled with water. Because ground water table depth rises and falls due to seasonal fluctuations in precipitation, ground water pumping withdrawals, and other factors, the thickness of the vadose zone is not constant. Like soil texture, the thickness of the vadose zone affects the time required for a release at the ground surface to reach the water table. The thicker the vadose zone, generally, the longer the travel time from ground surface to the water table. A relatively thick vadose zone also has more open pore space to temporarily store released fluid. A thick vadose zone can attenuate the effects of a produced water release more effectively than a thin vadose zone.

2.2 Climate

Precipitation and evaporation affect the water content of the vadose zone (prior to a release) and exert control over the migration of chloride after a release. In a humid climate, regular and generous precipitation over the annual cycle can create relatively uniform infiltration patterns and a predictable soil water profile. In arid climates, where rainfall occurs in short-duration thunderstorms punctuated by long drought periods, the infiltration is not uniform and occurs only immediately after large precipitation events that result in vadose zones with relatively low water contents.

Daily precipitation and evaporation data are inputs to the HYDRUS-1D model. Therefore, it can effectively simulate the effect of the two climate extremes, humid and arid, discussed above.

2.3 Brine Release Factors

2.3.1 Chloride Concentration of Release

Chloride concentration in oilfield produced water can be 100,000 ppm, or much lower if the producing formation is diluted with fresher water over geologic time. One of the easiest input parameters to measure in the field is the chloride concentration of the produced water. The effect of chloride concentration is also straightforward: the higher the chloride concentration, the greater the environmental threat.

2.3.2 Release Volume and Total Mass

The volume of the release multiplied by the chloride concentration of the release yields the total mass of chloride released to the environment. The total mass released is a very important input parameter because it determines for a specific site the risk for ground water impairment. The total mass of chloride can generally be estimated by a field investigation.

2.3.3 Height of Spill

Produced water releases occur within bermed areas when storage tanks fail or to the natural terrain due to transmission line leaks and other transportation accidents. Releases may pond in a berm or natural depression or can be dispersed over a large area. If the release is contained in a berm, the spill height is equal to or less than the height of the berm. In an open field, the spill height may vary. For a given site, the amount of produced water infiltration into the soil is a function of the hydraulic head or ponding depth. As the ponding depth increases, so does the hydraulic head, (pressure, at the soil/produced water spill interface). Understanding the depth of ponding and the total amount of infiltration guides the characterization efforts.

2.4 Groundwater Characteristics

The potential for ground water quality impairment depends to some extent on the aquifer characteristics such as ground water flux, aquifer thickness, and ambient chloride concentration.

2.4.1 Ground Water Flux

Ground water moves through an aquifer in response to its capacity for transmitting water, or, hydraulic conductivity (m/day), and the driving force caused by a sloping water table (hydraulic gradient). The hydraulic conductivity of aquifers can be measured in the field and can be found in publications that often provide estimates of this parameter. The hydraulic gradient can be measured in the field by determining the depth to water at 3 wells of known surface elevation. Multiplication of the hydraulic conductivity by the hydraulic gradient yields the ground water flux, which is the volume of water flowing through a unit area of aquifer over a specified time period (expressed in $m^3/(m^2 * day) = m/day$). The lower the ground water flux, the higher the probability that a release will cause unacceptable ground water quality impairment.

2.4.2 Aquifer Thickness

A thick aquifer contains more water than a thin aquifer. A given amount of chloride that enters from the vadose zone in a thick aquifer will result in a lower chloride concentration than the same amount entering a thin aquifer since aquifers that contain more water can be more effective at dilution. A thick aquifer that exhibits a large ground water flux may be able to absorb chloride from a large surface release without any severe impact to water quality.

2.4.3 Aquifer Ambient Chloride Concentration

Ambient chloride concentrations of ground water will influence whether or not a produced water release causes unacceptable ground water quality impairment. If ground water has a low chloride concentration, even a considerable amount of produced water may not cause chloride concentrations to exceed the U.S. EPA Secondary Standard of 250 ppm or preclude the use of the water for agricultural needs. A high chloride concentration in ground water increases the risk that a produced water release will render the groundwater unfit for use. Simple field measurements from nearby well water or published data can supply an accurate estimate of the ambient chloride concentration in an aquifer.

2.5 Heterogeneity

Heterogeneity, most often caused by the layering of different sediment or soil types within a vadose zone, is more common in nature than not. Heterogeneity affects the distribution of chloride and other solutes through its strong influence on dispersion and hydraulic conductivity.

One of the most common simplifying assumptions employed by regulators and guidance manuals is the assumption of homogeneity. However, a clay lens 1 m thick found 3 m below a produced water release in a sandy soil will have a profound effect on the migration of chloride through the vadose zone. Heterogeneity can increase the attenuation of a release and help mitigate the effects on ground water quality. Heterogeneity is not one of the 11 factors specifically considered in the initial research, but its effect on these 11 factors is considered in Chapters 6, 7, and 10.

2.6 Repeated Releases

Repeat releases are an issue at some sites. Several releases in the same location may result in a higher threat to ground water quality than a single event. Repeated releases can cause:

1. More chloride mass to enter the subsurface,
2. Higher water content in the vadose zone, and
3. Increased ambient chloride concentration in the underlying aquifer.

3.0 MODELING APPROACH

The modeling of produced water migration from the soil surface through the vadose zone into a shallow aquifer towards a monitoring well would require a sophisticated 3-dimensional model, which takes into account the full coupling between unsaturated flow in the vadose zone and saturated flow in the aquifer. Such an approach is outside the scope of this study since generally acceptable 3-dimensional models capable of such simulations are still being developed.

This study used an approach based on the assumption that flow through the vadose zone is mainly downward. This assumption is reasonable for humid climates where precipitation exceeds evapotranspiration most of the year. It is also reasonable in arid climates when the ground water table is so deep that no upward flow due to capillary rise can be maintained. Under these conditions, it is possible to de-couple the modeling of water flow and chloride transport in the vadose zone from the modeling of water flow and chloride transport in the aquifer. It is assumed that flow in the vadose zone is one-dimensional downward and flow in the aquifer is one-dimensional horizontal. This assumption allows us to first simulate water flow and chloride transport through the vadose zone using the model HYDRUS-1D. The output from HYDRUS-1D is the downward water flow seeping out of the vadose zone and the downward chloride flux over time. These outputs are used as input into the model for the aquifer. In this study, two models were used for the aquifer: MODFLOW and a simple groundwater mixing model. MODFLOW is a standard code for modeling water flow and solute transport through aquifers (Domenico & Schwartz, 1998). Since it takes quite some time to setup a simulation in MODFLOW, a validated excel spreadsheet mixing model was used to generate results more cost effectively.

3.1 Vadose Zone Model: HYDRUS-1D

3.1.1 Model Overview

HYDRUS-1D (Simunek et. al, 1998) is used to simulate 1-dimensional transport of water, heat, and solute movement in variably saturated porous media. The HYDRUS- 1D model was developed by the George E. Brown Jr., Salinity Laboratory, USDA, ARS, Riverside, California and is distributed by the International Ground Water Modeling Center (IGWMC), Golden, Colorado. A Microsoft Windows™-based Graphics User Interface (GUI) supports HYDRUS-1D.

The HYDRUS-1D model numerically solves the Richards' equation for water flow and Fickian-based advection-dispersion equations for heat and solute transport. 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 heat transport equation describes conduction as well as convection.

HYDRUS-1D can handle large numbers of soil layers and uses the van Genuchten-Mualem, Brooks-Corey, Kosugi lognormal, and Durner dual porosity models to describe soil hydraulic properties. When values of soil hydraulic properties are unavailable, HYDRUS-1D can estimate them from a small catalog of values based on major textural classes (e.g., sand, sandy loam, etc.) or neural network-based predictions.

The HYDRUS-1D code can simulate a wide range of boundary conditions. These are constant and time-variable pressure heads and fluxes, free drainage, seepage face, and an atmospheric boundary condition. An atmospheric boundary condition can be used to either generate run-off when the precipitation rate exceeds the infiltration capacity of the soil, or store excess water on the land surface allowing the water to infiltrate when precipitation stops. Time-variable conditions can be entered hourly, daily, or any general time interval.

HYDRUS-1D was used for the vadose zone simulations of this research project because of the importance of understanding the vertical transport of water and chloride through the vadose zone. The outputs from HYDRUS-1D are the daily water flow and chloride flux from the vadose zone over the time period of the simulation expressed as cm day^{-1} and mg cm^{-2} day^{-1} respectively. These outputs are used as inputs into the simple mixing model.

3.1.2 Applicability of HYDRUS-1D for Produced Water Releases

Surface or near surface releases of produced water migrate through the vadose zone under variably saturated conditions as a function of release volume, topography, and climatic conditions (i.e., precipitation and evapotranspiration). Although other vadose zone models exist that satisfy this criterion, HYDRUS-1D was selected over other models for the following three reasons:

1. It can simulate water and solute transport through heterogeneous porous media: horizons and sediments of varying geology;

2. It can incorporate daily climatic data; and

3. The researchers' familiarity with the model.

Dr. Jirka Šimunek of this team developed the HYDRUS-1D model with his colleagues Dr. van Genuchten and Dr. Sejna; Dr. Jan Hendrickx, another team member, has used the HYDRUS-1D model for many years for evaluation of groundwater recharge and salt movement through the vadose zone.

3.2 Saturated Zone Model: Mixing Model and MODFLOW

As stated, the objective of this part of this study is to evaluate the impact of produced water releases on ground water quality as measured in a well adjacent to and down gradient of the produced water release. The chloride flux leaving the vadose zone, the horizontal flux in the unconfined aquifer, the original chloride concentration in the ground water, and the thickness of the unconfined aquifer also affect the chloride concentration of the aquifer. Since the water flux seeping from the vadose zone and its chloride concentration vary with time, no simple analytical solutions are available to determine the time-varying chloride concentration in the well. Therefore, a simple spreadsheet ground water mixing model was implemented to determine the chloride concentration in the well. This mixing model uses the output of the HYDRUS-1D model as input. The aquifer volume and the mixing compartment underneath the spill must be defined as a first step in the ground water mixing modeling process. Assuming a circular spill area and a unidirectional horizontal flux in the aquifer, the highest impact will occur where the ground water has the longest exposure to the incoming chloride from the vadose zone. This takes place along the diameter of the circular spill. Therefore, the length of the mixing compartment is made equal to the diameter of the spill area, D. The depth of the mixing compartment is the thickness of the aquifer, H or the length of screen in a nearby observation well (generally 3 m) . The width, W, of the mixing compartment is taken to equal unity to simplify the calculations.

Considered next is the relation between the water flux seeping out of the vadose zone, q_v, the chloride concentration in the vadose zone flux, C_v, the horizontal flux in the aquifer underneath the release entering the compartment, q_{in}, the original chloride concentration in the aquifer, C_{in}, the horizontal flux in the aquifer underneath the release leaving the compartment, q_{out}, and the chloride concentration of the aquifer flux leaving the area underneath the release, C_{out}. The latter concentration will be monitored in the down gradient well.

The following reasonable assumptions were made to determine C_{out}:

1. Ground water flow is in steady state. The discharge entering into the mixing compartment from the vadose zone, $q_v DW$, plus the horizontal discharge in the aquifer entering the mixing compartment at its up-gradient side, $q_{in}HW$, are equal to the discharge leaving the mixing compartment, $q_{out}HW$.

2. Changes in thickness of the saturated aquifer are small compared to the total thickness of the aquifer H (i.e., water table fluctuations are small).

3. The thickness of the aquifer, H, and its porosity, n, are constant.

4. Mixing of the chloride entering the mixing compartment is complete and immediate. This assumption appears invalid from data published in the recent literature (LeBlanc et al., 1991; Zhang et al., 1998). The results of the mixing model can be used as an excellent indicator of the mean chloride concentration in a supply well penetrating the aquifer underlying the produced water release, but not as an indicator of the chloride distribution in the aquifer.

The volume of the mixing compartment, V, will be constant under these assumptions, and is equal to

$$V = D \times H \times W \times n \tag{3-1}$$

The water balance of the mixing compartment is equal to:

$$q_{in} \times H \times W + q_v \times D \times W = q_{out} \times H \times W \tag{3-2}$$

One can eliminate variable W from Eqs. [3-1] and [3-2] by putting W= 1 m.

The chloride balance of this mixing compartment during any time period dt is

$$\left[\left(q_{in} \times C_{in} \times H + q_v \times C_v \times D\right) - \left(q_{in} \times H + q_v \times D\right) \times C_{out}\right]dt = \left[D \times H \times n\right]dC \tag{3-3}$$

where dC is the change of chloride concentration occurring during time period dt.

Rearranging Eq. [3-3], one obtains the ordinary differential equation:

$$\frac{dC}{dt} = \frac{q_{in} \times C_{in} \times H + q_v \times C_v \times D - (q_{in} \times H \times + q_v \times D) \times C_{out}}{H \times D \times n} \quad \textbf{(3-4)}$$

As soon as chloride from the produced water release enters the ground water, the volume average concentration in the mixing compartment is C_{out} after complete mixing has occurred. Thus the chloride concentration of the water leaving the compartment, C_{out}, becomes:

$$C = C_{out} \qquad \text{and} \qquad dC = dC_{out} \quad \textbf{(3-5)}$$

Therefore, one can convert Eq. [3-4] in a forward finite difference expression:

$$\frac{C_{out}^{i+1} - C_{out}^{i}}{t^{i+1} - t^{i}} = \frac{q_{in}^{i} \times C_{in}^{i} \times H + q_v^{i} \times C_v^{i} \times D - (q_{in}^{i} \times H + q_v^{i} \times D) \times C_{out}^{i}}{H \times D \times n} \quad \textbf{(3-6)}$$

which yields an explicit expression for C_{out}^{i+1},

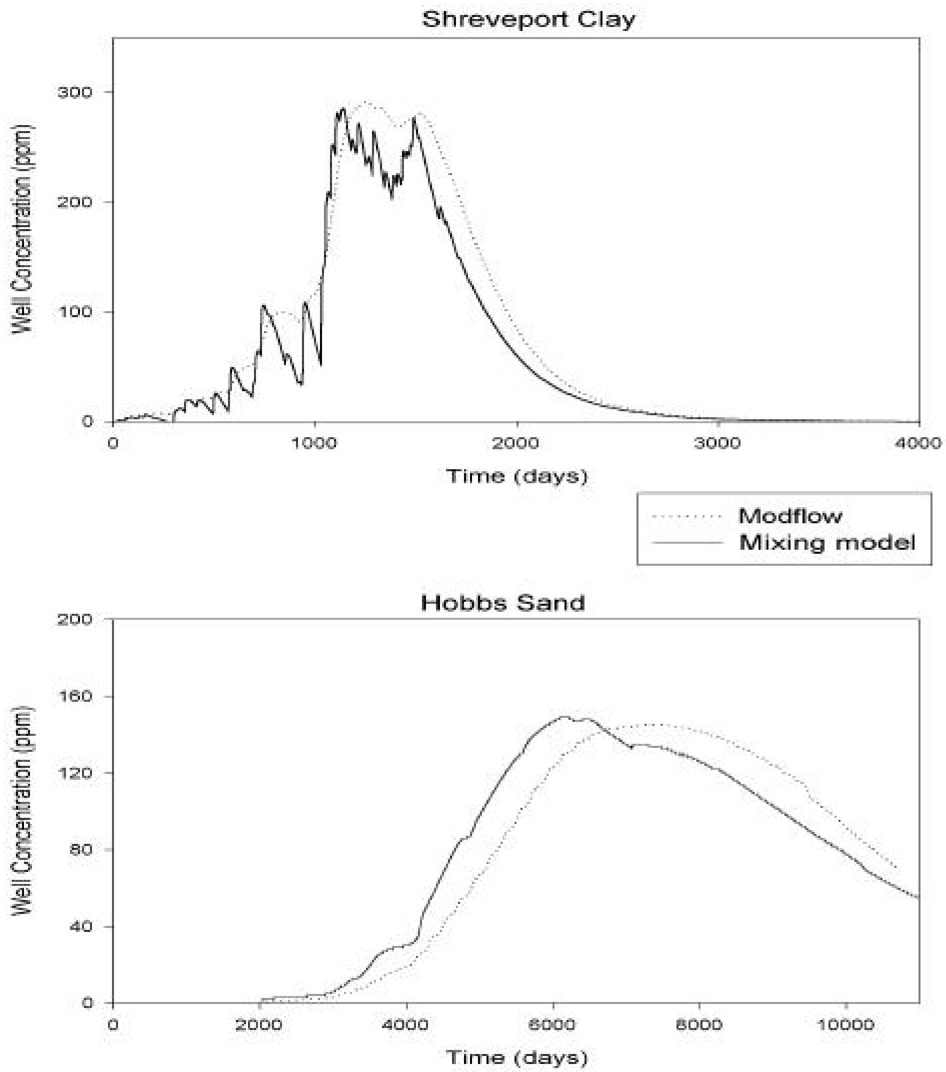
$$C_{out}^{i+1} = C_{out}^{i} + \frac{\left[q_{in}^{i} \times C_{in}^{i} \times H + q_v^{i} \times C_v^{i} \times D - (q_{in}^{i} \times H + q_v^{i} \times D) \times C_{out}^{i}\right] \times \left[t^{i+1} - t^{i}\right]}{H \times D \times n} . \quad \textbf{(3-7)}$$

Using the output from HYDRUS-1D: the chloride concentration, C_v^i, of the water, q_v^i, entering the ground water table on day, t^i, the mixing model of Eq. [3-7] has been put into a spreadsheet. By changing the values for spill diameter, D, ground water flux, q_{in}, original chloride concentration in the aquifer, C_{in}, and the aquifer thickness, H, the effect of these 4 factors of an unconfined aquifer have been evaluated.

Figure 3.1 presents 2 comparisons between the chloride concentrations in the well located down gradient of the entry point of the release obtained with the mixing model Eq. [3-7] and those obtained with the model MODFLOW. The two comparisons deal with 2 complete different sets of environmental and release factors. In Shreveport, Lousiana the vadose zone texture is clay, the dispersion length 0.1 m, release chloride concentration 10,000 ppm, spill height 0.6 m, and aquifer flux 0.05 m/day. In Hobbs, New Mexico vadose zone texture is sand, dispersion length 2.0 m, release chloride concentration 100,000 ppm, spill height 0.025 m, and aquifer flux 0.004 m/day. The maximum chloride concentrations predicted by the two models is quite similar, although the time of arrival to the maximum concentration is different for each model. This part of the study was conducted using the less expensive mixing model Eq. [3-7]. This approach using HYDRUS-1D in combination with MODFLOW and Eq. [3-7] is valid for situations where the vadose zone seepage flux, q_v, is downward. A downward flux in the vadose zone is always found in the profiles with a deep ground water table depth. However, in the profiles with a ground water table depth between 0 – (+/-) 10 m an upward flux from ground water table towards the soil surface does occur as a result of capillary rise. The magnitude of the upward capillary flux depends on soil type and climate.

A large amount of precipitation enables the downward vadose zone flux to dominate the chloride transport in both the sandy and clayey soil in the humid climate of Shreveport. Occasionally, in the clayey soil, an upward flux is encountered during short periods without rain.

Figure 3.1—Comparison between MODFLOW and the mixing model. Perturbations in the MODFLOW curve reflect the use of actual rainfall data.



An upward flux is sometimes found in the sand soil but is prevalent in the clay soil in the arid climate of Hobbs. For example, when the ground water table depth is 3 m, the average upward flux in a clay profile would be 0.04 cm/day or 13.5 cm/year; this upward capillary flux causes the chloride and brine to stay in the vadose zone and protects the ground water from impairment. In hydrogeological situations where capillary rise is common, brine movement towards ground water is sporadic. However, a big storm can suddenly push all of the brine into a shallow aquifer.

A strong dynamic interaction exists among all 11 factors, outlined in section 1.1.3, when water leaving the vadose zone, q_v, changes direction frequently in response to precipitation events (downward movement) and evapotranspiration (upward movement). In dry climates with shallow ground water (less than 3 m), upward movement of ground water into the vadose zone and then to the atmosphere is common. The only manner to correctly simulate the interaction between these factors under these conditions is by employing a 2- or 3-dimensional model, such as HYDRUS-2D. However, the main objective of this study is to examine the effect of surface spills of produced water on ground water quality, thus the mixing model Eq. [3-7] for ground water table depths of 3 m was used. The effect of capillary rise in diminishing the leaching of chloride to the ground water, and concentrating chloride in the root zone was not examined. The equation was used only for downward fluxes and was made inactive when the vadose zone flux, q_v, goes upward. It was initiated again with the next occurrence of a downward flux, q_v, taking the C_{out} value of the previous occurrence of a downward q_v. In this manner a conservative estimate is obtained of the chloride concentration in the monitoring well assuming perfect mixing for shallow ground water tables.

3.3 Data Sources

3.3.1 Soil Data

The HYDRUS-1D's catalog of soil hydraulic property values was used to define hydraulic characteristics of the vadose zone (Carsel and Parish, 1988). The catalog defines hydraulic properties for parameters in the van Genuchten (1980) analytical functions.

Data from the Soil Survey of Caddo Parrish, LA, and Lea County, NM, were used as well as data collected from state and federal government agencies to construct heterogeneous soil profiles. State and federal government agencies included the US Geological Survey (USGS), National Resource Conservation Service (NRCS), and NM Oil Conservation Division (NMOCD). Like the homogeneous profiles, hydraulic properties for each soil horizon or geologic unit were estimated from the soil hydraulic property values of HYDRUS-1D.

3.3.2 Climate Data

Climate data were purchased for Shreveport, LA and Lea County, NM from the National Climatic Data Center (NCDC, www.ncdc.noaa.gov). The data consisted of historical daily temperature and precipitation measurements collected at specific weather stations identified by a NCDC Coop identification number. Data for Lea County and Shreveport were collected at the Pearl, NM weather station (Coop # 296659) and the Shreveport Regional Airport, LA (Coop # 168440), respectively.

Potential evapotranspiration (PET) was calculated from daily temperature observations using the method of Samani and Pessarakli (1986).

When a HYDRUS-1D simulation was performed for a longer time period than the period of record for a weather station, the climate data was repeated for as many years as was necessary.

4.0 SENSITIVITY ANALYSIS OF FACTORS DETERMINING BRINE FATE

4.1 Purpose

After a produced water release, the concentration of chloride in the vadose zone decreases with time and distance traveled through the vadose zone towards ground water because of dilution with ambient soil water. Further dilution occurs in the aquifer after the chloride reaches the ground water. The maximum chloride concentration occurring at a well down gradient from the release will depend on all the factors that affect chloride transport through the vadose zone and shallow aquifer. Understanding these factors is critical for the design and implementation of a site characterization program after a produced water release. The degree of ground water quality impairment determines to a large extent the need for a ground water remedy. The purpose of this sensitivity study is to evaluate which of the 11 factors have the greatest effect on prediction of maximum chloride concentration in the well down gradient of the release.

4.2 Modeling Specifics

Simulation work was optimized to obtain the maximum amount of information from the modeling. Statistics of experimental designs (e.g. Law & Kelton, 2000; Snedecor & Cochran, 1967; Steel & Torrie, 1980) provided ways to decide which combination of factors to simulate so that the desired information can be obtained with the lowest possible number of simulations.

The factors used in experimental design statistics are the input variables to the simulation models. The outputs of the simulations are the responses. The responses that were considered in this study are the maximum chloride concentration, C_{max}, occurring in the well and the time at which the maximum chloride concentration reaches the well, T_{max}.

A 2^k *factorial design* was chosen that requires the selection of two levels of each factor in this study. This design results in a total of 2^k simulation runs, where k is the number of factors. Two values were chosen for each factor so that they represent two opposite conditions such as an arid and a humid climate. The factors can be qualitative-like climate or quantitative-like depth to ground water. The two input values should not be too extreme or unrealistic. Additionally, the two values should not be too similar or the simulations may not adequately evaluate important aspects of the transport process under consideration. The 11 factors of this sensitivity analysis (see Table 4-1) resulted in 2^{11} or 2,048 different produced water release scenarios.

4.2.1 Vadose Zone Factors

Climate

Two contrasting climates of Lea County, New Mexico, and Shreveport, Louisiana were selected for the sensitivity analysis. Lea County is located in the arid southwest, and Shreveport is in the humid south. Lea County's annual precipitation and potential evapotranspiration is 14 in. and 59 in., respectively, while annual precipitation and potential evapotranspiration for Shreveport is 46 in. and 67 in., respectively. Lea County and Shreveport also differ when precipitation occurs. In Lea County, the majority of precipitation occurs during the "monsoon" of July – August and much of the remainder of the year resembles drought conditions. Shreveport's precipitation falls throughout the year.

Table 4-1—Vadose zone, aquifer, and brine release factors determining maximum chloride concentration arriving at a monitoring well down gradient of a brine release

Factor	Factor	Factor	Maximum Chloride Concentration	
#	**Description**	**Abbreviation**	**Decrease**	**Increase**
1	Climate	clim	Arid	Humid
2	Soil Texture	soil	Clay	Sand
3	Initial Water Content	wcin	Wet	Dry
4	Chloride Dispersion Length	disp	2.0 m	0.1 m
5	Ground Water Depth	gwl	30 m	3 m
6	Ground Water Flux	qaq	0.05 m/day	0.001 m/day
7	Ambient Aquifer Cl Concentration	cin	0 ppm	100 ppm
8	Aquifer Thickness	thick	30 m	3 m
9	Release Volume	vol	100 bbls	10,000 bbls
10	Release Height	depth	0.025 m	.60 m
11	Release Chloride Concentration	clcon	10,000 ppm	100,000 ppm
10*11	Release Chloride Mass	clmass	250 g/m^2	60,000 g/m^2

Vadose Zone Texture

Sand and clay were selected as contrasting soil textures for the sensitivity analysis. Sand and clay differ not only in grain size but also in their ability to retain and transmit water. Sand has a relatively high saturated hydraulic conductivity and low water retention; whereas clay has a relatively low saturated hydraulic conductivity and high water retention.

Water Content in Vadose Zone

Higher initial water content in the vadose zone results in slower brine movement because the initial moisture must be displaced before the brine can move downward through the vadose zone. HYDRUS-1D was used to predict initial water contents for both vadose zone textures in both Lea County and Shreveport. These predictions were used as initial conditions in the sensitivity analysis.

Computer simulations were run for 100 years or until dynamic equilibrium was achieved between soil water content and climatic conditions for both the wet and dry initial conditions. To create *wet* conditions, simulations were run without any vegetation (low evapotranspiration); vegetation (high evapotranspiration) was included to create *dry* conditions. Evergreen plants capable of transpiring soil water all year round with a 3 m (~10 ft) deep root zone were assumed in the simulations. Transpiration of soil water created a drier soil profile than simulations without vegetation.

Dispersion Length of Chloride in Vadose Zone

A minimum and maximum chloride dispersion lengths of 0.10 m (0.33 ft) and 2.0 m (6.6 ft) was selected, respectively. The larger dispersion length will produce greater mixing of brine with ambient soil water in the vadose zone, and it is expected to result in a lower maximum chloride concentration in the well. Conversely, the smaller dispersion length will result in minimal mixing, e.g. minimal attenuation of the release, and larger maximum chloride concentrations. Dispersion lengths were selected from values reported in the literature (Gelhar, 1993).

Depth to Ground Water

Deep groundwater allows for more storage of brine and more attenuation of the maximum chloride concentration during its downward migration. Groundwater depths of 3.0 m (9.8 ft) and 30 m (98 ft) were selected for the sensitivity analysis. These depths represent reasonable values for a shallow and deep aquifer, respectively.

4.2.2 Aquifer Factors

Ground Water Flux

Groundwater flux represents the rate of groundwater movement and affects the ability of an aquifer to dilute chloride and other constituents of a produced water release. A large groundwater flux produces greater dilution.

The selection of minimum and maximum groundwater fluxes was based on literature values for the Ogalalla aquifer, Southern Lea County, New Mexico (Native and Smith, 1987). Minimum and maximum values used were 0.10 cm/day (0.0033 ft/day) and 5.0 cm/day (0.16 ft/day), respectively. The maximum flux used is lower than some of the ground water fluxes reported in the literature (e.g. 40 cm/day by Zhang et al., 1998), thus, reducing the dilution in the mixing zone in the simulations.

Aquifer Ambient Chloride Concentration

Ambient chloride concentrations selected for groundwater were 0 ppm and 100 ppm. One hundred parts per million or less is typical for groundwater of the Ogallala aquifer (Nicholson and Clebsch, 1961) and the Carrizo-Wilcox aquifer in Caddo Parish, Louisiana (Rapp, 1992). Although 10-ppm chloride is a more characteristic minimum value for the Ogallala and Carrizo-Wilcox aquifers, 0.0 ppm was selected to create a greater difference between minimum and maximum chloride concentrations of groundwater.

Aquifer Thickness

The thicker the aquifer, the more opportunity for mixing (dilution), and the lower the predicted chloride concentration in the aquifer. Two aquifer thicknesses were selected, 3.0 m (9.8 ft) and 30 m (98 ft). Three meters are approximately equal to the length of most well screens used to monitor the chloride changes. Therefore, an aquifer thickness of 3 m provides a good estimate of expected chloride concentrations at a monitor well in a thicker aquifer under conditions of limited vertical mixing. Many unconfined, alluvial aquifers are greater than 30 m thick, but for the sake of conservatism, 30 m was selected as the maximum value. A 30 m thick saturated sandy formation with a hydraulic conductivity of at least 0.0005 m/s (140 ft/day) is classified as a good aquifer (Freeze and Cherry, 1979).

4.2.3 Brine Release Factors

Release Volume

Minimum and maximum release volumes of 100 bbl (16 m^3) and 10,000 bbl (1,600 m^3), respectively, were selected for this analysis. These release volumes are representative of large and very large releases based on the experience of oil and gas industry personnel.

The 1-dimensional HYDRUS-1D model uses only spill height as an input variable. The spill volume was introduced into the mixing model using the spill diameter. For example, a 100 barrel release resulting in a produced water release of 0.025 m height with circular shape will have a diameter of 29 m while a release of 0.6 m height will have a diameter of only 6 m (Figure 4.1). Table 4-2 summarizes the 4 produced water release areas evaluated with the mixing model. These 4 release areas are combinations of the 2 spill heights (0.025 and 0.6 m) and 2 release volumes (large: 100 bbls and very large: 10,000 bbls).

All spill areas are represented as circles, and then, the mixing model is used to evaluate mixing along the diameter of each circular spill (see Table 4-2). The diameter of each circle represents the longest path groundwater must flow beneath each release area, and thus provides a conservative estimate of groundwater quality impairment at a well immediately down gradient of a release.

Chloride Concentration of Release

Chloride concentrations of 10,000 and 100,000 ppm were selected as the minimum and maximum concentrations for the produced water release input parameter in consultation with API. These concentrations are representative of most produced water releases.

The mixing model does not consider density differences between the density of the brine arriving at the aquifer and the density of the water in the aquifer. These differences (even if small) may cause brine to sink in an aquifer (LeBlanc et al., 1991; Zhang et al., 1998) and would influence the distribution of brine in the aquifer. Since our approach assumes complete mixing in the aquifer, the chloride distribution is not taken into account. Water extracted from a well by bailing or pumping typically would represent a well mixed sample. The results of the mixing model help to identify environmental and release characteristics that cause groundwater quality impairment and provide a measure of the overall impact of a produced water release on an aquifer.

Height of Spill

Minimum and maximum values of 0.025 m (1 in.) and 0.6 m (2 ft), respectively, were used as the spill height of produced water on the land surface, based on observations of oil and gas industry personnel. A 0.6 m (2 ft) height represents a discharge of 1600 m^3 (10,000-bbls) of produced water to a 2670 m^2 (0.7 acre) bermed area or large depression. Releases to flat or gently sloped areas are likely to result in initial heights of 0.025 m (1 in.) or less.

Figure 4.1—Schematic of two possible brine release characteristics after a release of 100 barrels.

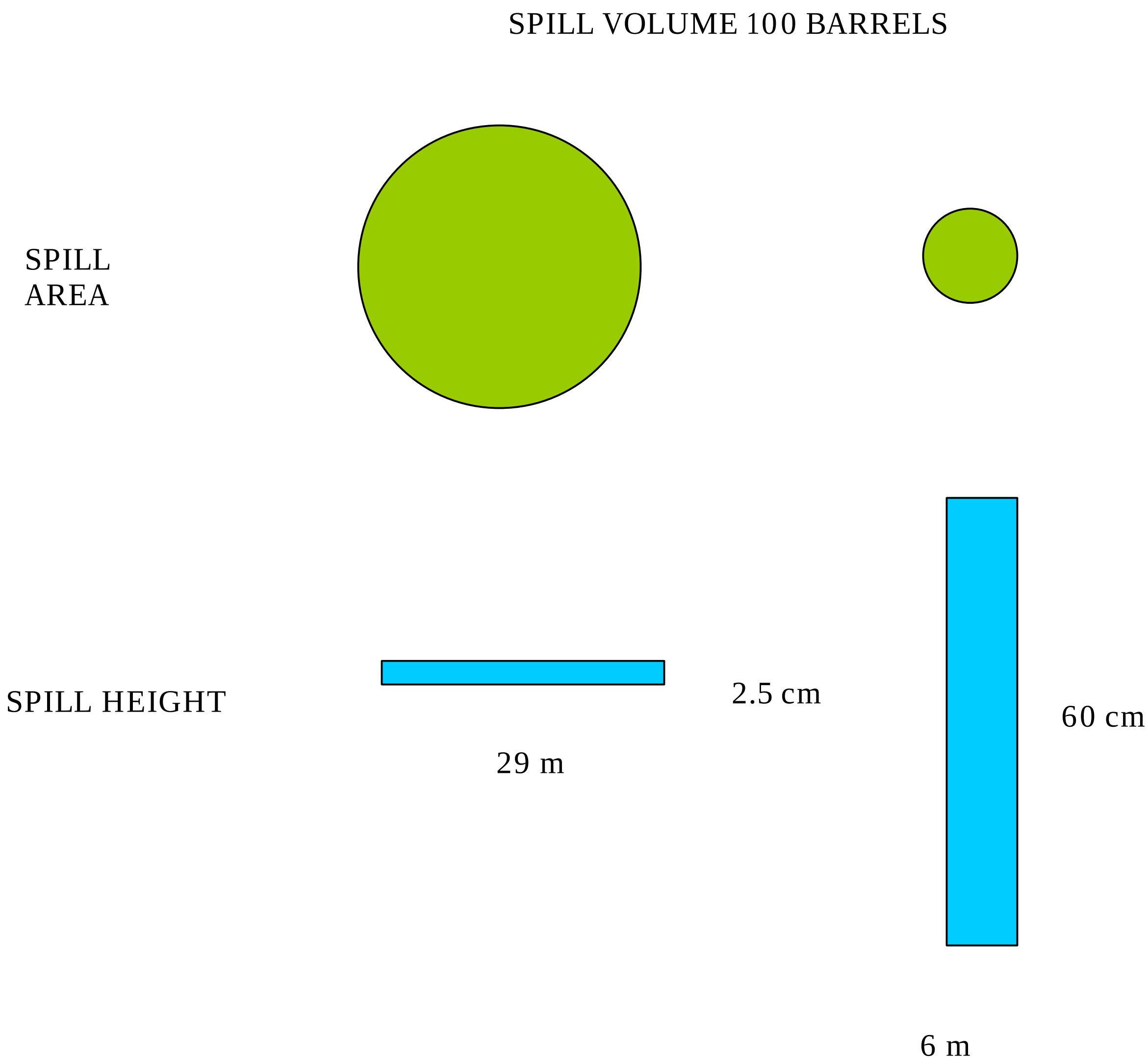


Table 4-2—Characteristics of brine releases in this study

Volume		Depth	Area		Diameter
Barrels	m^3	m	m^2	acres	m
100	16	0.025	640	0.16	29
		0.6	26.67	0.007	6
10000	1600	0.025	64000	16	285
		0.6	2666.67	0.7	58

Chloride Mass

Table 4-1 presents a final factor, “Release Chloride Mass”. This factor, which is the product of “Release Height” and “Release Chloride Concentration”, is the mass of chloride released to the ground surface per unit area. As Table 4-1 shows, a produced water release (see Release Chloride Concentration) of 100,000 ppm chloride that ponds to a depth of 0.6 meters (see Release Height) causes a subsurface chloride input of 60,000 g/m^2 (the Release Chloride Mass). This factor is discussed in more detail in later sections of this report.

4.3 Simulation Responses

The simulations with the HYDRUS-1D code and the mixing model yield large amounts of information about the water flow and the transport of chloride through the vadose zone and the underlying aquifer. As mentioned above, two critical response variables were selected for the sensitivity analysis: (i) the maximum chloride concentration in a down gradient monitoring well, C_{max}, and (ii) the time of arrival of the maximum chloride concentration at the monitoring well, T_{max}.

Maximum Chloride Concentration

The maximum chloride concentration defines the center of mass of a release as it migrates through the vadose zone into the aquifer and reaches a well. For this reason, the maximum chloride concentration, C_{max}, is used to identify those factors listed in Table 4-1 that have a significant influence on chloride migration through the vadose zone and the aquifer as the release moves toward the well. Evaluation of C_{max} can also identify the environmental conditions that result in significant attenuation of brine. For example, for those simulations where C_{max} is much less than the original chloride concentration of the produced water, environmental factors cause significant brine attenuation. Additionally, an evaluation of C_{max} can be used to identify release scenarios that pose little or no threat to groundwater quality. For instance, simulations that predict a C_{max} less than the EPA Secondary Water Quality Standard of 250-ppm chloride will not cause water quality impairment. On the other hand, when predictions of C_{max} are greater than 250 ppm, ground water quality may be threatened by the release. Thus, the maximum chloride concentration in the well provides important information about the risk for ground water impairment and its severity.

Time of Arrival of Maximum Concentration at the Well

Time of arrival of maximum concentration, $T_{max,}$ is the time required for the chloride center of mass to reach the well. It dictates the urgency to implement a field investigation and possible remedy. A relatively rapid response is required if simulations suggest a chloride concentration of 250 ppm or more at a well within a few years. However, when input factors combine to predict that decades or centuries are required for a well to show ground water impairment, an immediate ground water investigation may be of little value.

4.4 Statistical Analysis of the Responses at a Monitoring Well

Following the statistical approach by Law & Kelton (2000) for simulation modeling and analysis, the impact of each factor presented in Table 4-1 on the migration of chloride through the vadose zone and aquifer was determined. This was accomplished by inspecting the effect of each factor on the maximum chloride concentration in a down gradient well, C_{max}, and the arrival time of this concentration, T_{max}, at the well.

4.4.1 Maximum Chloride Concentration

Table 4-3 presents the sensitivity of C_{max} to each of the 11 factors considered in this study (Table 4-1). The factors are sorted according to their impact on C_{max} in Table 4-3. The most important factors are the Height of Brine (produced water) Release and the Release Chloride Concentration. Changing the Height of Brine Release from 0.025 – 0.6 m while holding all other factors fixed results in an average increase of maximum chloride concentration of 4,340 ppm. Changing the Release Chloride Concentration from 10,000 to 100,000 ppm results in an average increase of 4,017 ppm in maximum chloride concentration in the well. The absolute concentration values depend on the setup of the simulation experiment. The relative effects of each factor were added in Table 4-3. The factors Height of Brine Release and Release Chloride Concentration have relative effects of 1.00 and 0.93 respectively, much higher than of any other factor. The predicted difference in C_{max} due to the difference in Release Chloride Concentration is 93% of predicted difference for the Height of Brine Release. The predicted difference in C_{max} for the two climates indices, however, was only 28% of predicted difference for the Height of Brine Release. As Table 4-3 shows, Initial Water Content of Soil exerts the smallest influence on the prediction of $C_{max.}$

The two most important factors, Height of Brine Release and the Release Chloride Concentration, determine the Mass of Chloride entering the soil surface during a release. If the Height of Brine Release or the Release Chloride Concentration increases, the Mass of Chloride increases and consequently, the maximum chloride concentration increases. Because the Mass of Chloride appears to be the key factor in determining the maximum chloride concentration arriving at a down gradient monitoring well, the sensitivity analysis was repeated using Mass of Chloride instead of Height of Brine Release and Release Chloride Concentration. The Initial Water Content of Soil was eliminated in the second sensitivity analysis since this factor has very little effect on C_{max}.

The results of the second analysis are presented in Table 4-4 and in Figure 4.2. The mean chloride concentration of all 256 scenarios with Mass of Chloride 250 g/m^2 is 89 ppm and that of all 256 scenarios with Mass of Chloride 60,000 g/m^2 is 8,446 ppm (See Figure 4-2). The difference between these two values is 8,357 ppm, which is the predicted sensitivity of the maximum chloride concentration for an increase of Mass of Chloride from 250 to 60,000 g/m^2 when holding all other factors fixed.

The Thickness of Aquifer also has a large impact with a sensitivity of 5,632 ppm for a change from 3 to 30 m. All other factors are less important. For comparison, the relative impacts of each factor was determined by dividing each affect by the influence of the Mass of Chloride (Table 4-4). The most important factors Mass of Chloride and Thickness of Aquifer have relative effects of 1.00 and 0.67, respectively. The factors Soil, Aquifer Flux, and Dispersion Length have relative effects of 0.43, 0.42, and 0.32, respectively. The factors Climate, Ground Water Depth, and Volume of Brine Release have much less impact with relative effects of 0.25, 0.22, and 0.20. Ambient Chloride Concentration (Relative effect 0.01) has virtually no effect.

Table 4-3—Main effects of the vadose zone, aquifer, and brine release factors on the maximum chloride concentration arriving at the monitoring well C_{max}, first sensitivity analyzes

Factor	Effect on C_{max}	
	ppm	Relative Effect
Height of Brine Release	4340	1
Release Chloride Concentration	4017	0.93
Thickness of Aquifer	3237	0.75
Soil	2070	0.48
Aquifer Flux	1994	0.46
Dispersion Length	1545	0.36
Climate	1184	0.27
Ground Water Depth	1081	0.25
Volume of Brine Release	932	0.21
Ambient Cl Concentration	76	0.02
Initial Water Content of Soil	25	0.01

Figure 4.2—The effect of nine brine release, vadose zone, and aquifer factors on the maximum chloride concentration in a down gradient monitoring well

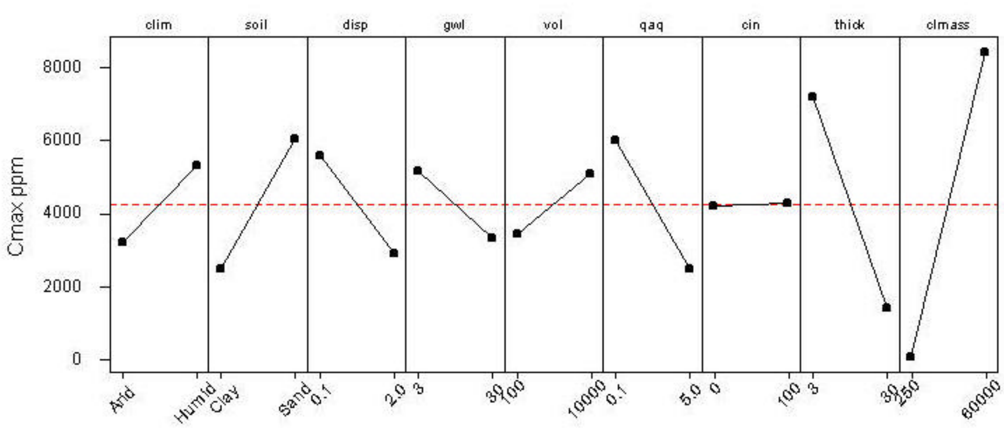


Table 4-4—Main effects and important interactions of the vadose zone, aquifer, and brine release factors on the maximum chloride concentration arriving at the monitoring well C_{max} and the time of arrival of the maximum concentration T_{max}, second sensitivity analyzes

Factor	Effect on C_{max}		Effect on T_{max}	
	ppm	Relative Effect	Years	Relative Effect
Main Effects				
Chloride Mass	8,357	1	52	0.46
Aquifer Thickness	5,632	0.67	5	0.04
Soil	3,560	0.43	106	0.93
Aquifer Flux	3,525	0.42	7	0.06
Dispersion Length	2,699	0.32	11	0.06
Climate	2,099	0.25	114	1
Ground Water Depth	1,826	0.22	104	0.91
Volume of Brine Release	1,631	0.2	0	0
Ambient Cl Concentration	82	0.01	44	0.39
Interaction Effects				
Chloride Mass x Aquifer Thickness	5,573	0.67		
Chloride Mass x Soil	3,519	0.42		
Chloride Mass x Aquifer Flux	3,509	0.42		
Aquifer Thickness x Aquifer Flux	2,529	0.3		
Aquifer Thickness x Soil	2,509	0.3		
Soil x Aquifer Flux	1,223	0.15		
Soil x Climate			98	0.86
Climate x Depth Ground Water			95	0.83
Soil x Depth Ground Water			90	0.79

The predicted maximum and minimum values of C_{max} for a factor of interest can depend on the values of other factors. Where this is the case, the two factors are said to interact. An Analysis of Variance revealed that 6 interactions affect the maximum chloride concentration. These are the interactions between:

- Chloride Mass and Thickness of Aquifer,
- Chloride Mass and Vadose zone texture,
- Chloride Mass and Aquifer Flux,
- Thickness of Aquifer and Aquifer Flux,

- Thickness of Aquifer and Vadose zone texture, and
- Vadose Zone Texture and Aquifer Flux.

Table 4-4 shows the relative importance of each interaction and the interactions are presented in Figure 4.3. As shown in Figure 4.3, if Mass of Chloride increases on average from 250 to 60,000 g/m^2 above an aquifer with a thickness of 3 m, the maximum chloride concentration at the well increases on average from 118 to 14,501 ppm. The same increase of Mass of Chloride occurring above an aquifer with a thickness of 30 m causes a more modest chloride increase from 60 to 2,757 ppm. In a sandy vadose zone, C_{max} increases from 110 to 11,985 ppm in response to the different chloride loads to the ground surface. However, different produced water releases to a clay result in smaller differences, 68 to 4,906 ppm, but fall within the range of responses in a sandy zone.

The implication of the results of the sensitivity analysis is that determination of Mass of Chloride per unit surface area and Thickness of Aquifer is critical for the evaluation of ground water impairment. Knowledge of Vadose Zone Texture Conditions, Aquifer Flux, Dispersion length, Climate, Ground Water Depth, and Volume of Brine Release can provide useful additional information, while ambient Chloride Concentration and Initial Water Content of Soil provide little relevant information.

The results of the sensitivity analysis cannot be used to directly evaluate field sites because they are based on the average change of maximum chloride concentration. For each factor, the maximum chloride concentration exhibits a wide range of values as is shown in Table 4-5.

Figure 4.3—Interaction effects between the factors soil, flux in aquifer, thickness of aquifer, and chloride load on the maximum chloride concentration in a down gradient monitoring well

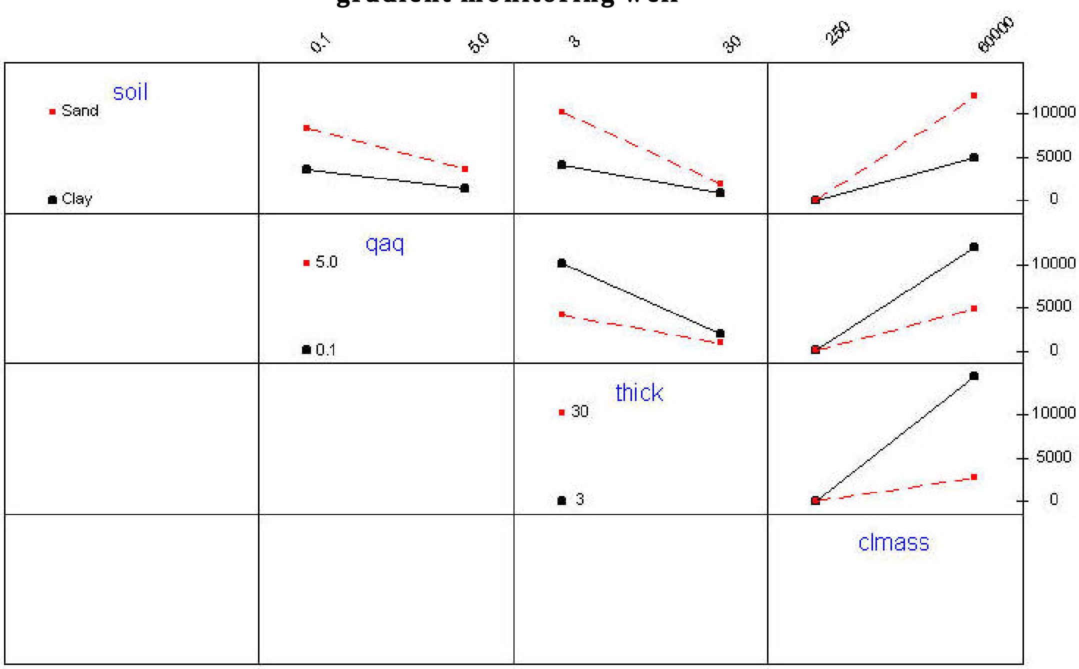


Table 4-5—Statistics of maximum chloride concentrations (ppm) determined in the sensitivity analysis

Main Effect	Level	Mean	Minimum	Maximum
Mass of Chloride	250 g/m^2	89	0	303
	60,000 g/m^2	8,446	0	46,633
Thickness of Aquifer	30 m	1,429	0	15,354
	3 m	7,195	0	46,633
Soil	Clay	2,487	0	37,233
	Sand	6,047	2	46,633
Aquifer Flux	0.05 m/day	2,505	0	29,779
	0.001 m/day	6,030	0	46,633
Climate	Arid	3,218	0	44,372
	Humid	5,317	0	46,633
Ground Water Depth	30 m	3,354	0	40,758
	3 m	5,181	0	46,633
Volume of Brine Release	100 bbls	3,452	0	41,603
	10,000 bbls	5,083	0	46,633
Dispersion Length	2.0 m	2,918	0	25,653
	0.1 m	5,617	0	46,633
Ambient Cl Concentration	0 ppm	4,226	0	46,593
	100 ppm	4,308	0	46,633

4.4.2 Arrival Time of Maximum Chloride Concentration

Table 4-4 displays the effects of the 11 factors on the arrival time of the maximum chloride concentration at the well. The arrival time strongly depends on climate (relative effect of 1.0 in Table 4-4), vadose zone texture, and ground water depth. In the arid climate of Lea County, New Mexico, a produced water release will require an additional 114 years (40,515 days) for the maximum concentration to arrive at a well than a similar release in the humid climate of Shreveport, Louisiana. The vadose zone texture and ground water table effects are of the same order of magnitude (106 and 104 years respectively). Other factors are less important. Figure 4-4 graphically displays this same information. The Analysis of Variance identified three important interactions that effect the length of time required for C_{max} to reach a well:

- Vadose Zone Texture and Climate,
- Climate and Depth to Ground Water, and
- Vadose Zone Texture and Depth to Ground Water.

The lower right section of Figure 4.5 shows that the Depth to Ground Water has little effect on the arrival time of C_{max} if the texture of the vadose zone is sand. In a clay profile, however, the time of arrival is very different: nearly 80,000 days (219 years). This same relationship is expressed with the interaction between Climate and Depth to Ground Water (plotted in the upper right portion of Figure 4.5). In a humid climate, the texture of the vadose zone has little impact on the arrival time of C_{max}. However, in the arid Lea County, a release to a clay profile will require over 200 years longer for C_{max} to reach a well than the same release to a sandy vadose zone would.

Figure 4.4—The effect of nine brine release, vadose zone, and aquifer factors on the time when the maximum chloride concentration arrives in a down gradient monitoring well

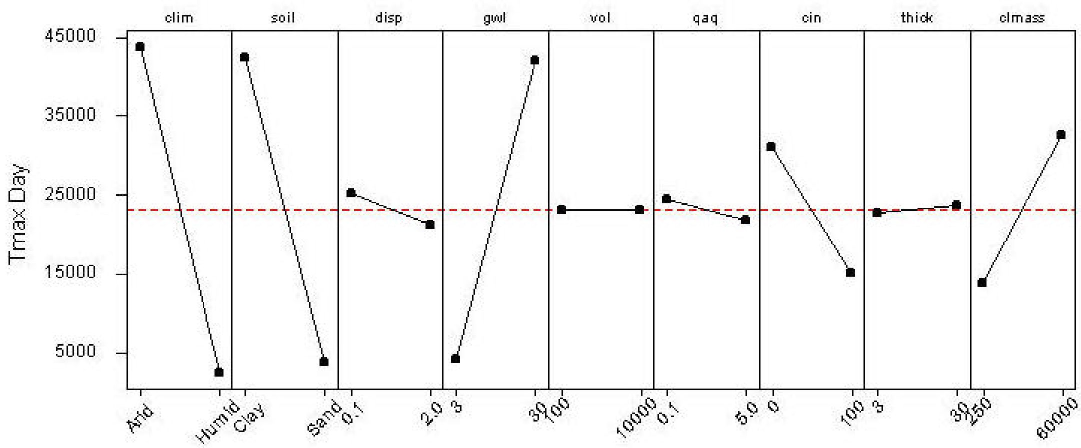
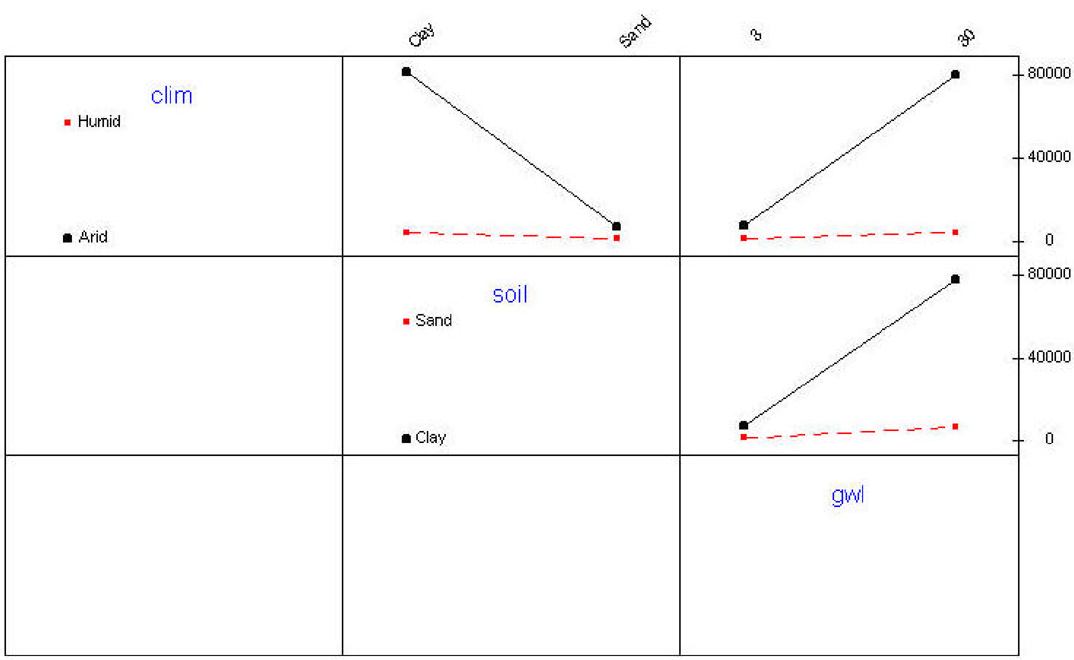


Figure 4.5—Interaction effects between the factors climate, soil, and ground water depth on the time when the maximum chloride concentration arrives in a down gradient monitoring well



5.0 INITIAL VERTICAL DISTRIBUTION OF CHLORIDE (FIRST YEAR)

5.1 Purpose

Produced water releases are often sudden and accidental, and are a result of either a pipeline rupture or a valve failure at a tank battery. The best strategy for prevention of ground water impairment after a produced water release is to clean up prior to deep infiltration of the chloride into the vadose zone. After the produced water has infiltrated more than a few meters into the soil, mitigating any perceived threat by soil removal may be difficult. The objective of this chapter is to explore to what depth chloride will migrate into the vadose zone during the first weeks following a release to determine when one must initiate a characterization and/or remediation program.

5.2 Modeling Methodology

Ninety-six scenarios were evaluated using the input parameters to the HYDRUS-1D model presented in Table 5-1. Four soil types were evaluated under arid and humid climate conditions. For each soil type (sand, sandy loam, clay loam, and clay) simulations were run for three produced water heights (0.025 m, 0.3 m, and 0.6 m), with a chloride concentration of 10,000 ppm released in a vadose zone of 3 m and 30 m thick, with dispersion coefficients of 0.1 and 2 m. The combination of all these factors yields 96 scenarios and provides a good picture of what occurs when even one variable is changed.

Model outputs for the first 5 weeks after the release as well as after 50 weeks were examined. The simulations provided information on the depths corresponding at chloride concentration of 250 ppm and the maximum chloride concentration at short time periods after the produced water release. The predicted effect of the spill on groundwater quality was not evaluated.

Table 5-1—Input Parameters for HYDRUS1D Model for Analysis of Initial Vertical Brine Distribution

Climate	Arid (Hobbs), Humid (Shreveport)
Vadose Zone Texture	Sand, sandy loam, clay loam, clay
Initial Water Content of Vadose Zone	Wet initial conditions (no vegetation)
Dispersion Length	0.1 m, 2.0 m
Depth to Ground Water	3 m, 30m
Chloride in Release	10,000 ppm
Height of Spill	0.025 m, 0.3 m, 0.6 m

5.3 Analysis and Data Presentation

Tables 5-2 show how far a chloride concentration of 250 ppm has moved down in the profile during the first 5 weeks, and the 50th week after a 10,000 ppm chloride release. Table 5-2.1 shows results in the humid climate with a ground water table depth of 3 m, and Table 5-2.2 shows the humid climate with a ground water table depth of 30 m. Tables 5-2.3 and 5-2.4 show an arid climate with a ground water table depth of 3 m and 30 m, respectively.

The depth corresponding to 250 ppm chloride in the soil water differs widely between the modeled scenarios. One week after a release, the shallowest depth of penetration is 0.28 m in clay (arid and humid, 0.025 m spill height). The maximum depth of 250 ppm chloride in the pore water is 13.42 m in a Shreveport sand release scenario. To facilitate review of Tables 5-2, yellow shading is used to highlight when the depth of 250 ppm chloride pore water was between 3 and 5 m. The area shaded in red indicates times when chloride penetration exceeded 5 m.

The following observations can be made concerning the initial migration of chloride in the vadose zone:

1. In all of the 96 scenarios, 250 ppm chloride is found in pore water at depths of at least 0.28 m below ground surface.

2. In 61 of these 96 simulations, 70% or more of the vertical transport observed in the 50-week period occurred by the fifth week after the release.

3. After initial penetration of at least 0.28 m, chloride continues to migrate downward during the 50-week observation period.

4. In Tables 5-2.1 and 5-2.3 (which present data for ground water table depth equal to 3 m), the depth of penetration of 250 ppm chloride often is located below the ground water table. Since HYDRUS-1D deals only with vertical flow, these cases are representative of an aquifer without horizontal flow and, thus, present a worse case scenario. In aquifers with a horizontal groundwater flux, chloride dilution would have resulted in a lower maximum chloride concentration.

The depth of the maximum chloride concentration was also evaluated during this same period to better understand the distribution of the chloride in the vadose zone. Table 5-3, presents 24 typical cases from the 96 simulations; these cases refer to a dispersion length of 2 m and a depth to ground water of 30 m. The following observations can be made from data in Table 5-3.

1. Five weeks after a spill, only 2 of the 24 scenarios show the maximum chloride concentration deeper than 0.1 m. These 2 scenarios are sand textures in the arid climate of Hobbs with spill heights of 0.3 m and 0.6 m, where the penetration depths were 1.97 and 2.3 m respectively. In Shreveport under the same soil and ground water depth conditions, the penetration depths were 0.01 m. Normally one would expect a deeper penetration in the more humid climate of Shreveport. This difference in penetration depths is explained by 2 in. of cumulative precipitation in Hobbs in week 2 after the produced water release while in Shreveport only ¼ in. of rain was measured in the first week after the release. Thus, local weather conditions immediately after a produced water release are more important for determination of initial brine penetration depth than the climate. However, after 50 weeks the humid climate in Shreveport results in deeper penetration for all cases than observed under the arid conditions of Hobbs.

2. After 50 weeks, the maximum chloride concentration for 9 of the 24 simulations remains at the ground surface. Six out of these 9 simulations are clay textures in Hobbs.

3. For the remaining 15 simulations, the maximum chloride concentration lies below 1 meter.

4. The maximum concentration is directly related to the spill height (chloride loading). The greater the mass of chloride applied to the ground per unit area, the higher the chloride concentration in soil water.

Table 5-2.1—Depth of Penetration of chloride concentration 250 ppm; Humid Climate, Depth of Ground Water Table = 3 m

			Week 1	Week 2	Week 3	Week 4	Week 5	Week 50
Soil	Brine (m)	Disp (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)
C	0.025	0.1	0.28	0.29	0.3	0.31	0.32	1.42
C	0.025	2	0.76	0.8	0.89	0.94	0.98	-
C	0.3	0.1	1.59	1.77	1.79	1.79	1.79	2.55
C	0.3	2	3.76	4.3	4.41	4.48	4.52	5.7
C	0.6	0.1	1.59	2.58	2.72	2.76	2.78	3.42
C	0.6	2	3.76	5.72	6.19	6.33	6.42	7.6
Cl	0.025	0.1	0.31	0.32	0.33	0.34	0.34	1.45
Cl	0.025	2	0.87	0.91	0.91	0.88	0.85	-
Cl	0.3	0.1	1.58	1.77	1.82	1.87	1.9	2.7
Cl	0.3	2	3.86	4.4	4.7	4.89	5.03	6.78
Cl	0.6	0.1	1.78	2.7	2.9	3	3.06	4
Cl	0.6	2	4.12	6.08	6.67	7.02	7.25	9.6
Sl	0.025	0.1	0.57	0.64	0.67	0.7	0.71	3.1
Sl	0.025	2	1.3	1.58	1.73	1.82	1.9	-
Sl	0.3	0.1	2.87	3.19	3.34	3.42	3.49	4.64
Sl	0.3	2	4.81	5.54	5.87	6.07	6.2	8.27
Sl	0.6	0.1	3.78	4.22	4.41	4.52	4.59	5.73
Sl	0.6	2	6.86	7.74	8.12	8.31	8.43	10.44
S	0.025	0.1	1.03	1.19	1.26	1.3	1.35	4.25
S	0.025	2	2.18	2.52	2.72	2.78	2.79	-
S	0.3	0.1	3.79	3.92	3.98	4.01	4.04	5.68
S	0.3	2	6.97	6.37	6.47	6.52	6.58	9.38
S	0.6	0.1	4.82	4.97	5	5.02	5.07	6.68
S	0.6	2	8.29	8.57	8.65	8.71	8.76	11.49

C: Clay

Cl: Clay loam

Sl: Sandy loam

S: Sand

Yellow: Indicates the depth of 250ppm chloride pore water is between 3 and 5 m.

Red: Indicates where the depth of 250 ppm chloride pore water exceeds 5 m.

Table 5-2.2—Depth of penetration of chloride concentration 250 ppm; Humid Climate, Depth of Ground Water Table = 30 m

			Week 1	Week 2	Week 3	Week 4	Week 5	Week 50
Soil	Brine (m)	Disp (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)
C	0.025	0.1	0.28	0.29	0.3	0.31	0.32	1.45
C	0.025	2	0.75	0.8	0.88	0.94	0.97	-
C	0.3	0.1	1.51	1.6	1.61	1.62	1.62	2.45
C	0.3	2	3.63	3.99	4.08	4.14	4.17	5.43
C	0.6	0.1	1.58	2.58	2.72	2.76	2.78	3.47
C	0.6	2	3.76	5.72	6.19	6.32	6.42	7.52
Cl	0.025	0.1	0.31	0.32	0.33	0.33	0.34	1.46
Cl	0.025	2	0.88	0.91	0.9	0.87	0.83	-
Cl	0.3	0.1	1.59	1.74	1.81	1.85	1.89	2.7
Cl	0.3	2	3.85	4.42	4.7	4.88	5.03	6.79
Cl	0.6	0.1	1.79	2.69	2.89	2.98	3.06	4
Cl	0.6	2	4.12	6.06	6.67	6.99	7.26	9.6
Sl	0.025	0.1	0.57	0.64	0.67	0.7	0.72	3.56
Sl	0.025	2	1.3	1.58	1.73	1.81	1.9	-
Sl	0.3	0.1	3.2	3.65	3.84	4	4.13	6.99
Sl	0.3	2	5.62	7.22	8.04	8.5	9	14.11
Sl	0.6	0.1	5.12	5.72	6.08	6.36	6.6	9.76
Sl	0.6	2	8.58	16.93	18.99	20.88	22.32	>30
S	0.025	0.1	1.03	1.19	1.26	1.3	1.35	7.88
S	0.025	2	2.17	2.65	2.96	3.2	3.34	-
S	0.3	0.1	5.42	6.21	6.65	7.08	7.39	13.68
S	0.3	2	9.06	11.81	13.39	13.88	14.54	24.85
S	0.6	0.1	8.63	9.96	10.78	11.21	11.63	18.68
S	0.6	2	13.42	16.93	18.99	20.88	22.32	> 30

C: Clay

Cl: Clay loam

Sl: Sandy loam

S: Sand

Yellow: Indicates the depth of 250ppm chloride pore water is between 3 and 5 m.

Red: Indicates where the depth of 250 ppm chloride pore water exceeds 5 m.

Table 5-2.3—Depth of penetration of chloride concentration 250 ppm; Arid Climate, Depth of Ground Water Table = 3 m

			Week 1	Week 2	Week 3	Week 4	Week 5	Week 50
Soil	Brine (m)	Disp (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)
C	0.025	0.1	0.28	0.47	0.5	0.54	0.56	0.83
C	0.025	2	0.64	0.92	1.03	1.08	1.1	1.45
C	0.3	0.1	1.25	1.7	1.78	1.83	1.84	1.96
C	0.3	2	2.93	3.96	4.24	4.35	4.41	4.87
C	0.6	0.1	1.25	2.05	2.68	2.75	2.79	2.95
C	0.6	2	2.94	4.62	5.9	6.17	6.3	7
Cl	0.025	0.1	0.29	0.42	0.5	0.54	0.56	0.87
Cl	0.025	2	0.5	0.6	0.86	0.95	1.03	1.38
Cl	0.3	0.1	1.16	1.66	1.84	1.95	2	2.4
Cl	0.3	2	1.72	2.95	3.63	4.01	4.24	5.94
Cl	0.6	0.1	1.16	1.93	2.6	3.76	2.94	3.62
Cl	0.6	2	1.72	3.37	5.16	5.92	6.26	8.78
Sl	0.025	0.1	0.46	0.59	0.84	0.94	1.02	2.33
Sl	0.025	2	0.68	0.84	1.22	1.46	1.65	2.62
Sl	0.3	0.1	1.53	2.52	2.8	2.96	3.06	3.69
Sl	0.3	2	1.82	3.42	4.35	4.79	5.05	6.4
Sl	0.6	0.1	1.54	2.6	3.18	3.7	3.95	4.78
Sl	0.6	2	1.72	3.54	5.31	6.47	7.01	8.6
S	0.025	0.1	0.88	1.08	1.67	1.84	1.98	3.45
S	0.025	2	1.24	1.65	2.39	2.78	2.87	2.85
S	0.3	0.1	2.52	3.38	3.61	3.68	3.72	4.45
S	0.3	2	2.99	5.16	5.66	5.84	5.92	7.32
S	0.6	0.1	2.53	3.44	4.14	4.53	4.64	5.37
S	0.6	2	2.99	5.29	6.82	7.57	7.78	9.15

C: Clay

Cl: Clay loam

Sl: Sandy loam

S: Sand

Yellow: Indicates the depth of 250ppm chloride pore water is between 3 and 5 m.

Red: Indicates where the depth of 250 ppm chloride pore water exceeds 5 m.

Table 5-2.4—Depth of penetration of chloride concentration 250 ppm; Arid Climate, Depth of Ground Water Table = 30m

			Week 1	Week 2	Week 3	Week 4	Week 5	Week 50
Soil	Brine (m)	Disp (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)	Depth (m)
C	0.025	0.1	0.28	0.47	0.51	0.54	0.55	0.83
C	0.025	2	0.64	0.91	1.03	1.08	1.1	1.45
C	0.3	0.1	1.51	1.71	1.78	1.82	1.83	1.95
C	0.3	2	3.47	3.9	4.18	4.29	4.38	4.79
C	0.6	0.1	1.57	2.59	2.75	2.79	2.83	2.97
C	0.6	2	3.6	5.66	6.12	6.28	6.39	7
Cl	0.025	0.1	0.3	0.41	0.5	0.54	0.57	0.91
Cl	0.025	2	0.44	0.52	0.74	0.84	0.92	1.52
Cl	0.3	0.1	1.53	1.69	1.84	1.92	1.96	2.38
Cl	0.3	2	1.9	2.22	2.43	2.63	2.76	4.34
Cl	0.6	0.1	1.73	2.66	2.9	3.02	3.11	3.76
Cl	0.6	2	2.1	3.51	4.02	4.31	4.54	7
Sl	0.025	0.1	0.47	0.59	0.86	0.95	1.02	2.34
Sl	0.025	2	0.68	0.84	1.22	1.48	1.66	3.33
Sl	0.3	0.1	2.88	3.32	3.54	3.72	3.86	3.96
Sl	0.3	2	3.72	4.62	5.3	5.87	6.36	11.59
Sl	0.6	0.1	4.86	5.45	5.81	6.1	6.32	8.98
Sl	0.6	2	6.14	7.5	8.55	9.34	9.97	17.38
S	0.025	0.1	0.88	1.08	1.65	1.88	2.01	5.46
S	0.025	2	1.25	1.66	2.46	3.05	3.54	6.84
S	0.3	0.1	5.15	5.95	6.45	6.68	6.95	11.06
S	0.3	2	6.56	8.27	9.97	11.57	12.44	19.91
S	0.6	0.1	8.38	9.51	10.28	11.03	11.54	16.43
S	0.6	2	10.33	13.65	15.19	16.67	18.12	> 30

C: Clay

Cl: Clay loam

Sl: Sandy loam

S: Sand

Yellow: Indicates the depth of 250ppm chloride pore water is between 3 and 5 m.

Red: Indicates where the depth of 250 ppm chloride pore water exceeds 5 m.

Table 5-3—Depth of Penetration of the Maximum Chloride Concentration

		Week 1		Week 2		Week 3		Week 4		Week 5		Week 50	
Soil	Brine (m)	Conc (ppm)	Depth (m)	Conc (ppm)	Depth (m)	Conc (ppm)	Depth (m)	Conc (ppm)	Depth (m)	Conc (ppm)	Depth (m)	Conc (ppm)	Depth (m)
Humid Climate, Ground Water Table at 30 m. Dispersion length = 2 m													
C	0.025	1260	0.01	1260	0	1160	0.01	1110	0.01	974	0.07	214	1.01
C	0.3	5270	0	5530	0	5770	0	5940	0	5510	0.07	2140	1.17
C	0.6	5410	0	6640	0	7350	0	7830	0	7580	0.07	3530	1.5
Cl	0.025	1330	0	1340	0	1340	0	1320	0	1130	0.05	225	1.01
Cl	0.3	4480	0.06	5270	0	5720	0	5730	0	5350	0.06	1930	1.55
Cl	0.6	5740	0	7000	0	7660	0	8180	0	7630	0.07	3230	1.87
Sl	0.025	2120	0.04	2350	0	2310	0	2310	0	2130	0.09	221	3.23
Sl	0.3	5160	0.07	6280	0	6420	0	6540	0	6130	0.01	1950	3.96
Sl	0.6	6410	0.08	7880	0	8090	0	8270	0	7770	0.01	3130	4.36
S	0.025	2450	0.1	2780	0	2750	0	2740	0	2460	0.01	237	7.08
S	0.3	5910	0.13	6760	0	6830	0	6880	0	6380	0.01	2200	8.14
S	0.6	7020	0.13	8020	0	8120	0	8190	0	7640	0.01	3540	9.53
Arid Climate Ground Water Table at 30 m. Dispersion Length = 2 m													
C	0.025	2150	0	972	0	932	0	789	0.02	856	0	619	0
C	0.3	5350	0	3560	0.38	3590	0	3390	0.36	3610	0	4200	0
C	0.6	5480	0	6690	0	6510	0	5810	0.23	6320	0	7080	0
Cl	0.025	3870	0	1650	0	1530	0	1240	0	1370	0	1030	0
Cl	0.3	6360	0	4430	0.53	4520	0	4150	0.33	4580	0	5520	0
Cl	0.6	6570	0	5830	0.38	6040	0	5530	0.36	6100	0	7490	0
Sl	0.025	4920	0	1830	0	1790	0	1340	0	1630	0	741	0
Sl	0.3	8610	0	4790	0.91	4410	0.53	4300	0.69	5180	0	3530	0
Sl	0.6	9730	0	5970	0.98	5890	0	5410	0.98	6280	0	4560	0
S	0.025	4960	0	1650	0	1620	0	1200	0.03	1320	0	395	2.24
S	0.3	8520	0	5540	1.38	4790	1.84	4670	1.51	4580	1.97	2990	5.75
S	0.6	9560	0	6830	1.44	6150	2.5	5980	2.57	5900	2.3	4490	7.15

C: Clay Cl: Clay Loam Sl: Sandy Loam S: Sand

The depth of the maximum concentration varies from 0.0 to 0.13 m in the humid climate and from 0.0 to 2.57 m in the arid climate in the first 4 weeks after a release. This shows that though the depth to 250 ppm chloride in soil water (see the 5-2 Tables) may be several meters below ground surface, the maximum chloride concentration remains at relatively shallow depths. Table 5-3 shows the maximum concentration moving up and down in the profile in response to rainfall events and subsequent evaporation. A combined effect of evaporation and capillary rise in fine textured soils tends to keep the maximum concentration at the surface in the arid environment. In a humid climate such as Shreveport, the maximum concentration will gradually move deeper into the profile. However, the effect of climate only becomes apparent after 50 weeks. In the first 5 weeks, the local weather determines the fate of the chloride. For example, due to dry weather in Shreveport during the first 5 weeks after the release, the penetration depths of maximum chloride concentration remain less than 1 m: from 0.0 to 0.13 m. Because of wet weather in Hobbs during the first 5 weeks after the release, the maximum chloride concentration reaches a depth of 2.57 m.

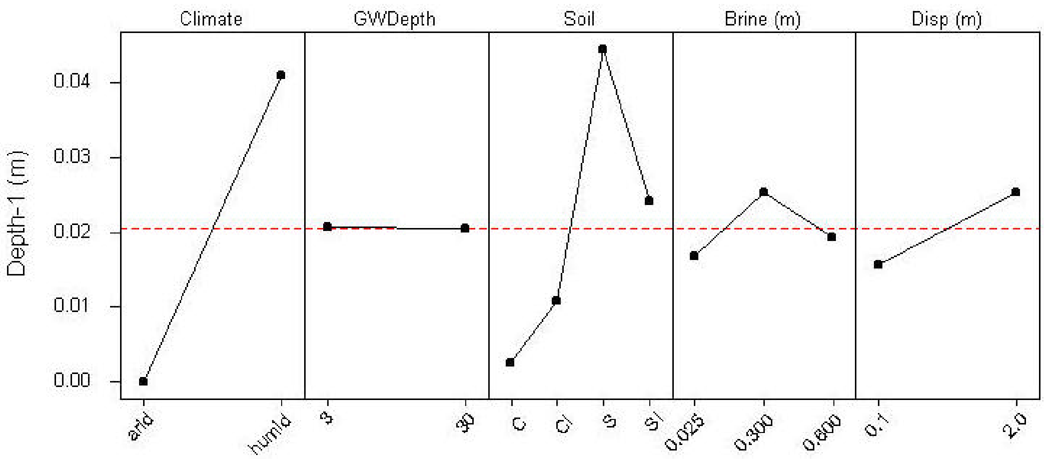
A sensitivity analysis was conducted, similar to the one discussed in Chapter 4, to quantify the effects of different environmental factors (climate, soil, ground water table depth, dispersion length and produced water height) that are considered in Tables 5-2 and Table 5-3. The results are presented in Figures 5-1 - 5-3, summarized below.

Climate clearly is an important factor. After 50 weeks (Figure 5.3) the average penetration depth of maximum chloride concentration is about 1 m in the arid climate versus about 3 m in the humid climate. The effect of climate is variable during the first 5 weeks after the release. The penetration depth can be greater in the humid climate (week 1), or it can be greater in the arid climate (weeks 2 – 5) because of local weather conditions at the site, as discussed above. The most important factor is soil type: the average penetration depths in clay, clay loam, sandy loam, and sand are about 0.2, 0.3, 2.0 and 5.0 m, respectively. Clay prevents deep penetration because its high soil water content, and its fine texture that allows upward water movement during dry periods. Sand promotes deep penetration because of its high hydraulic conductivity, low soil water content, and its coarse texture that prohibits upward water movement through capillary rise. Ground water table depth, and height of the produced water release have a minor effect on the penetration depth of the brine, while dispersion has a negligible effect.

Figure 5.4 presents the distribution of the concentration with depth for 4 different soils in arid and humid climates for a ground water depth of 30 m and a dispersion length of 0.1 m. During the first 5 weeks after a release, the initial depth of impact depends on local weather conditions and soil type. After 50 weeks climate and soil type are the dominant influences. For clay and clay loam, the increase in penetration depth between week 5 and week 50 is relatively minor compared with those in sand and sandy loam. For sand and sandy loam, the center of mass moves deep into the profile by week 50, especially in the humid climate. In fine textured soils (clays) at week 50, the maximum chloride concentration has not moved deeper than 2 m. However for a sand, chloride has penetrated as far as 9 m under humid conditions. Excavation and removal of the chloride mass may be a cost-effective remedy for the release, if environmental and release factors combine to limit chloride migration to the uppermost 0.5 m of soil. If migration exceeds 1 meter, as is the case for many scenarios, other soil restoration options may be more appropriate.

Figure 5.1—Sensitivity analysis of depth of maximum chloride concentration in the Weeks 1 and 2

5.1a—Depth of C_{max} in week 1



5.1b—Depth of C_{max} in week 2

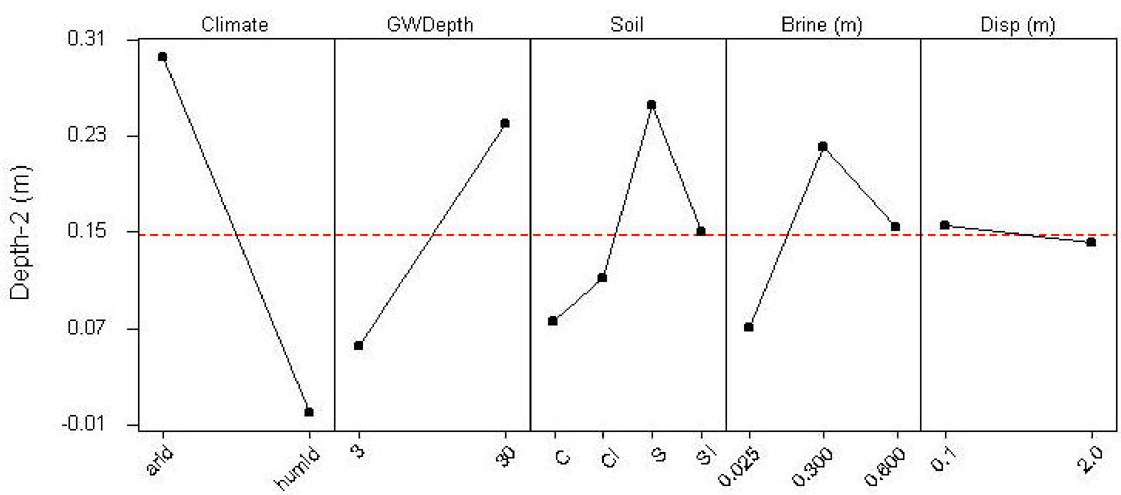
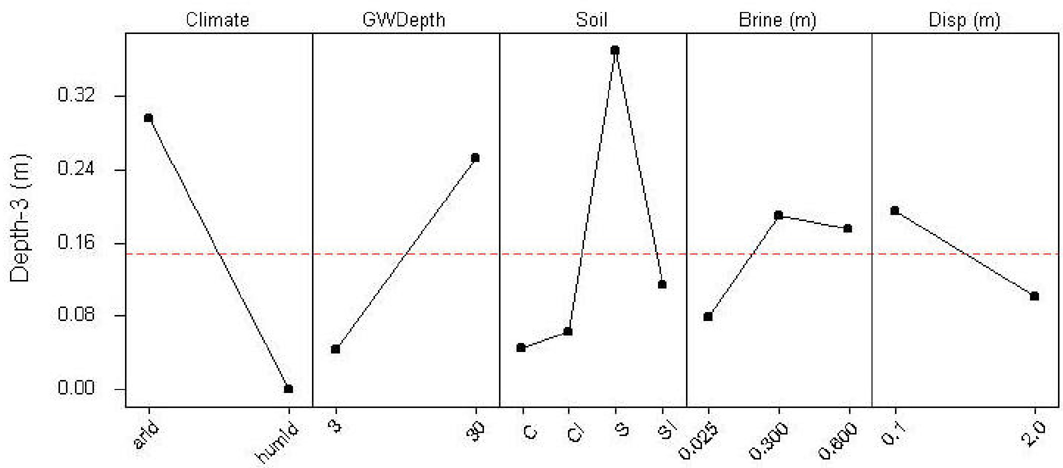


Figure 5.2—Sensitivity analysis of depth of maximum chloride concentration in Weeks 3 and 4

5.2a—Depth of C_{max} in week 3



5.2b—Depth of C_{max} in week 4

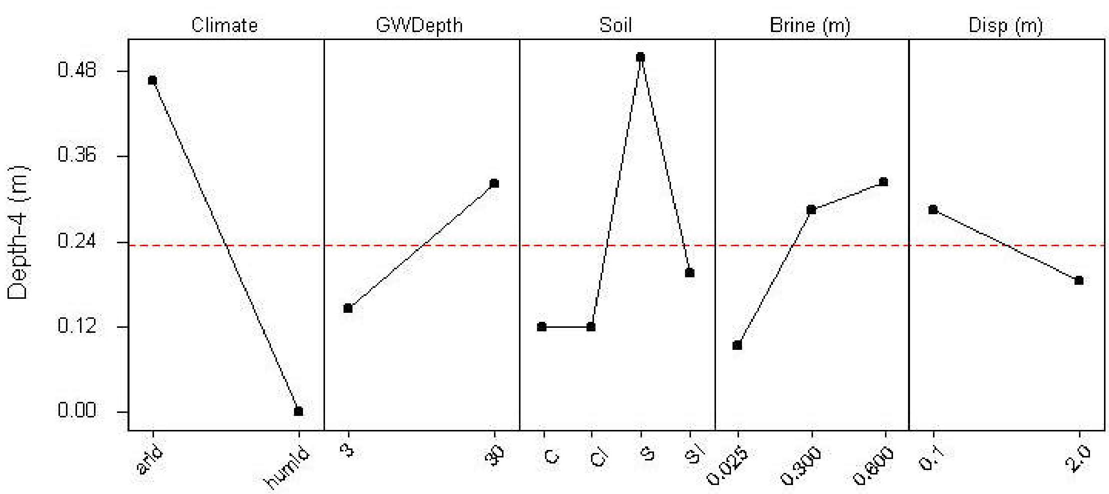
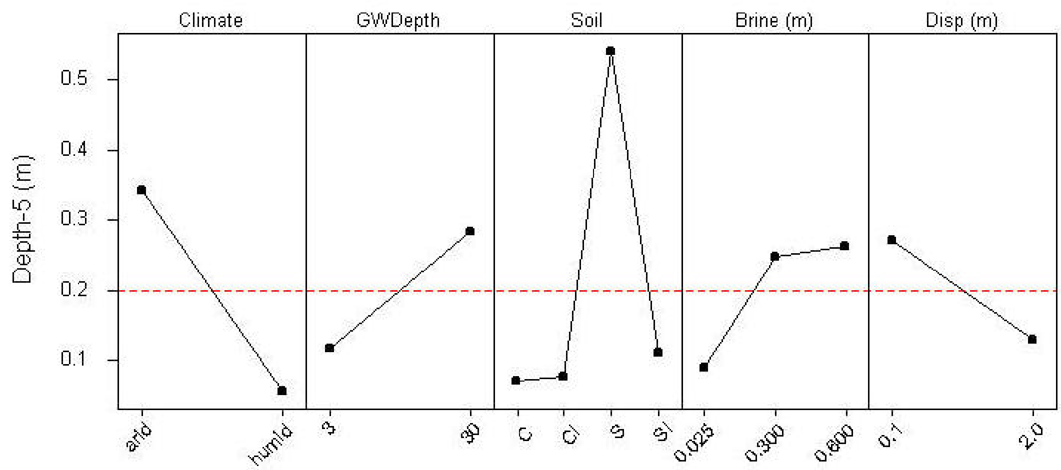


Figure 5.3—Sensitivity analysis of depth of maximum chloride concentration in weeks 5 and 50

5.3a—Depth of C_{max} in week 5



5.3b—Depth of C_{max} in week 50

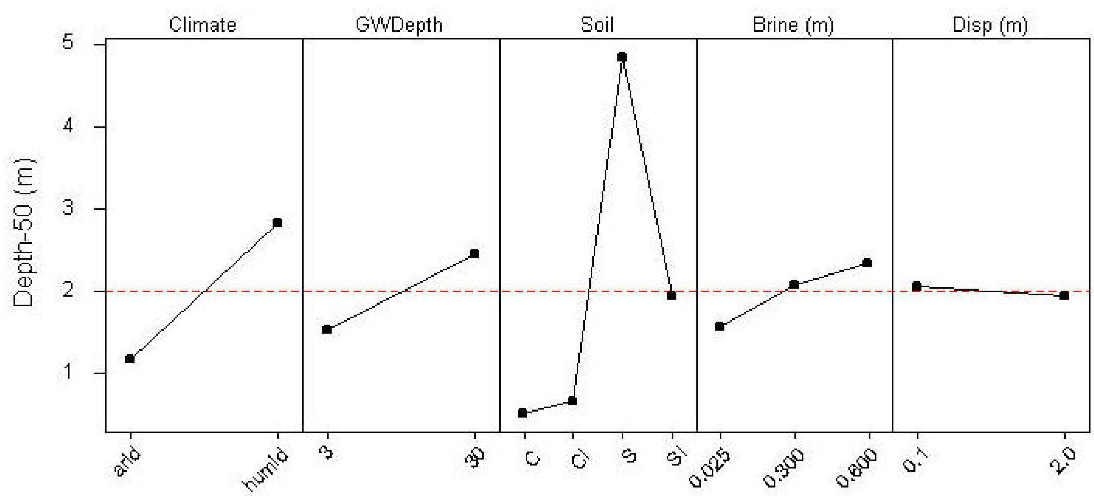


Figure 5.4—Distribution of chloride concentration with depth in the arid climate

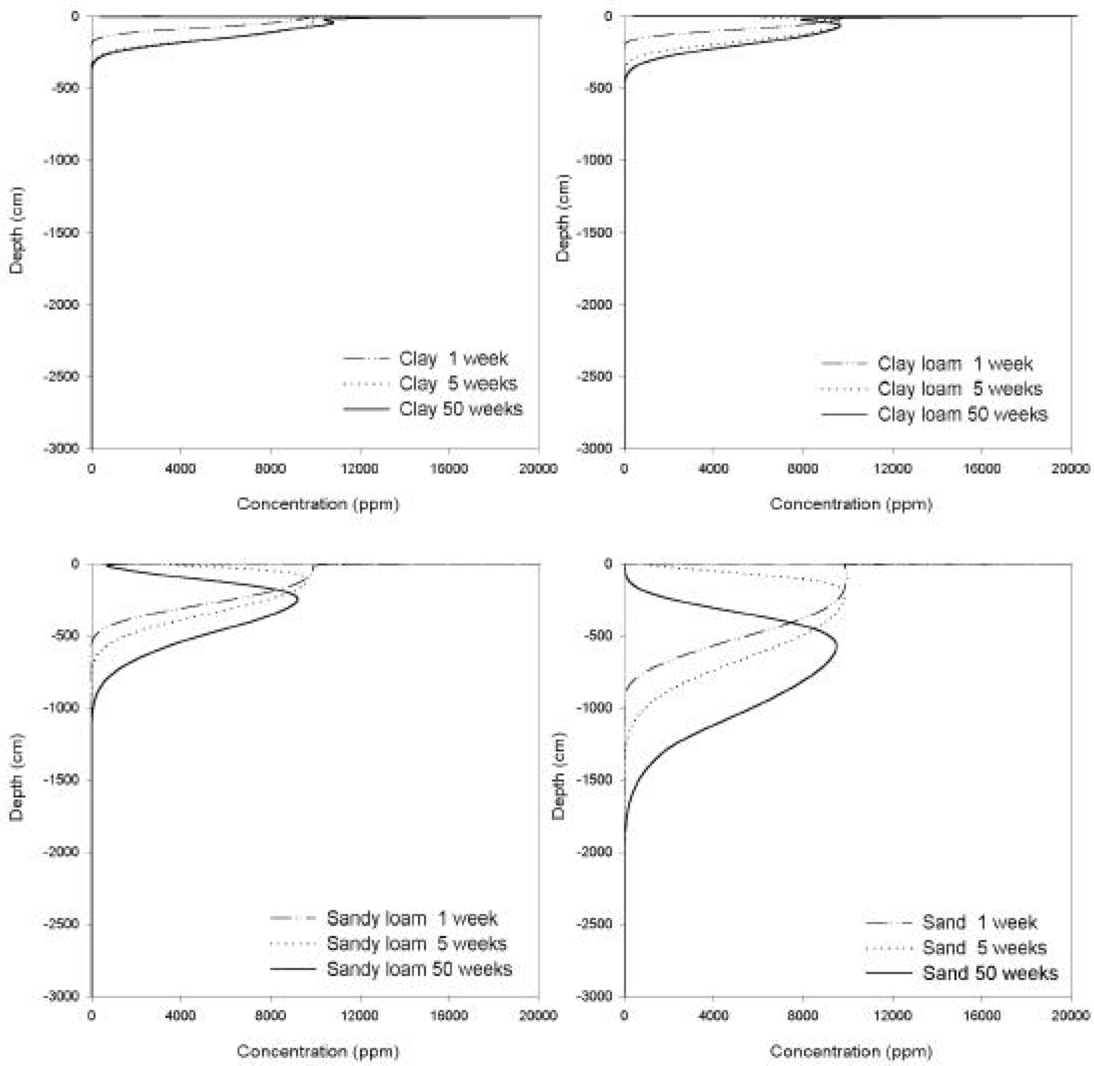
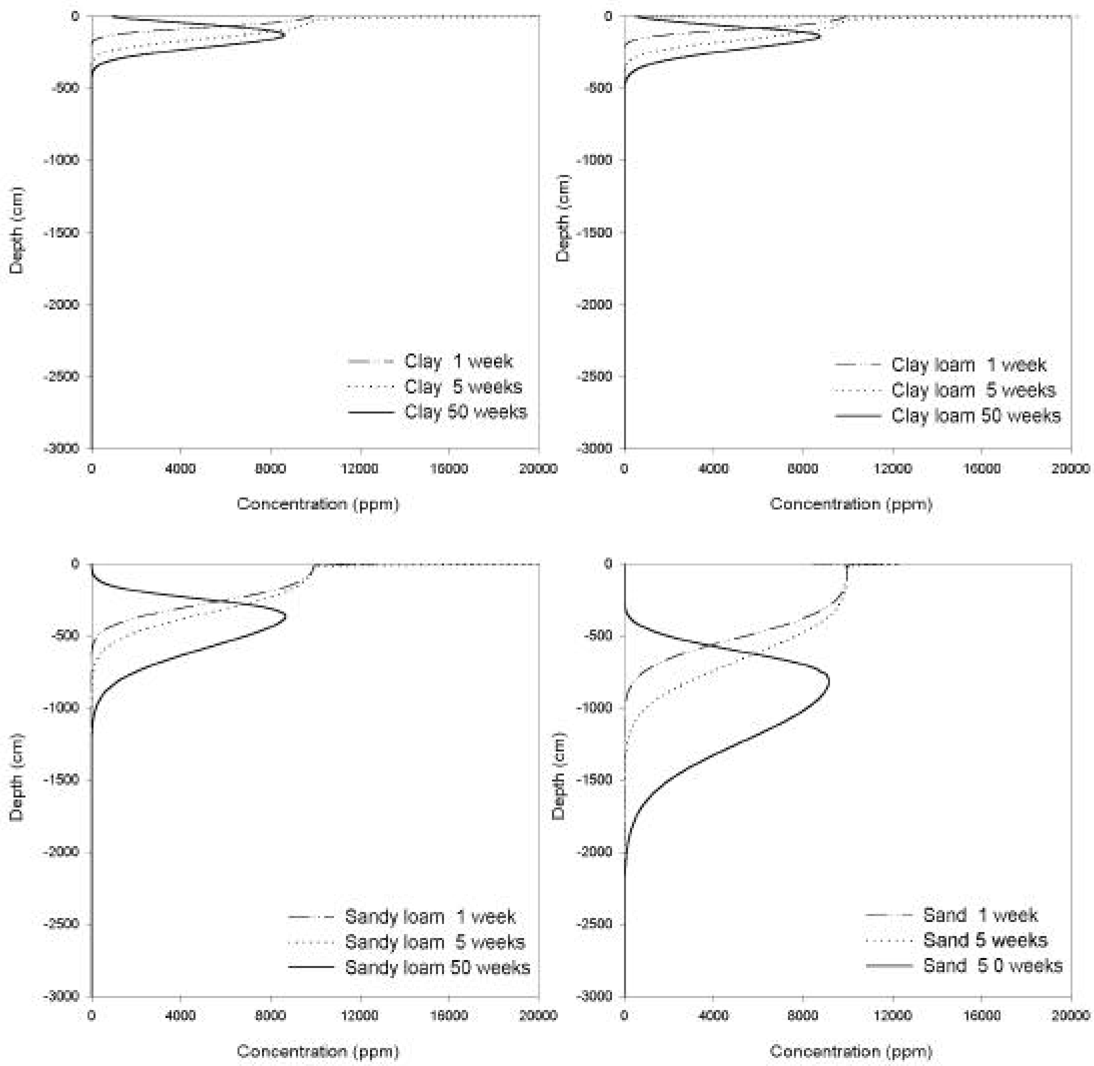


Figure 5.5—Distribution of chloride concentration with depth in the humid climate



6.0 HETEROGENEITY

6.1 Purpose

Thus far, this report has dealt with homogeneous soil profiles and vadose zones for the evaluation of the factors that determine the fate of chloride after a produced water release in the previous chapters. As noted, homogeneous vadose zones rarely occur in nature.

The objective of this chapter is to evaluate how the clay layers intermixed with sand affect the chloride movement in the vadose zone and the subsequent impact in the chloride concentration in the ground water. This portion of the study will also check whether the conclusions regarding chloride movement through homogeneous profiles (Chapter 4) are valid for actual heterogeneous profiles.

6.2 Modeling Methodology and Input

Selected for this analysis were four stratigraphic profiles that represent actual conditions near Hobbs, New Mexico (arid climate), and near Shreveport, Louisiana (humid climate), and two additional profiles for each climate to determine the effect of an increasing cumulative thickness of clay layers. Table 6-1 presents the stratigraphy associated with each profile. Profiles 1 and 3 are identical and common profiles in both locations. In Profile 2, the uppermost clay layer is replaced with caliche, a common lithology near Hobbs and many other regions in the arid Southwest. Profile 4 contains more clay horizons than Profile 3, but the same total thickness of clay (3 m). In Profiles 5 and 6, the number of clay horizons and the total thickness of clay are increased. Profile 5, includes a total of 10 m of clay in 5 layers, each 2 m thick. Profile 6 contains a total of 20 m of clay in 10 separate horizons.

The transport of chloride was simulated assuming a dispersion length of 2.0 m and a release of 100,000 ppm, and a height of 0.025 m for all 8 simulations, and a ground water table depth of 30 m. The migration of the maximum chloride concentration was evaluated through the vadose zone. The underlying aquifer was assumed to have a thickness of 3 m, a ground water flux of 5 cm/day and a background chloride concentration of 100 ppm. The chloride concentration in ground water was evaluated with the mixing model previously used in the sensitivity analysis and validated with MODFLOW.

6.3 Analysis and Data Representation

Simulations of Profiles 1 and 2 in the arid climate of Hobbs generated the same output. For both profiles, the maximum concentration of chloride at the base of the vadose zone and the chloride concentration in the well down gradient of the release were the same. As Table 6-2 shows, the simulations predict a maximum chloride concentration of 190 ppm about 15 years after the release. As shown in the sensitivity analysis, a homogeneous, 30-m-thick sand profile causes a maximum chloride of 221 ppm in the well. A release to a 30-m-thick clay profile causes no predicted ground water quality impairment since the maximum chloride concentration is only 105 ppm, well below the threshold value of 250 ppm. As clay content in the profile increases to 10 m (Profile 5) and 20 m (Profile 6), the predicted chloride concentration in the monitoring well decreases to 201 ppm and 147 ppm respectively.

The data show that an increase in total thickness of clay layers in a profile will slow down the chloride movement and result in lower maximum concentrations in the well. However, small deviations from this general behavior may occur because of weather variability causing temporal variability of ground water recharge at the ground water table. For example, the Hobbs Profiles 1 and 2, with a total clay layer thickness of 3 m, show a chloride concentration of 190 ppm in the well. This is lower than the 201 ppm found in Profile 5 with 10 m of clay. Inspection of the simulation results demonstrates that in Profile 5, the ground water recharge was relatively elevated during the period when the maximum chloride concentration reached the ground water table.

In Shreveport, a similar relationship was observed. Profiles 3 and 4 generate the same output. Both scenarios show 393 ppm chloride in the well after 4.32 years. A release to a 30 m thick sand profile results in a maximum chloride concentration in the well of 419 ppm. Where the total clay content is greater (Profiles 5 and 6), the simulation experiment predicts lower chloride concentrations in the well. Simulations of Profile 5 (10 m of clay) predict 295 ppm chloride in the well, and Profile 6 (20 m of clay) predicts 208 ppm chloride.

Observed chloride concentrations simulated for a well down gradient of the release for the heterogeneous profiles decrease with increasing clay layer thickness in the vadose zone, and fall within the range predicted of the homogeneous sand and clay profiles. This is strong evidence that the results from our sensitivity study and simulations in homogeneous profiles can be used for the evaluation of chloride fate in heterogeneous profiles.

Table 6-1—Inout Parameters for the Heterogeneous Profiles

Climate	Arid (Hobbs)		Humid (Shreveport)		Arid &Humid	Arid &Humid
	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 6
Soil Texture	0-1 m sand	0-1 m sand	0-1 m sand	0-2 m sand	0-1 m sand	0-1 m sand
	1-3 m clay	1-3 m caliche	1-3 m clay	2-3 m clay	1-3 m clay	1-3 m clay
	3-4 m sand	3-4 m sand	3-4 m sand	3-5 m sand	3-4 m sand	3-4 m sand
	4-5 m clay	4-5 m clay	4-5 m clay	5-6 m clay	4-6 m clay	4-6 m clay
	5-30 m sand	5-30 m sand	5-30 m sand	6-20 m sand	6-7 m sand	6-7 m sand
				20-21 m clay	7-9 m clay	7-9 m clay
				21-30 m sand	9-10 m sand	9-10 m sand
					10-12 m clay	10-12 m clay
					12-13 m sand	12-13 m sand
					13-15 m clay	13-15 m clay
					15-30 m sand	15-16 m sand
						16-18 m clay
						18-19 m sand
						19-21 m clay
						21-22 m sand
						22-24 m clay
						24-25 m sand
						25-27 m clay
						27-28 m sand
						28-30 m clay
Dispersion	200 cm	200 cm	200 cm	200 cm	200 cm	200 cm
GW Depth	30 m	30 m	30 m	30 m	30 m	30m
GW Flux	5 cm/day	5 cm/day	5 cm/day	5 cm/day	5 cm/day	5 cm/day
Aquifer Cl	100 ppm	100 ppm	100 ppm	100 ppm	100 ppm	100 ppm
Aquifer Th	3 m	3 m	3 m	3 m	3 m	3m
Release Vol	100 barrels	100 barrels	100 barrels	100 barrels	100 barrels	100 barrels
Rele. Height	2.5 cm	2.5 cm	2.5 cm	2.5 cm	2.5 cm	2.5 cm
Release Cl	100,000 ppm	100,000 ppm	100,000 ppm	100,000 ppm	100,000 ppm	100,000 ppm

Table 6-2—Maximum Concentration at the Groundwater Table and in the Well

Hobbs (Arid)										
	Sand		Profile 1, 2		Profile 5		Profile 6		Clay	
	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)
GW Table	13.2	1290	15.6	911	24.5	550	36.5	382	551	299
Well	15.5	221	15	190	28	201	36.7	147	545	105

Shreveport (Humid)										
	Sand		Profile 3, 4		Profile 5		Profile 6		Clay	
	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)	Time (Years)	C_{max} (ppm)
GW Table	3.2	1050	3.9	787	4.5	567	7.9	366	21.1	294
Well	3.4	419	4.3	393	4.4	295	9.5	208	21.4	193

7.0 VERTICAL CHLORIDE DISTRIBUTION OVER THIRTY YEARS

7.1 Purpose

Studying the initial depth of chloride penetration revealed that the vertical distribution of chloride 1 year after the release depends on local weather conditions and soil type. In fine textured soils, the bulk of the chloride mass remains relatively close to the soil surface making excavation and removal of chloride mass a practical remedy for soil restoration. The purpose of this chapter is to investigate chloride distributions during the first 30 years after a release to better understand different options for soil restoration.

7.2 Modeling Methodology

In this analysis, 22 scenarios were selected from the previous simulations to illustrate how the chloride is distributed with depth over time. Table 7-1 presents the factors in the vadose zone considered in each case. The transport of chloride over time was examined for 3 heterogeneous profiles simulated previously in Chapter 6.

Table 7-1—Factors in the Vadose Zone Considered in the Simulations

Profile	Climate	Ground Water Depth (m)	Release Height (cm)	Release concentration (ppm)	Dispersion Length (cm)
Clay	Arid, humid	3 – 30	2.5 – 60	100,000	200
Sand	Arid, humid	3 – 30	2.5 – 60	100,000	200
Heterogeneous Profile 3	Arid, humid	30	2.5	100,000	200
Heterogeneous Profile 5	Arid, humid	30	2.5	100,000	200
Heterogeneous Profile 6	Arid, humid	30	2.5	100,000	200

7.3 Analysis and Data Presentation

Table 7-2 presents the advance of the chloride center of mass over time under the following conditions:

- Chloride concentration after the release of 100,000 ppm,
- Spill heights of 0.025m and 0.60m, and
- Homogeneous sand and clay profiles,
- Arid and humid conditions.

The maximum concentrations decrease with depth and time for all cases. In general, greater release heights result in deeper centers of mass for any given time. The exceptions are clay profiles in arid climates where the effect of capillary rise causes very low recharge rates and extremely slow (e.g. 600 years) migration rates through the clay profile. The slow recharge rate also results in the higher maximum concentrations under arid conditions. For example, under humid conditions after 5 years, a release of 0.025 m in a profile of 30 m of sand results in a maximum concentration of 230 ppm at the water table. While under arid conditions, 5 years of transport results in a maximum concentration of 2,130 ppm at 9.4 m. For clay profiles under humid conditions, the center of mass moves slower than in a sand profile. For example, a release height of 0.025 m above a 30 m deep water table, in a 3-year period, the maximum concentration in a clay profile is 1,060 ppm at 2.82 m versus 1,080 ppm at 23.79 m in the sand profile.

Figures 7.1 and 7.2 present the distribution of the chloride concentration with depth for a clay and a sand in arid and humid climates. Ground water depths are 3 and 30 m at 1, 2, and 5 years after the release. For the profiles with the ground water at 3 m, the concentration decreases with time but varies very little with depth. In the profile of clay in the arid climate, the higher concentrations remain close to the surface and the distribution of the chloride concentration with depth remains almost constant with time.

Simulations predict that in the arid climate chloride in ground water will exceed 250 ppm only in a sand profile 3 m thick. In the humid climate, the worst case is sand with the ground water table at 3 m where a chloride concentration of 822 ppm arrives at the well in 0.5 years. The humid clay scenario with a 3 m thick vadose zone predicts the second highest chloride concentration in the wells, 523 ppm in 3 years after the release. For sand with the ground water table at 30 m, the maximum concentration is 419 ppm at 3.4 years.

Table 7-3 presents the output for the 3 heterogeneous profiles under arid and humid conditions. In the first 3 years in the arid climate, essentially no difference is observed in the vertical distribution over time with the amount of clay. This is because each profile contains a 2 m thick clay horizon from 1 to 3 m below the ground surface. In the arid climate it takes about 3 years for the chloride to move to a depth of 3 m. In the humid climate, the maximum chloride concentration penetrates to a depth of 3 m (including 2 m of clay) in less than 1 year. This results in different penetration depths after three years in the three heterogeneous profiles. The profile with the least clay has the deepest penetration of the maximum chloride concentration at 17.25 m.

Since clay layers contain more water than sand (e.g. 20 volume percent for sand versus 40 volume percent for clay), the maximum chloride concentrations are smaller in the profiles with the most clay. This is caused by dilution of the produced water by soil moisture. In year 5 in the humid climate, the center of mass has moved to the water table at 30 m in profiles with 3 and 10 m of accumulated clay layers, but has only reached 17.25 m in the profile with 20 m of accumulated clay. Under arid conditions, the maximum chloride concentration after 5 years is at 3.8 m in the profile with 3 m of accumulated clay and at 2.8 m in the profiles with 10 and 20 m of accumulated clay layers.

Figures 7.3 and 7.4 show different curves for selected times representing the distribution over time with heterogeneity. They show that under humid conditions, the chloride center of mass moves quicker, and the solute is distributed more widely over depth with a subsequent decrease in maximum concentration. It is also clear that under arid conditions, the differences (because of heterogeneity), appear later than for humid conditions. The maximum chloride concentration in the well is attenuated by the amount of clay in the profile. In the humid climate, the maximum chloride concentrations in the well are higher than in the arid climate. For the thickness of 3, 10, and 20 m, the concentrations are 393, 295, and 181 ppm in the humid climate versus 190, 185, and 147 ppm in the arid climate. One year after a produced water release, most of the chloride mass has penetrated to a depth below the soil surface that it is difficult to reach using excavation techniques.

Figure 7.1—Vertical chloride distribution in homogeneous clay profiles in arid and humid climates

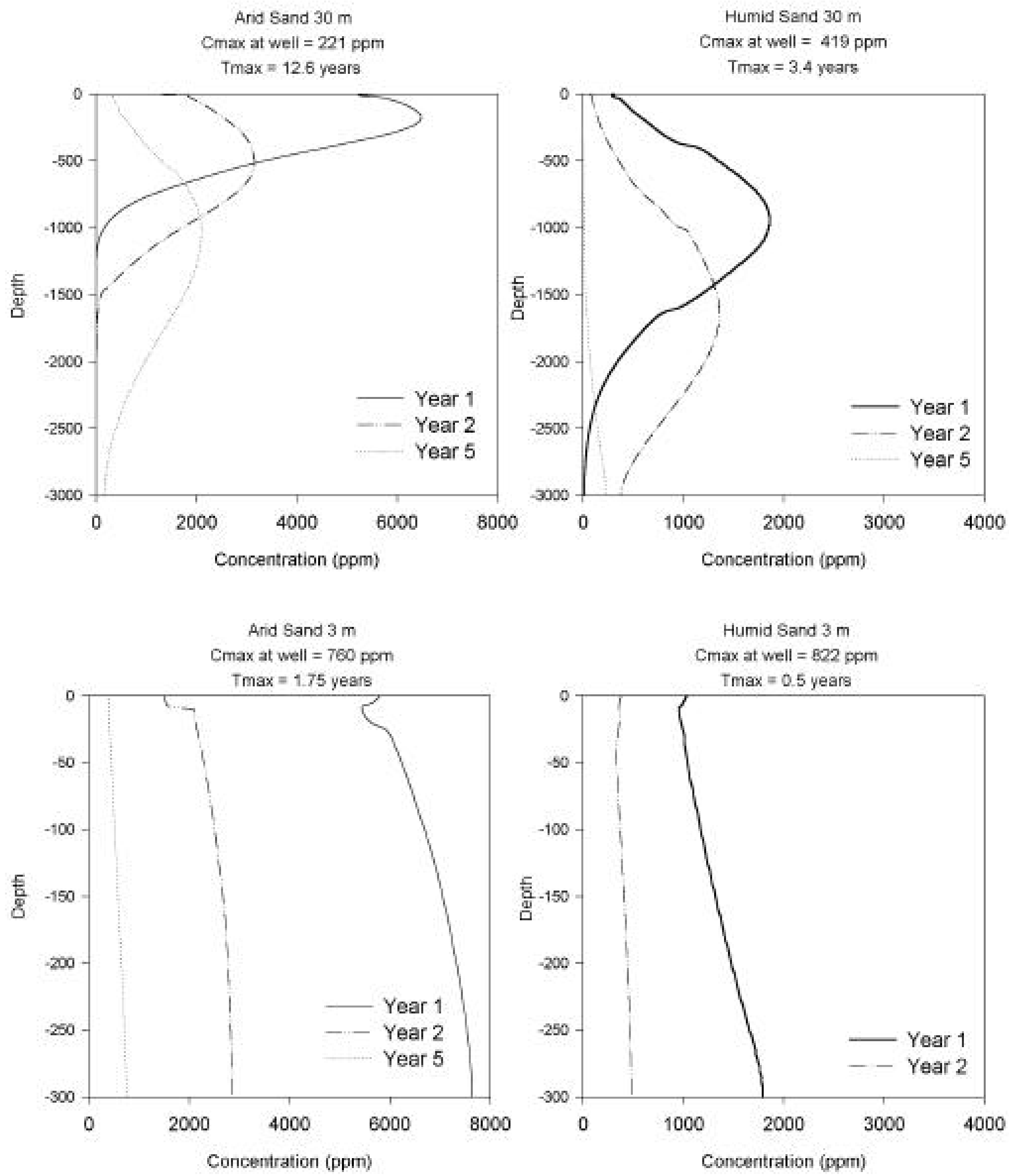


Figure 7.2—Vertical chloride distribution in homogeneous sand profiles in arid and humid climates

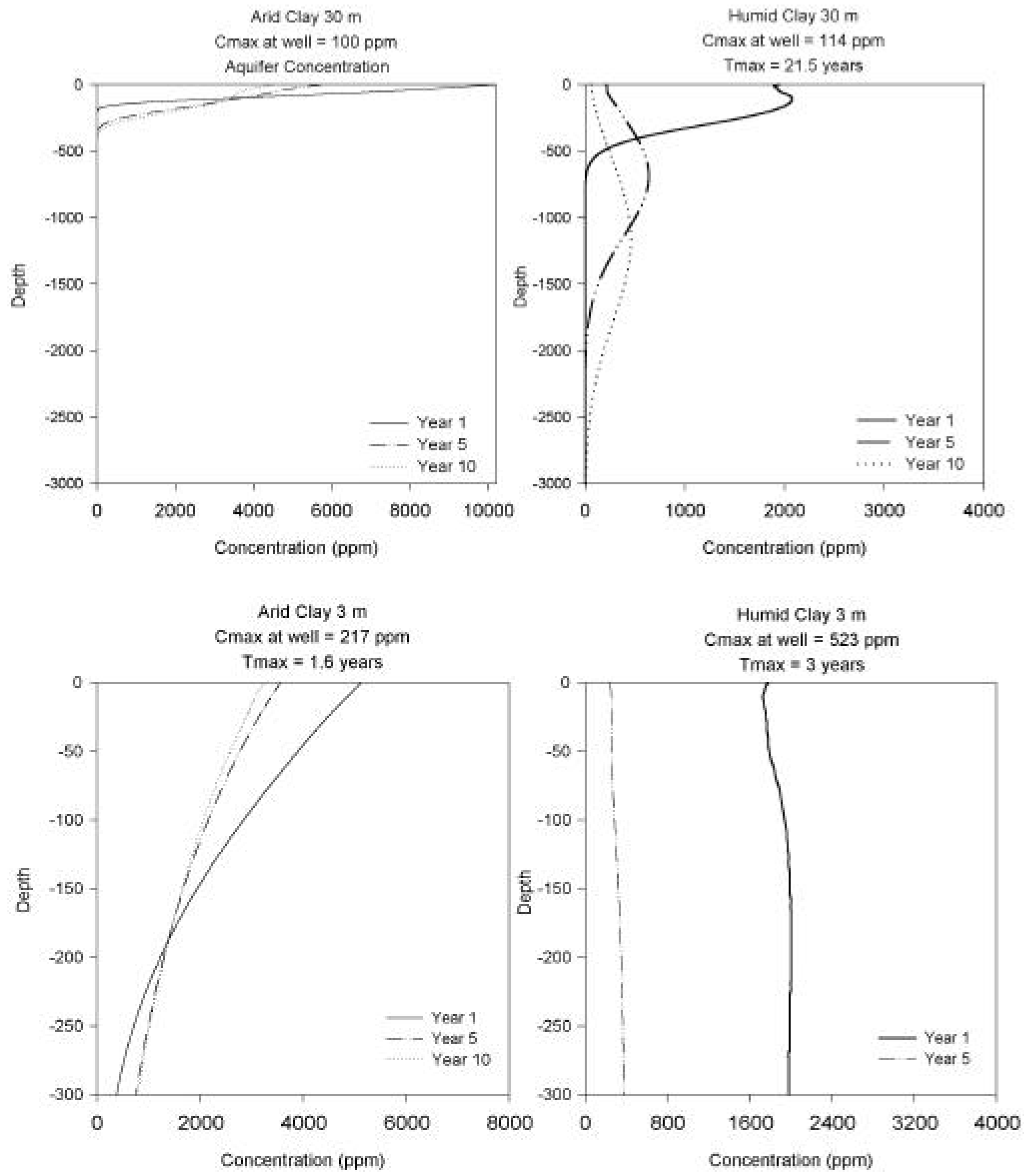


Figure 7.3—Vertical chloride distributions in heterogeneous profiles with 3, 10, and 20 m of accumulated clay layers in an arid climate

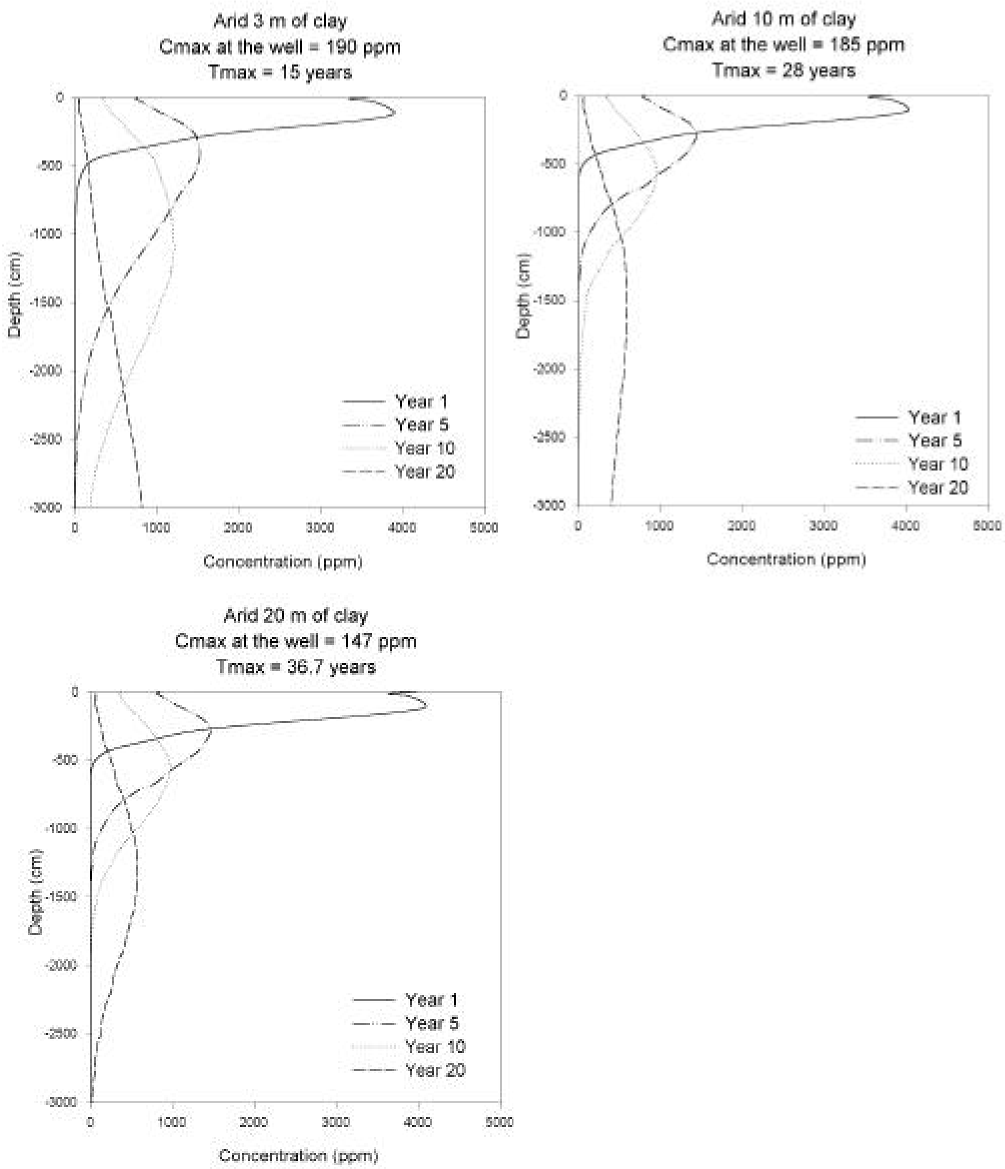


Figure 7.4—Vertical chloride distributions in heterogeneous profiles with 3, 10, and 20 m of accumulated clay layers in humid climates

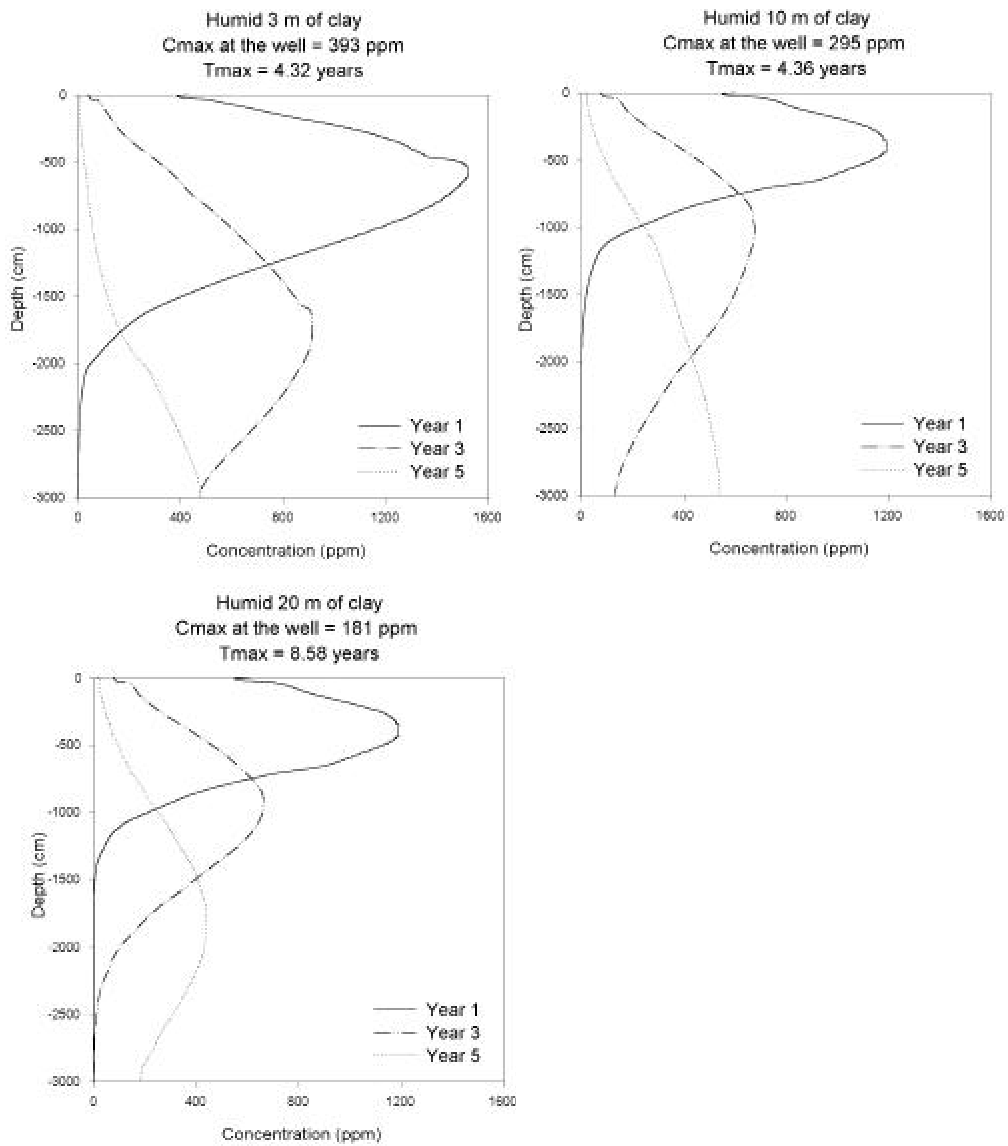


Table 7-2—Distribution of Chloride Over Time in Homogeneous Profiles

Release Height = 2.5 cm

	Sand 30 m				Sand 3 m				Clay 30 m				Clay 3 m			
	Arid		Humid		Arid		Humid		Arid		Humid		Arid		Humid	
	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)
Year 1	6470	165	1860	907	7630	288	3130	292	10200	0	2080	101	5120	0	2000	157
Year 2	3150	489	1360	1590	2860	288	482	300	5850	9	1510	160	3310	9	1850	284
Year 3	2650	681	1080	2379	1696	300	87	300	6030	0	1060	282	3640	0	1370	300
Year 5	2130	940	230	3000	743	300			5950	0	642	679	3560	0	376	300
Year 10	1570	1696			30	300			5530	0	462	1160			83	300
Year 20	521	3000							2750	0	301	2432				
Year 30	13	3000							1790	0	111	2900				

Release Height = 60 cm

	Sand 30 m				Sand 3 m				Clay 30 m				Clay 3 m			
	Arid		Humid		Arid		Humid		Arid		Humid		Arid		Humid	
	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)
Year 1	53800	436	30900	1245	54700	293	4810	297	84900	0	33800	168	42700	0	42200	287
Year 2	43600	927	25800	2054	18700	293	396	300	68000	0	27400	230	30200	9	36900	277
Year 3	40600	1112	22900	3000	11000	278	15	300	76100	0	21400	374	34300	0	27200	300
Year 5	35600	1490	3400	3000	4840	293			78100	0	14100	718			7500	300
Year 10	30100	2299	15	3000	196	300			68900	0	10500	1210			1640	272
Year 20	7650	3000							48800	0	7020	2541			21.6	300
Year 30	155	3000							34900	0	2440	2960				

Table 7-3—Distribution of Chloride Over Time in Heterogeneous Profiles

	3 m of clay				10 m of clay				20 m clay			
	Arid		Humid		Arid		Humid		Arid		Humid	
	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)	C_{max} (ppm)	Depth (cm)
Year 1	3890	108	1520	537	4030	103	1190	356	4090	100	1190	359
Year 2	2080	212	1190	1128	2070	202	860	583	2090	192	861	578
Year 3	1800	244	915	1725	1780	225	678	1012	1810	228	662	900
Year 5	1520	382	478	3000	1440	269	540	3000	1470	284	442	1752
Year 10	1210	1073			959	557	84	3000	974	554	302	3000
Year 20	817	3000			590	1388			573	1230		
Year 30	129	3000			437	3000			420	2089		

8.0 REPEATED RELEASES

8.1 Purpose

Repeat releases are an issue at some sites. In this chapter predictions are presented of the maximum chloride concentrations in a down gradient monitoring well as a result of 3 repeated releases taking place, at 1-year and 5-year time intervals, respectively.

8.2 Modeling Methodology and Input

The affect of repeated releases in the arid and humid climates was evaluated using 5 different hydrogeological profiles and different ground water depths (Table 8-1). For each of these scenarios, HYDRUS-1D was used to predict the chloride concentration at the ground water table interface for 3 consecutive releases at 1-year intervals. A spill height of 2.5 cm with a concentration of 100,000 ppm was assumed. In addition, simulations were performed for a homogeneous profile of 30 m sand for both arid and humid conditions with 3 similar releases at 5-year intervals. The HYDRUS-1D results have been used to run 320 scenarios with the mixing model to combine the effects of a number of releases (one release vs. three releases one year apart), a release volume (100 and 10,000 barrels), a flux in the aquifer (0.1 and 5 cm per day), a chloride concentration in the aquifer (0 and 100 ppm), and a depth of the aquifer (3 and 30 m).

Table 8-1—Factors in the vadose zone considered in the simulations

Climate	Total Clay Thickness (m)	Total Sand Thickness (m)	Ground Water Depth (m)
Arid	0	30	30
Arid	15	15	30
Arid	0	20	20
Arid	10	10	20
Arid	5	5	10
Humid	0	30	30
Humid	30	0	30
Humid	15	15	30
Humid	10	20	30
Humid	20	10	30

8.3 Analysis and Data Presentation

Figure 8.1 presents the correlation between the maximum concentrations at the well after 1 and 3 releases at 1-year intervals for the humid and arid conditions respectively. In the humid climate, the maximum concentration, after 1 release, varies from 23 ppm to 823 ppm versus 72 ppm to 2,138 ppm for 3 releases in 1-year intervals. The maximum concentration increases almost proportionally with the number of the repeated releases. It is 2.5 times larger for the 3-release scenario than for one release. In the arid climate, the maximum concentration, after one release, varies from 16 ppm to 1,129 ppm versus 48 ppm to 3,277 ppm for 3 releases during 1-year intervals. The maximum concentration after 3 releases is 2.8 times larger than after 1 release. This relationship is consistent with a principal observation derived from the sensitivity analysis: the chloride concentration in ground water is greatly influenced by the mass of chloride released to the soil.

Figure 8.2 compares the concentration breakthrough curves occurring after 1 release, 3 releases during 1-year intervals, and 3 releases during 5-year intervals in a homogeneous sand profile of 30 m depth, under humid and arid conditions. In the humid climate, three releases at one-year intervals merge together and result in a maximum concentration almost 3 times higher than the a concentration occurring after only 1 release (500 ppm v. 170 ppm). However, releases at 5-year intervals are essentially independent one from another. They behave as a succession of 3 single releases with maximum concentrations equal to that observed after 1 release (170 ppm). This relationship is not observed with the arid climate. Figure 8.2 shows that a 5-year interval between releases is not long enough to cause independent behavior. In the arid climate simulations, the maximum concentration at the well is 305 ppm for 3 releases during 1-year intervals and 317 ppm during intervals of 5 years. However, the maximum concentration for repeated releases remains about 3 times higher than the predicted maximum concentration for a single release event (100 ppm).

One can predict the effect of repeated releases when the releases occur about 1 year apart by multiplying the maximum concentration in the well expected after 1 release by the number of releases. However, when the repeated releases are separated in time by a period larger than the time needed for the maximum concentration after 1 release to reach the well, the maximum concentration is expected to be equal to that found after 1 release.

Figure 8.1—Comparison of maximum well concentrations after one release and after three releases at one-year intervals in the humid and arid climates

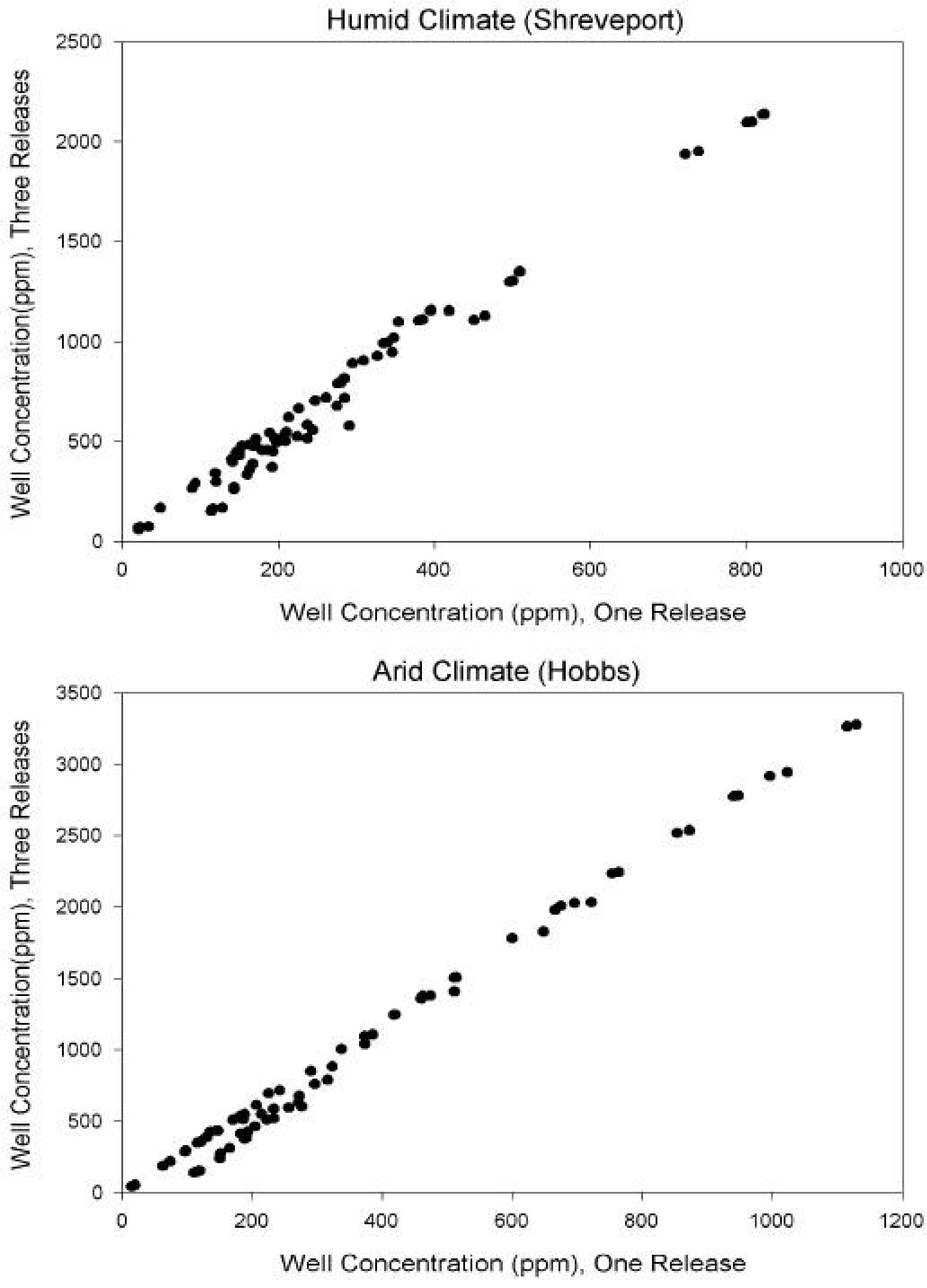
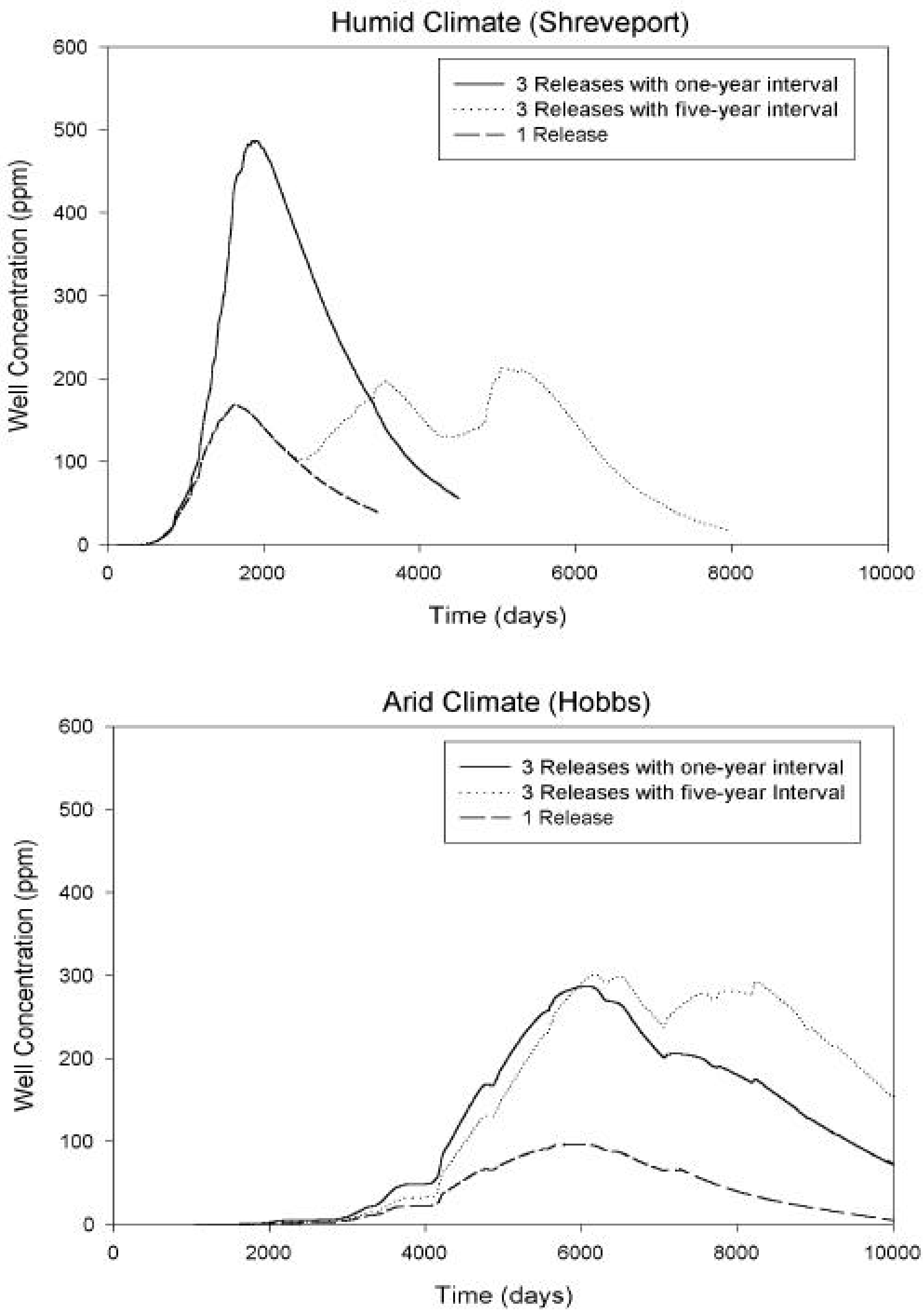


Figure 8.2—Breakthrough curves at the well after one release and three releases at one-year and five-year intervals, respectively, through a homogeneous 30 m deep sand profile in the humid and arid climates



9.0 SOIL RESTORATION

9.1 Purpose

As previously noted, chloride remaining in the soil after a produced water release may stunt or kill vegetation. Without implementing a soil restoration program, re-seeding is ineffective. To restore soil productivity, several options are available. One option, commonly used in agriculture, is applying water to the surface soil to leach the salts to depths below the root zone. The purpose of this chapter is to explore whether this restoration method is feasible in the arid conditions of Hobbs, New Mexico and to determine if soil leaching poses a threat to ground water quality. Simulations described earlier suggest that soil leaching occurs naturally in a humid climate, eliminating the need for additional application of water. Therefore, a simulation experiment of soil leaching in a humid climate was not performed.

9.2 Modeling Methodology and Input

The feasibility of soil leaching was evaluated for the arid climate using homogeneous sand and clay profiles with a ground water depth of 30 m. Spill heights of 0.025 and 0.6 m were examined for one conservative dispersion length of 0.1 m. For each of the leaching scenarios HYDRUS-1D simulations were performed to predict the chloride concentration in a 30 m deep vadose zone after a produced water release with a chloride concentration of 100,000 ppm.

Soil leaching where ground water table depths were at 3 m was not evaluated. Under these conditions, leaching may increase the maximum chloride concentration in the ground water. In addition, in an arid climate, the chloride would immediately move back into the soil profile due to capillary rise.

A water application rate of 2 cm per day was selected. This rate is sufficiently low to prevent ponding and permit infiltration into low permeability clay soils. Water application (restoration) was started 90 days after the spill occurred, and water was applied until the simulations showed migration of the chloride below the root zone of the vegetation; and the maximum chloride concentration in the root zone (3 m) was below 500 ppm. After restoration, the simulations were continued until the 30 m profile was free of chloride in the sand soil and for 20 years in the clay soil.

Prior to starting the chloride leaching restoration program, the application of gypsum to the affected area may be required to lower the sodium absorption ratio (SAR) values and to increase soil permeability. However, the addition of gypsum to the soil was not simulated.

9.3 Data Analysis and Presentation

Figures 9.1 and 9.2 compare the chloride concentrations in a homogeneous sand and clay vadose zone respectively, without restoration and with restoration, and at different times after the spill. Due to the high permeability of the sand soil, restoration is a relatively fast process. In the sandy vadose zone, the chloride concentration in the root zone of 3 m depth meets the 500 ppm criterion 45 days (1.5 month) after the initiation of the restoration for a produced water release height of 0.025 m. Without soil leaching, the upper 3 m of soil exceeds 500 ppm for 668 days or for almost 2 years. In the clay soil, the chloride concentration in the root zone of 3 m meets the 500 ppm criterion, 110 days or almost 3 months after the initiation of the restoration for a produced water release height 0.025 m. Without soil leaching the upper 3 m of soil exceeds 500 ppm for more than 20 years after the release. Figure 9.3 presents the average concentrations of chloride in the 3 m deep root zone in the sand and clay vadose zones, without restoration, by soil leaching and without soil leaching. It is clear that soil leaching results in a quick and dramatic lowering of the chloride concentration in the root zone. In the sandy soil, complete restoration may be reached after a little less than 2 years without soil leaching, but in the clayey soil, chloride concentrations in the root zone will remain high for at least 20 years, without restoration.

The mixing model was used to evaluate the maximum chloride concentrations in a well down gradient of the release in a 30 m thick aquifer overlain by a 30 m thick sandy vadose zone. The results of these calculations are presented in Table 9-1. No results for a clay vadose zone have been presented since it takes approximately 500 years for the maximum chloride concentration to arrive at the well. In addition, the sensitivity analysis showed that the maximum concentrations in the well, under a clay vadose zone, are lower than those predicted in a sandy vadose zone. It is clear that soil restoration by soil leaching does not lead to higher chloride concentration in the ground water. In most cases presented in the table, the maximum chloride concentration tends to be slightly lower after restoration than without restoration. Table 9-1 also shows that the effects of spill height, release volume, and aquifer flux on the maximum concentration are similar for the cases with and without restoration. Since chloride concentrations for sand are higher than those for clay (see Chapter 4), it can be concluded that soil leaching is an attractive option for soil restoration in the root zone because relatively low, maximum chloride concentrations are seen in the well.

These simulation experiments indicate that soil restoration by leaching often will be a viable option in arid climates. However, site data are required to optimize the leaching procedure for a given location.

Table 9-1—Maximum chloride concentrations in a 30 m thick aquifer overlain by a 30 m thick sand vadose zone after a spill with chloride concentration 100,000 ppm

Spill Height (m)	Spill Volume (barrels)	Aquifer Flux (m/day)	Maximum Chloride Concentration (ppm) No Restoration	Restoration
0.025	100	0.001	267	260
0.025	100	0.05	57	46
0.025	10,000	0.001	291	295
0.025	10,000	0.05	200	172
0.6	100	0.001	4,380	3,096
0.6	100	0.05	217	157
0.6	10,000	0.001	6,759	6,272
0.6	10,000	0.05	1,589	1,074

Figure 9.1—Chloride depth profiles in a 30 m deep sand vadose zone after a spill height of 2.5 cm with concentration 100,000 ppm with and without restoration by soil leaching during 45 days. Leaching starts on day 90 at a rate of 0.02 m/day

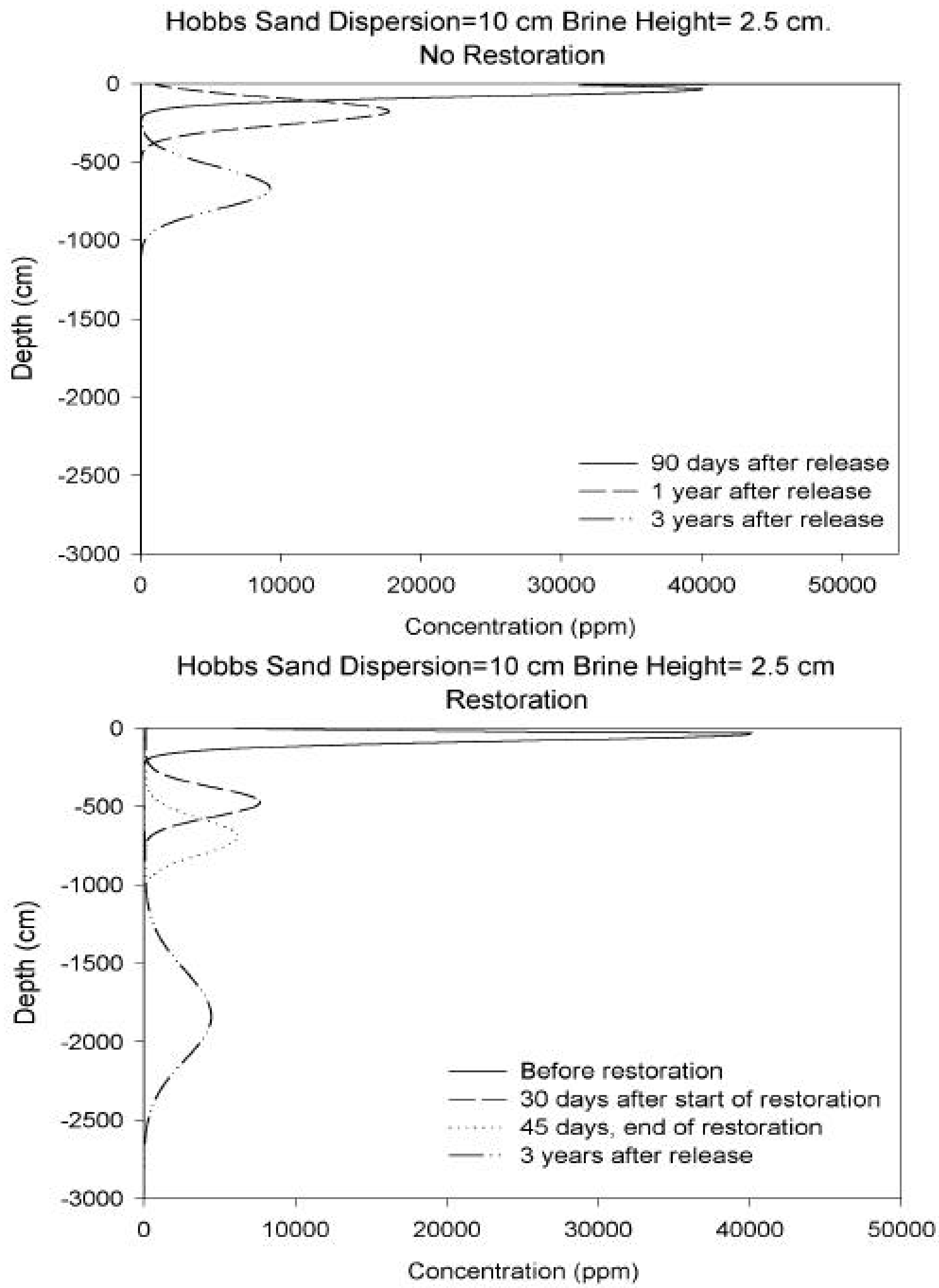


Figure 9.2—Chloride depth profiles in a 30 m deep clay vadose zone after a spill height of 2.5 cm with concentration 100,000 ppm with and without restoration by soil leaching during 110 days

Leaching starts on day 90 at a rate of 0.02 m/day

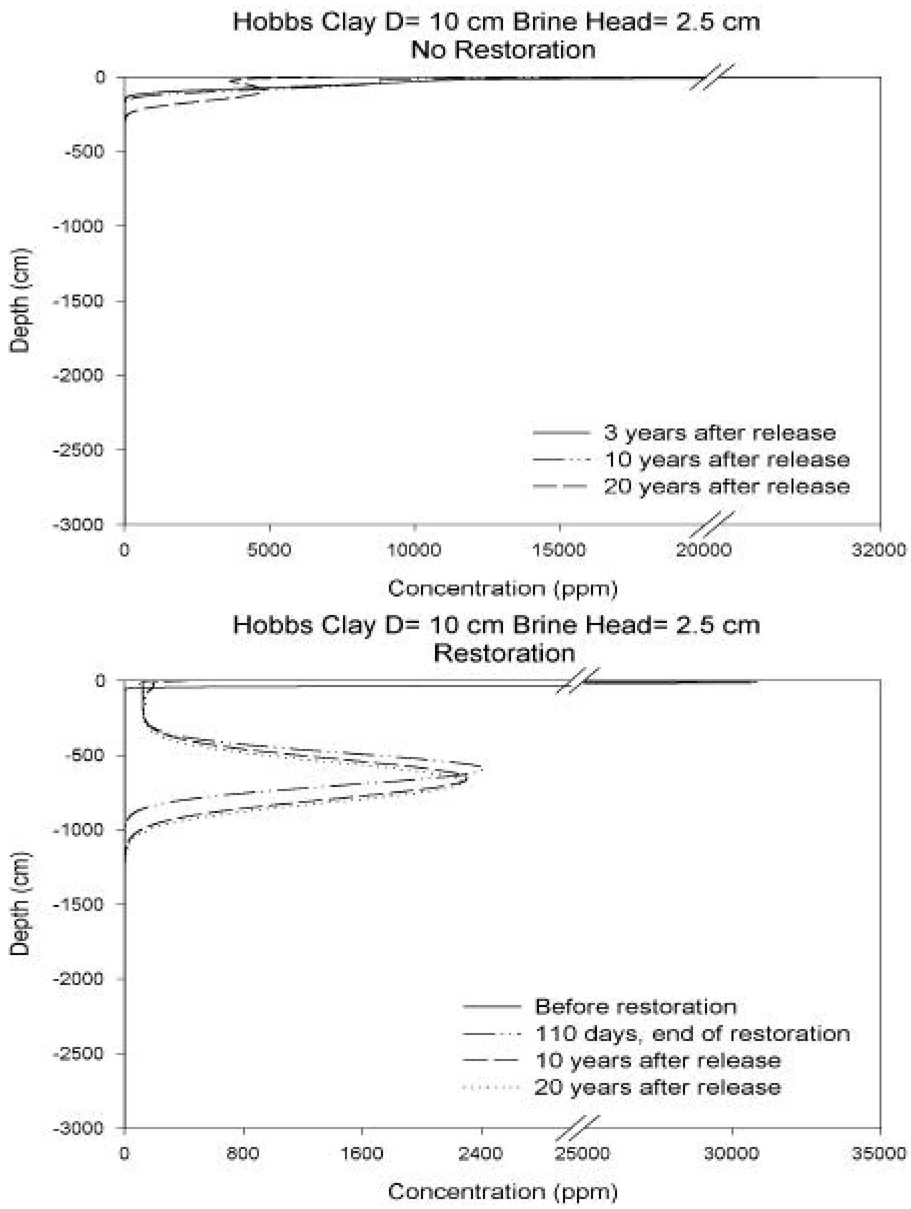
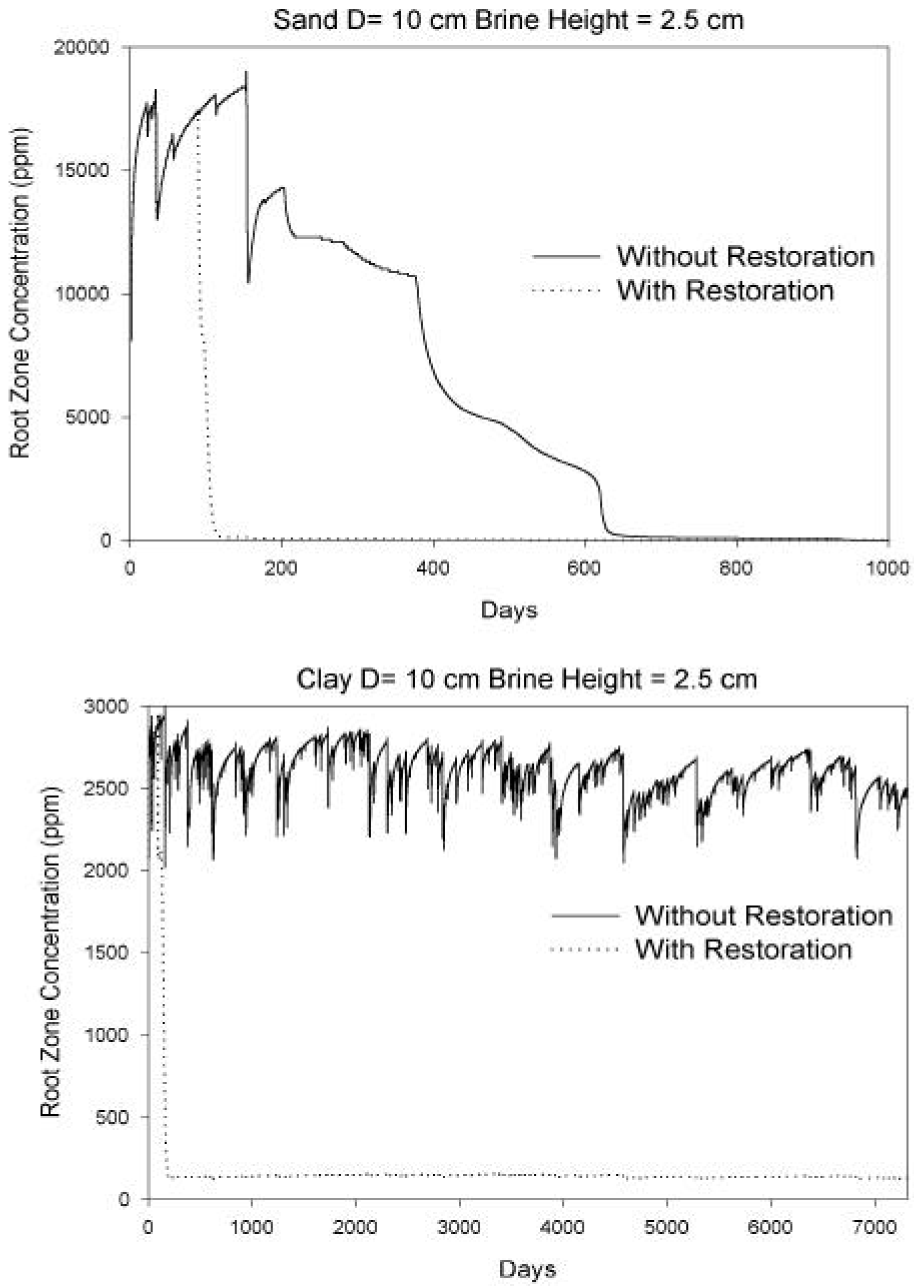


Figure 9.3—Chloride concentrations in 3 m deep root zones with and without restoration by soil leaching in a sand and clay vadose zone after a spill height of 0.025 m with chloride concentration 100,000 ppm



10.0 EFFECTS OF VEGETATION

10.1 Purpose

The sensitivity analysis described in Chapter 4 was conducted without including the effect of vegetation on the maximum chloride concentration and its arrival time at the well. After a produced water release, vegetation will often succumb due to the osmotic stresses imposed by the salts in the root zone and many sites remain barren for several years after a release. However, at some sites, vegetation spontaneously returns a few years after the release. In Hobbs (New Mexico), spill sites are often invaded by Four Wing Salt Bush while in Shreveport (Louisiana), cold and warm season grasses will start growing as soon as salt levels in the root zone decrease.

The presence of vegetation will lead to a decrease of downward water fluxes in the vadose zone. In a very arid climate, many researchers maintain that vegetation eliminates all downward water movement thereby trapping the chloride in the vadose zone. The sensitivity analysis demonstrated that decreased downward flux of water in arid climates (also caused by evapotranspiration) increases the travel time of the chloride through the vadose zone. Simulation results showed greater arrival times of the maximum chloride concentration at the well and slightly lower maximum ground water concentrations in the arid climate as compared to the humid climate. The purpose of this section is to explore and quantify the effects of vegetation on the maximum chloride concentration and its arrival time at the well.

10.2 Modeling Methodology and Input

The effects of vegetation were evaluated using homogeneous sand and clay profiles in Shreveport and a homogeneous sand profile in Hobbs with a ground water depth of 30 m. The homogeneous clay profile for Hobbs was not evaluated because our predictions suggested that ground water in the well is not impaired, even in the absence of vegetation. Spill heights of 2.5, 30, and 60 cm were examined with aquifer fluxes of 0.1, 2.5, and 5 cm/day. The spill volume was 100 barrels (or 16,000 liters). For each of the release scenarios, HYDRUS-1D was used to predict the chloride concentration in the 30-m-deep vadose zone after a produced water release with a concentration of 100,000 ppm. Next, the mixing model was used to find the maximum chloride concentration at the well and its arrival time.

The Hobbs scenario assumed that the evergreen Four Wing Salt Bush would invade sites where produced water releases have occurred. This evergreen plant will transpire all year long. In Shreveport, the scenario assumed that grasses will invade former release sites. A combination of cold and warm season grasses will also result in year-long transpiration. A rooting depth of 0.5 m was chosen for the bush and grasses. The transpiration term of the model was initiated when the mean average root zone chloride concentration fell below 500 ppm. Simulations were continued until the maximum chloride concentration has passed the well.

10.3 Data Analysis and Presentation

Figure 10.1 presents a schematic to explain the differences in water and solute fluxes under bare soils and vegetation. The water flux reaching the aquifer from the vadose zone will be larger under a bare soil than under vegetation since the transpiration by vegetation is much more than evaporation from a bare soil. In deep vadose zones, often a pseudo steady state downward water flux develops. Under these conditions the maximum chloride concentration arriving from the vadose zone into the aquifer depends more on the depth of the vadose zone and dispersion length than on the magnitude of the water flux. As a consequence the maximum chloride concentration at the vadose zone ground water interface will be quite similar below a vegetated and non-vegetated ground surface. Since the solute flux from the vadose zone is equal to the *water flux* times *solute concentration*, the solute flux from the vadose zone will be larger under the non-vegetated vadose zone than under the vegetated vadose zone. Thus, under vegetated conditions the chloride mass requires more time to seep from the vadose zone into the aquifer. As a consequence, the ground water flux will cause more dilution of the chloride flux under vegetated conditions and the chloride concentration in the well decreases accordingly.

Figures 10.2 and 10.3 show how chloride moves through the system in a 30-m-deep clay profile in Shreveport under vegetated and non-vegetated conditions. Specifically, Figure 10.2A clearly shows that water fluxes from the vadose zone are much larger under bare soil conditions than under vegetated conditions. Figure 10.2B shows the chloride concentration at the bottom of the vadose zone. As expected, the maximum chloride concentration entering the aquifer is similar in both cases. However, the larger water fluxes under the bare soil allow the breakthrough of the chloride through the vadose zone to occur in less time than under vegetated conditions. Under the bare soil, chloride requires about 20,000 days or 50 years to leave the vadose zone while under vegetation the model predicts more than double this time is needed. Thus, the effect of vegetation is to reduce the solute flux into the aquifer (Figure 10.3A), which leads to a lower maximum chloride concentration in the well (Figure 10.3B). Under bare soil, the maximum concentration is slightly more than 300 ppm while under vegetation it decreases to approximately 140 ppm.

Table 10-1 presents the arrival times and maximum chloride concentrations found in Hobbs and Shreveport. In Shreveport, vegetation causes all sand and clay simulations to yield a lower maximum chloride concentration in the well. Conversely in Hobbs, 7 out of 18 simulations in sand with vegetation result in a higher maximum chloride concentration in the well. However, 6 of the 7 cases are related to maximum concentrations well below 250 ppm under both vegetated and non-vegetated conditions. In the eighth case the concentration under vegetation is only 7% higher than under bare soil. In Shreveport, vegetation causes 1% – 27% lower maximum chloride concentration in sand and a 4% – 60% decrease in clay. In 11 simulations at Hobbs, vegetation lowers the maximum concentration from 4% – 62%.

Table 10-1 also presents the effect of vegetation on the arrival times of the maximum chloride concentration in the well. With few exceptions vegetation increases the arrival time of the maximum chloride concentration in the well.

These simulations suggest that the presence of vegetation will not lead to higher maximum chloride concentrations in the well and often will mitigate the maximum chloride concentration. The small number of simulations performed for this section do not allow for complete understanding the interaction between vegetation and maximum chloride concentration. Nevertheless, the establishment of vegetation after soil restoration appears to be a good practice to further reduce the risk for ground water impairment.

Figure 10.1—Schematic of water and solute fluxes as well as chloride concentrations evaluated with HYDRUS1D and the mixing model under bare soil and vegetation

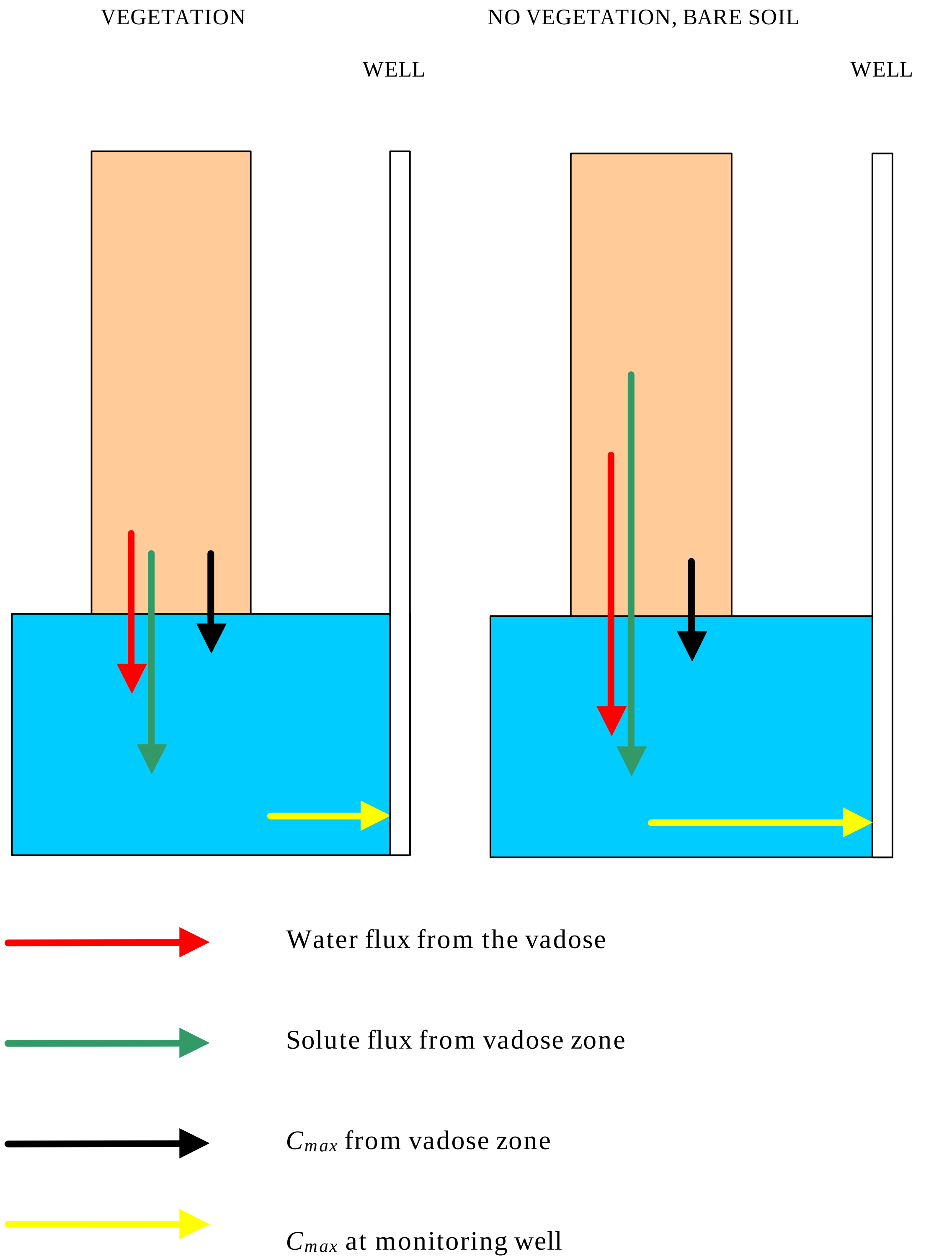


Figure 10.2—Vadose zone water flux and chloride concentration of the water entering into the shallow aquifer in a 30 m deep clay profile in Shreveport under bare soil and vegetation

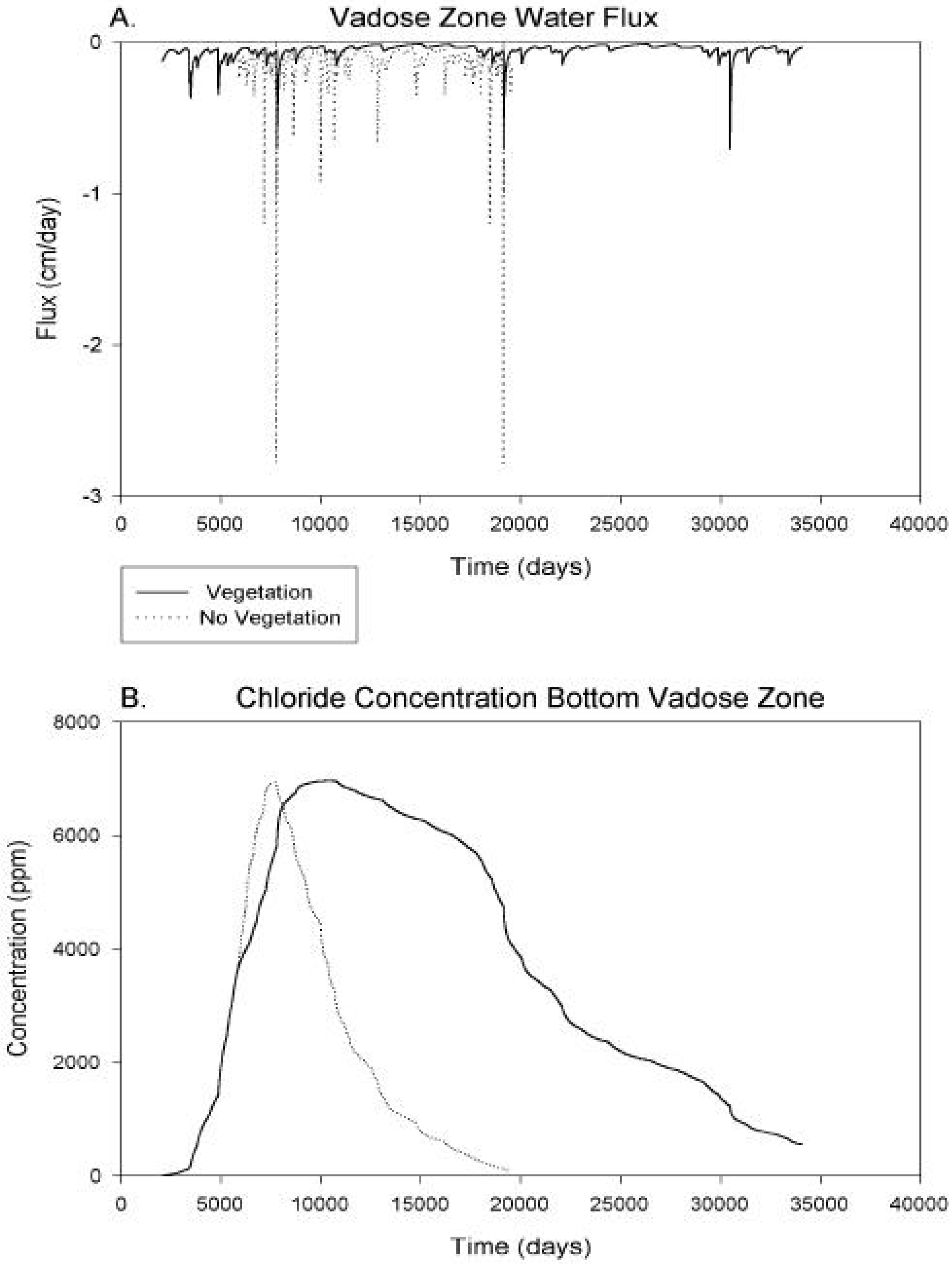


Figure 10.3—Vadose zone chloride flux and chloride concentration in the well in a 30 m deep clay profile in Shreveport under bare soil and vegetation

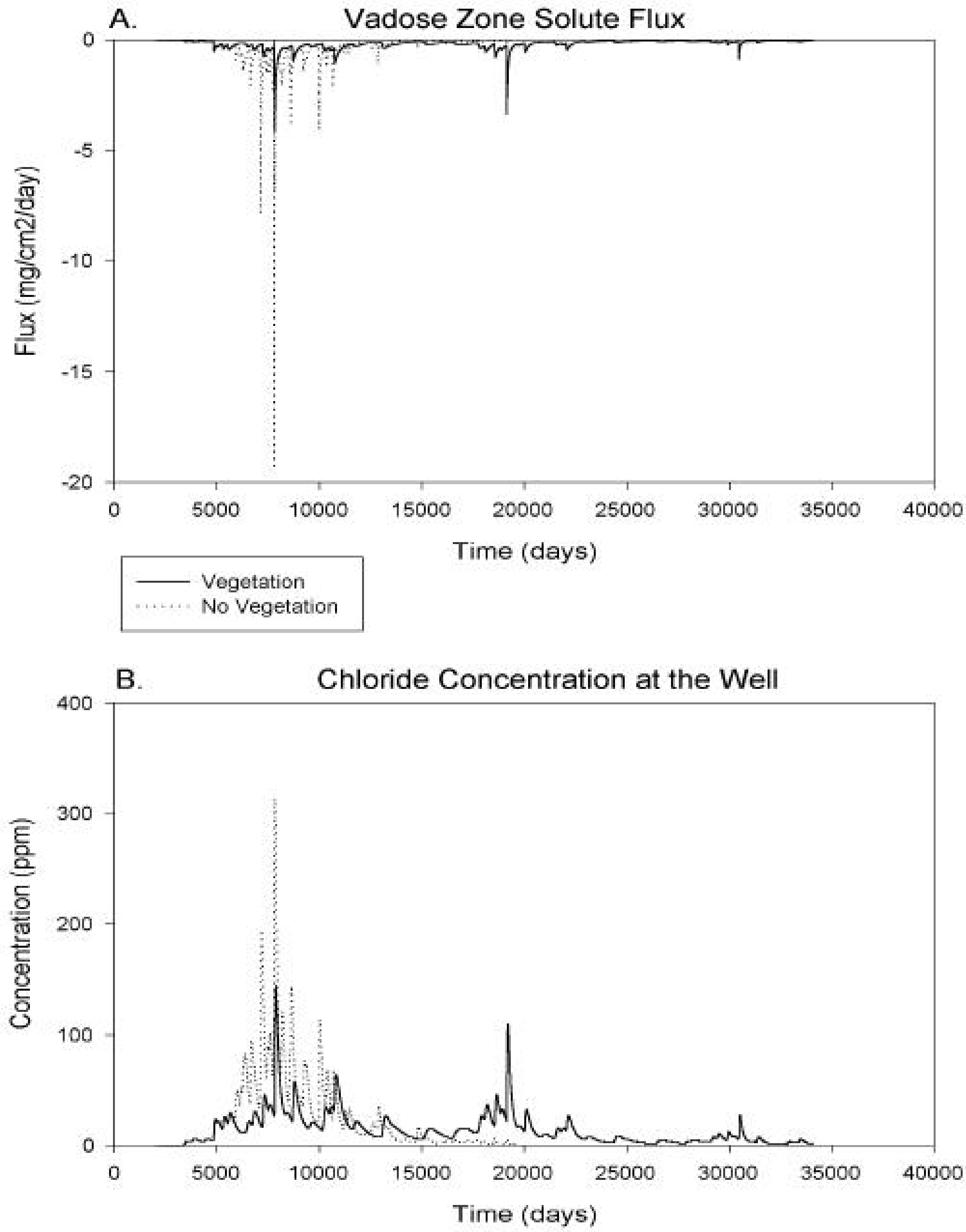


Table 10-1—Comparison of maximum chloride concentrations and arrival times at the well under bare soil and vegetation

	FACTORS			VEGETATION		NO VEGETATION	
	Brine Height (cm)	Aquifer Flux (cm/d)	Aquifer Thickness (m)	Concentration at well (ppm)	Arrival time (days)	Concentration at well (ppm)	Arrival Time (days)
HOBBS							
SAND	2.5	0.1	30	151	10995	177	6467
	30	0.1	30	1020	10577	1399	5743
	60	0.1	30	1632	4912	2216	5747
	2.5	2.5	30	31	10404	28	5621
	30	2.5	30	156	10378	144	4219
	60	2.5	30	109	3219	283	4306
	2.5	5	30	21	10378	15	5631
	30	5	30	96	10358	94	4207
	60	5	30	63	3212	165	4290
	2.5	0.1	3	823	10701	855	5756
	30	0.1	3	6722	10417	7983	5289
	60	0.1	3	11408	4884	13675	5051
	2.5	2.5	3	264	10404	235	5650
	30	2.5	3	1454	10382	1356	4220
	60	2.5	3	1057	3222	2642	4307
	2.5	5	3	191	10396	135	5644
	30	5	3	904	10359	905	4211
	60	5	3	623	3217	1574	4289
SHREVEPORT							
SAND	2.5	0.1	30	192	2620	213	1768
	30	0.1	30	1918	1868	2265	1617
	60	0.1	30	3564	1630	4010	1608
	2.5	2.5	30	59	1790	81	1599
	30	2.5	30	265	1625	358	1235
	60	2.5	30	427	873	510	1213
	2.5	5	30	38	1627	49	1413
	30	5	30	176	1622	209	1212
	60	5	30	268	870	293	1211
	2.5	0.1	3	803	1419	809	1975
	30	0.1	3	8679	1628	9125	1343
	60	0.1	3	16143	1262	16615	1241
	2.5	2.5	3	414	1673	489	1346
	30	2.5	3	2285	1626	2923	1214
	60	2.5	3	3763	873	4336	1213
	2.5	5	3	307	1627	350	1238
	30	5	3	1592	1623	1847	1212
	60	5	3	2470	870	2643	1212

Table 10-1—Comparison of maximum chloride concentrations and arrival times at the well under bare soil and vegetation (continued)

	FACTORS			VEGETATION		NO VEGETATION	
	Brine Height (cm)	Aquifer Flux (cm/d)	Aquifer Thickness (m)	Concentration at well (ppm)	Arrival time (days)	Concentration at well (ppm)	Arrival Time (days)
SHEREVEPORT							
CLAY	2.5	0.1	30	86	22253	119	9264
	30	0.1	30	471	19340	964	8686
	60	0.1	30	835	8084	1714	7916
	2.5	2.5	30	18	19228	31	7840
	30	2.5	30	72	19180	178	7826
	60	2.5	30	145	7858	313	7821
	2.5	5	30	12	19197	21	7828
	30	5	30	47	19166	118	7815
	60	5	30	94	7839	207	7810
	2.5	0.1	3	264	19319	276	7842
	30	0.1	3	2172	11029	3034	7855
	60	0.1	3	4219	8027	5888	7852
	2.5	2.5	3	125	19212	177	7836
	30	2.5	3	609	19185	1317	7824
	60	2.5	3	1244	7856	2390	7817
	2.5	5	3	92	19192	141	7829
	30	5	3	417	19169	947	7814
	60	5	3	844	7839	1705	7810

11.0 UNDERSTANDING THE ROLE OF EACH FACTOR

11.1 Produced Water Release Characteristics

The most important factor that affects prediction of ground water quality impairment after a produced water release is the mass of chloride released per unit area. Without knowledge of the chloride load, (expressed as g/m^2) predicting the potential for ground water quality impairment is impossible. The chloride load can be calculated by multiplying the spill height (meters) by the chloride concentration of the spill (grams/cubic meter). If these release characteristics are not known, it is possible to determine the chloride load by soil sampling or noninvasive (electromagnetic induction) techniques.

The volume of the released produced water alone has little impact on ground water quality, and is a poor predictor of ground water impairment. If one knows the volume of the spill and the surface area affected by the spill, one can estimate the spill height and, therefore, the chloride load.

Aquifer Characteristics

The chloride concentration in the ground water resulting from a release depends on:

1. The amount of water available in the aquifer to dilute the chloride load, and

2. The ambient concentration of the chloride in the ground water.

The water available in an aquifer is a function of the saturated thickness of the aquifer and the aquifer flux. Aquifer thickness is the most important factor determining the dilution potential of an aquifer. A thicker aquifer will allow more dilution, resulting in a lower chloride concentration than in a thinner aquifer. Aquifer thickness can be determined from well logs or geophysical methods. The larger the ground water flux, the more water will be available over time to dilute the chloride mass seeping out of the vadose zone. Thus, the greater the ground water flux, the lower the chloride concentration. In aquifers used for irrigation and drinking water supplies, the ground water flux (hydraulic conductivity * hydraulic gradient) is generally known.

The ambient chloride concentration in potable aquifers is generally rather low (often ranging between 50 and 200 ppm) and, therefore, will have little influence on the maximum chloride concentration resulting from a produced water release.

11.2 Vadose Zone Characteristics

The vadose zone characteristics determine the *rate* at which a certain chloride load enters the aquifer. Where the chloride mass enters the aquifer over a long time period, the chloride concentration in the aquifer will increase slightly or not at all. However, when the chloride load enters the aquifer all at once, the resulting chloride concentration may become high.

The chloride flux through the vadose zone is determined by soil texture and dispersion length. A finer vadose zone texture generally leads to higher soil water content and slower chloride flux. A greater dispersion length results in more dispersion of the chloride in the vadose zone and its more gradual arrival at the aquifer. In general, the finer the soil texture and the greater the dispersion length in the vadose zone, the lower the chloride concentration in the aquifer.

The effect of vadose zone thickness (or ground water depth) depends on a complex relationship of soil texture and climate. For a humid climate, simulation results show an almost continuous downward flux of water and chloride. A produced water release over a thin vadose zone will result in higher chloride concentrations in the ground water than the same produced water release over a thicker vadose zone. In an arid climate, a thin vadose zone may result in an almost continuous upward flux of water and chloride because of evapotranspiration and capillary rise from the underlying aquifer. Under these conditions, the released produced water may never reach the ground water, remaining close to the surface. The depth from which upward flow can maintain itself in an arid climate depends on the soil texture. Also, evapotranspiration can cause an upward flow from aquifers as deep as 10 m. Thicker vadose zones result in lower chloride concentrations in the aquifer.

The chloride concentration of the soil water in the vadose zone at the time of the release has little or no effect on the final chloride concentration in the aquifer.

11.3 Climate

Climate affects the downward flux of water and chloride in the vadose zone. In an arid climate, more time is required for the chloride load to reach the aquifer than in a humid climate. Therefore, there is more time for dilution into the soil water than in a humid climate. In addition, the chloride mass arriving at the ground water per time unit will be smaller than in a humid climate. For these reasons an arid climate will result in lower chloride concentrations than a humid one.

Regardless of the climate, it is the weather conditions immediately after the release that determines the short-term vertical chloride distribution in the vadose zone.

11.4 Vegetation

The effect of vegetation on the maximum chloride concentration in the well depends on a number of factors that interact with each other: depth of roots, root distribution with depth, soil hydraulic properties, climate, and salt sensitivity of the vegetation. A comprehensive analysis of all these factors has not been conducted. However, a first analysis using common characteristics of Four Wing Salt Bush in Hobbs and grasses in Shreveport revealed that the restoration of vegetation never will result in a large increase of maximum chloride concentration. Under many conditions, vegetation will result in a lower maximum chloride concentration in the well. Overall, the effect of vegetation is to mitigate to some degree the impact of chloride on ground water quality.

12.0 VERIFICATION OF MODEL HYDRUS 1D FOR PREDICTION OF CHLORIDE FATE

12.1 Purpose

In this report, the HYDRUS-1D model was used in combination with a simple mixing model for the evaluation of chloride fate after produced water releases. The simulations showed that chloride released to a vadose zone will often not result in unacceptable ground water quality impairment. Of the thousands of release scenario simulations, the models predicted that 53% of the cases would not exceed 250 ppm chloride in ground water. In only 3% of the scenarios did the models predict a chloride concentration greater than 1,000 ppm. In general, livestock can thrive on water exhibiting a chloride concentration of 1500 ppm or less. Chloride concentrations less than 2500 mg/L may be used for livestock with minimal effect.

The purpose of this chapter is to conduct a verification of the model HYDRUS-1D using field data obtained by Rice Operating Company (Rice). The verification of HYDRUS-1D is necessary in order to know how well HYDRUS-1D simulates chloride transport through vadose zones around Hobbs, New Mexico.

12.2 Approach

The approach is to compare chloride distributions observed in the field with those simulated with the HYDRUS-1D model using the input data provided by Rice as well as reasonable estimates for data not available from the field.

In order to compare the predictions from HYDRUS-1D with the chloride concentrations measured in the field, one must convert the chloride concentrations in soil (mg per kg of moist soil, C_{soil}) to chloride concentration in soil water (mg per liter of soil water, C_{water}), which is the output of HYDRUS-1D. The equation below provides for this conversion.

$$C_{water} = C_{soil}\, r_{water} \frac{1+w}{w} \qquad \textbf{(12-1)}$$

The gravimetric water content, w, and soil density, r_b, is commonly measured. However, a precise conversion demands the volumetric water content of the soil, θ, which is not routinely collected in the field, and use of the following equation.

$$C_{water} = C_{soil} \frac{r_b + r_{water} q}{r_{water} q} \qquad \textbf{(12-2)}$$

Estimates of the bulk density were based on our observations of soil texture from samples provided by Rice. A simulated soil water content by HYDRUS-1D was used to obtain approximate value for water content. For eolian sand, clay, and loam the $(\rho_d+\theta)/\theta$ values are 9, 5, and 7 respectively, and ρ_w is the density of water. These values were used to convert the measured chloride contents in the soil from mg per kg moist soil to mg per liter of soil water. The calculated chloride concentration in soil water from field samples was then compared to concentrations predicted by HYDRUS-1D.

12.3 Description of Sites and Boundary Locations

For this experiment, data from 4 produced water release sites was used. Two releases were uncontrolled, similar to any accidental release; these 2 releases occurred at junction boxes. The other two releases were controlled applications of brine at anode beds. The brine release characteristics of the sites are presented in Table 12-1. The hydrogeological characteristics of the sites are presented in Table 12-2.

To obtain realistic initial (pre-release) conditions, the model HYDRUS-1D was used to simulate soil water contents during a 47-year period using the same daily precipitation and potential evapotranspiration data employed throughout this report. For these initial simulations, soil profile data provided by Rice was used. The bottom boundary condition was the ground water table. The top boundary conditions consist of daily evaporation and precipitation rates. Zero evaporation in the junction boxes was assumed since they are covered. For the anode bed brine applications, the soil profile underneath the four feet deep bed was used, as described in the Rice field notes. Because Rice applied the brine to the excavated bed then covered the excavation, zero evaporation was assumed. The junction boxes are often located in topographic depressions that make them prone to flooding. For this reason, it was assumed that at least some water will infiltrate during precipitation events. In the simulations, infiltration is assumed to be equal to the daily precipitation rate. The two anode beds in this study consisted of backfilled sand material placed without compaction. As a result the hydraulic conductivity of the beds will be rather high—especially immediately after construction—which will result in fast penetration of the precipitation. Therefore, for the beds, the infiltration is assumed to be equal to daily precipitation.

12.4 Hydrus 1D Simulations

The initial and boundary conditions described above was used as input into the HYDRUS-1D model. To fine tune the match between the measured and simulated chloride profiles, the dispersivity lengths were adjusted within the reasonable range of values from 1 to 20 cm.

12.4.1 Anode Beds (Sites L-21 and M-33)

From the HYDRUS-1D catalog the hydraulic properties were assigned for each soil type. The volume, the area, and the concentration of the brine were known so one could calculate the height of the release. The period between the releases and the sample dates was simulated using the initial and boundary conditions discussed above. To match the observed and simulated maximum concentration, the dispersivity length was adjusted to 2 cm in both profiles. Figure 12.1 shows that the measured and the simulated concentrations along the depth profile match very well.

Table 12-1—Characteristics of the four sites used for the verification of the HYDRUS1D model

Site L-21	
Type: Anode Bed	
Volume of the initial brine input	20bbls
Chloride concentration in brine	1620000 ppm
Date of brine flood	8/6/2002
Volume of additional flood	20bbls
Chloride concentration in brine	100 ppm
Date of additional flood	8/11/2002
Sample date	9/10/2002
Site M-33	
Type: Anode Bed	
Volume of the initial brine input	10 bbls
Chloride concentration in brine	162000 ppm
Date of brine flood	7/15/02
Sample date	9/10/2002
Site EME M-3-1A-21S 36E	
Type: Junction Box	
Volume of the brine	unknown
Concentration of the brine	unknown
Date of the release	unknown
Site EME P36-2 19S 3E	
Type: Junction Box	
Volume of the brine	unknown
Concentration of the brine	unknown
Date of the release	unknown

Table 12-2—The hydrogeological characteristics of the four sites used for the HYDRUS1D verification

M-33 GW depth = 30 feet

Depth (ft)	Lithology	Model Approach
0 – 4	Caliche	
4 – 12	Brown red sand	Eolian sand

L-21 GW depth = 30 feet

Depth (ft)	Lithology	Model Approach
0 – 4	Sand with caliche and clay	
4 – 5	Clay and caliche	Clay
5 – 8	Sand and caliche	Loam
8 – 10	Tan sand	Loam
10 – 12	Brown sand	Eolian sand

EME-P36-2-19S 36E GW depth = 50 feet

Depth (ft)	Lithology	Model Approach
0 – 12	Sand and caliche	Sandy Loam
12 – 14	Bedded chert	Clay
14 – 15	Red Sand	Sand
15 – 18	Red sand and gravel	Sand
18 – 20	Red Sandy clay	Sandy clay

EME M-3-1A 21S 36E GW depth = 129 feet

Depth (ft)	Lithology	Model Approach
0 – 7	Sand	Sand
7 – 19	Caliche	Sandy loam
20 – 21	Sandstone	Loamy sand
21 – 29	Sand	Sand

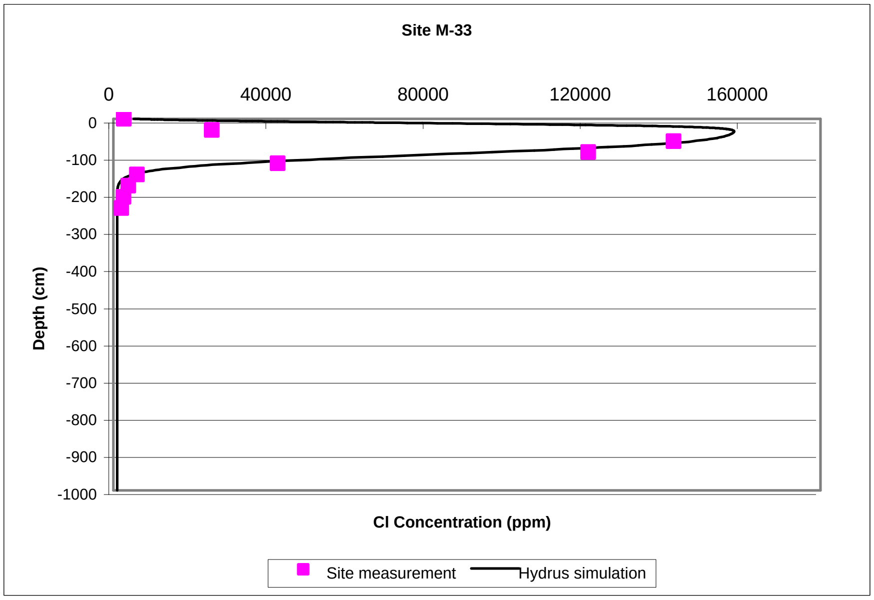
12.4.2 Junction Boxes (Sites EME P36-2 19S 3E and EME M-3-1A 21S 36E)

At the junction boxes no information was available on the release volume nor about its concentration. Therefore, the chloride load was calculated based on the measurements of chloride content in the soil. Next, this indirectly measured chloride load was used to evaluate different release heights and concentrations corresponding to the measured chloride load. For site EME P36-2 19S 3E, a release height of 70 cm with concentration 100,000 ppm and followed chloride movement for 500 days was simulated. The dispersivity length was adjusted to 10 cm. For site EME M-3-1-A 21S 36E, two consecutive releases were simulated: the first one with a height of 10 cm and chloride concentration of 40,000 pp and the second one, 800 days later, 18 cm with a concentration of the 42,000 ppm. The dispersivity lengths for the 3 different textures found in the vadose zone of this site (see Table 12-2) were adjusted to, respectively, 20, 1, and 5 cm for the sand, sandy loam, and loamy sand. Figure 12.2 shows that the measured and simulated concentrations along the depth profiles match very well.

12.5 Data Analysis and Presentation

The good match between simulated and observed chloride concentrations clearly demonstrates that HYDRUS-1D is an excellent tool to analyze chloride movement after brine releases. However, the close match does not indicate that HYDRUS-1D will predict exactly chloride fate for any given brine release. This is not possible since real hydrogeological situations are often so complex that they cannot be captured easily by any model. A model like HYDRUS-1D should be seen more as an analysis tool for complex hydrological situations than as a perfect predictor.

Figure 12.1—Measured and simulated chloride profiles with depth under the anode beds M-33 and L-21



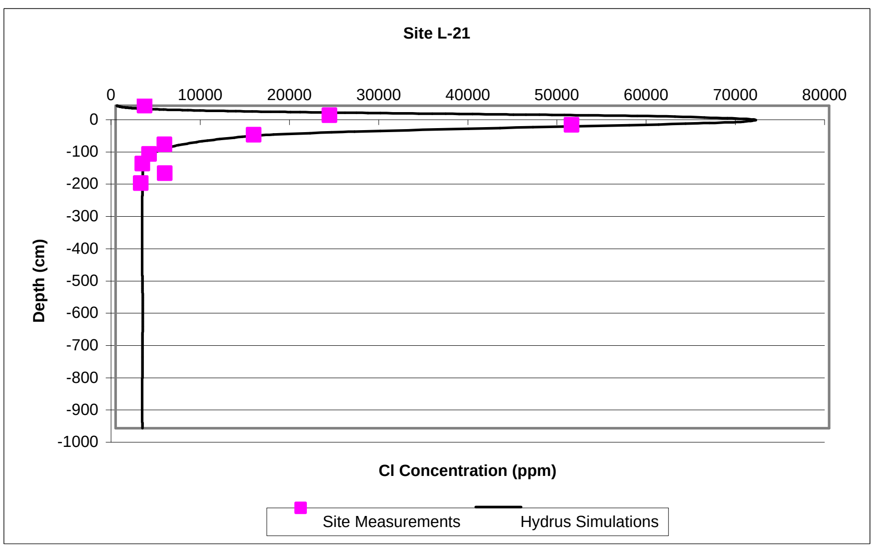
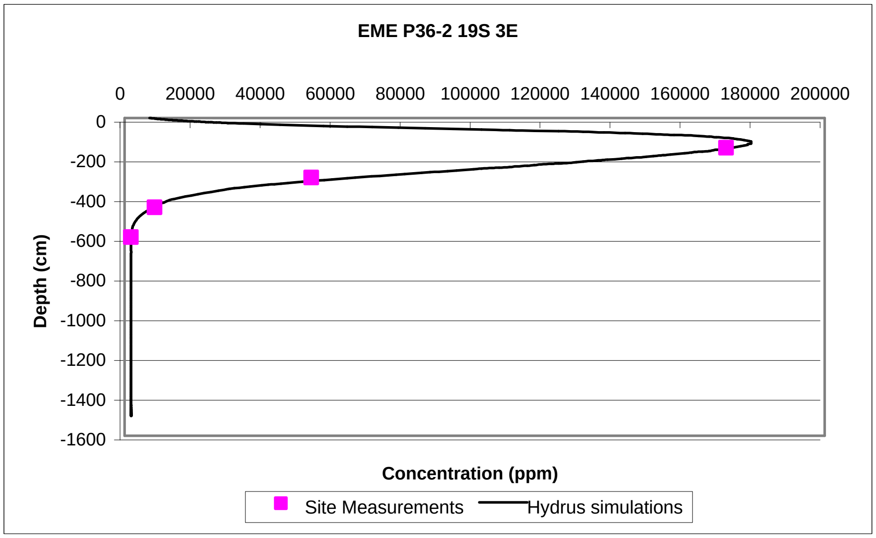
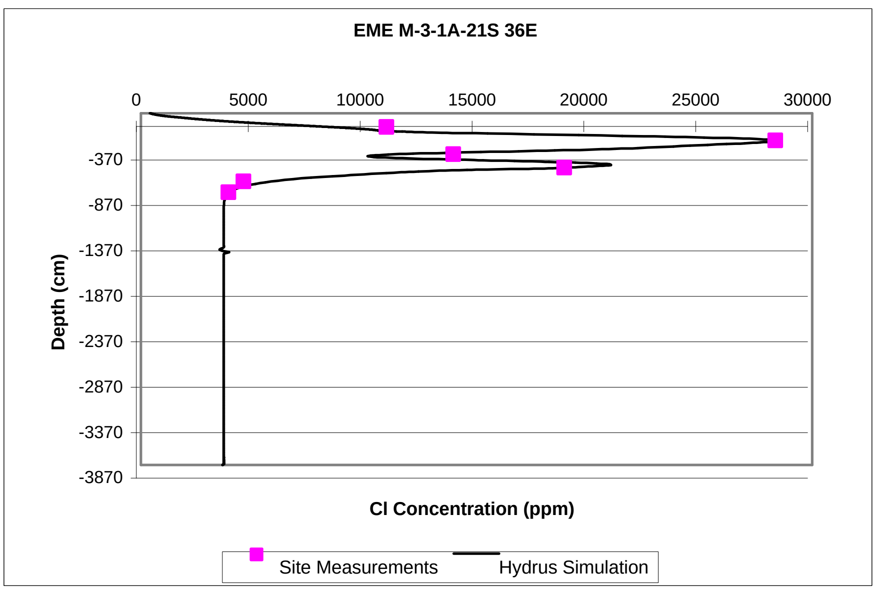


Figure 12.2—Measured and simulated chloride profiles with depth under the junction boxes EME P36-2 19S 3E and EME M-3-1A-21S 36E





References:

Carsel, R.F., and R. S. Parrish. 1988. "Developing Joint Probability Distributions of Soil Water Retention Characteristics". Water Resources Research 24:755-769.

Carty, D.J., S.M. Swetish, W.F. Priebe, and W. Crawley. 1997. *Remediation of Salt- Affected Soils at Oil and Gas Production Facilities*. API Publication Number 4663.

Domenico, P.A. and F.W. Schwartz. 1998. *Physical and Chemical Hydrogeology*, 2nd Edn. John Wiley and Sons, Inc. New York.

Freeze, R.A. and J.A. Cherry. 1979. *Groundwater*. Prentice-Hall, Inc. New Jersey.

Gelhar, L.W. 1993. *Stochastic Subsurface Hydrology*. Prentice Hall, Englewood Cliffs, New Jersery

Law, A.M. and D.M. Kelton. 2000. *Simulation Modeling and Analysis*, 3th Edn. McGraw-Hill. New York.

LeBlanc, D.R., S.P. Garabedian, K.M. Hess, L.W. Gelhar, R.D. Quadri, K.G. Stollenwerk, and W.W. Wood. 1991. "Large-scale natural gradient tracer test in sand and gravel, Cape Cod, Massachusetts. 1. Experimental design and observed tracer movement." Water Resources Research 27:895-910.

Native, R. and D.A. Smith. 1987. "Hydrogeology and Geochemestry of the Ogallala Aquifer, Southern High Plains". Journal of Hydrology, Volume 91, 217-253 p.

Nicholson. A., Jr. and A. Clebsch, jr. 1961. "Geology and Ground Water Conditions in Southern Lea County, New Mexico". U.S. Geological Survey Ground-Water Report 6. New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico, 123 p.

Rapp. T.R. 1992. "Ground-Water Resources of Caddo Parish, Louisiana". Louisiana Department of Transportation and Development. Technical Report No. 58, 89pp.

Rassam, D., J. Šimunek, and M. Th. Van Genuchten, "Modeling Variably Saturated Flow with HYDRUS-2D", ND Consult, Brisbane, Australia, 261pp., 2003.

Runyon, C. and Bader, J. 1995. "Water Quality for Livestock and Poultry, Guide M-115", New Mexico State University. http://www.cahe.nmsu.edu/pubs/_m/m-112.html

Samani, Z.A. and M. Pessarakli. 1986. "Estimating Potential Crop Evapotranspiration with Minimum Data in Arizona", *Transactions of the ASAE* Vol.29, No 2,pp.522-524.

Snedecor, G.W. and W.G. Cochran. 1967. *Statistical Methods*, 6th Edn. The Iowa State University Press, Ames, Iowa.

Šimunek, J., M. Šejna, and M. Th. van Genuchten, The HYDRUS-1D software package for simulating the one-dimensional movement of water, heat, and multiple solutes in variably-saturated media. Version 2.0, *IGWMC - TPS - 70*, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado, 202pp., 1998.

Šimunek, J., M. Šejna, and M. Th. van Genuchten, The HYDRUS-2D software package for simulating two-dimensional movement of water, heat, and multiple solutes in variably saturated media. Version 2.0, *IGWMC - TPS - 53*, International Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado, 251pp., 1999.

Steel, R.G.D. and J.H. Torrie. 1980. *Principles and procedures of statistics. A biometrical approach*. 2th Edn. McGraw-Hill, New York.

van Genuchten, M. Th. 1980. “A closed-form equation for predicting the hydraulic conductivity of unsaturated soils”, *Soil Sci. Soc. Am. J., 44*, 892-898.

Zhang, H., F.W. Schwartz, W.W. Wood, S.P. Garabedian, and D.R. LeBlanc. 1998. “Simulation of variable-density flow and transport of reactive and nonreactive solutes during a tracer test at Cape Cod, Massachusetts”. Water Resources Research 34:67-82.

Appendix A—Results of homogenous and heterogeneous profiles

Table A.1—Design matrix for the factors that affect chloride movement in the vadose zone and aquifer as well as two response variables in the monitoring well. Brine concentration 10,000 ppm

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
1	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	3	222930	36
2	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	3	8760	82
3	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	3	10725	163
4	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	3	2337	151
5	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	3	152400	11
6	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	3	7793	26
7	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	3	10478	68
8	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	3	2068	62
9	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	3	234340	394
10	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	3	8661	1764
11	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	3	5679	3046
12	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	3	2171	3237
13	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	3	183070	108
14	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	3	7849	581
15	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	3	10533	1216
16	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	3	1857	1327
17	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	3	0	0
18	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	3	1707	152
19	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	3	3501	236
20	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	3	434	211
21	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	3	28467	62
22	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	3	1842	106
23	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	3	8800	175
24	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	3	364	150
25	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	3	0	0
26	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	3	1290	3208
27	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	3	3490	3475
28	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	3	315	4157
29	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	3	27149	70
30	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	3	1054	2063
31	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	3	33	2061
32	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	3	102	1943
33	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	3	233900	75

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
34	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	3	8730	85
35	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	3	10776	171
36	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	3	2324	254
37	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	3	177830	24
38	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	3	7790	27
39	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	3	10555	74
40	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	3	2129	64
41	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	3	240470	1269
42	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	3	8667	2063
43	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	3	5724	4075
44	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	3	2192	3590
45	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	3	188950	361
46	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	3	7820	660
47	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	3	10522	1799
48	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	3	1910	1511
49	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	3	0	0
50	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	3	1472	155
51	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	3	944	244
52	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	3	438	215
53	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	3	28470	69
54	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	3	1804	110
55	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	3	949	185
56	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	3	369	154
57	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	3	0	0
58	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	3	1647	3722
59	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	3	629	4433
60	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	3	324	4659
61	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	3	28251	107
62	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	3	1916	2546
63	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	3	475	2560
64	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	3	167	2182
65	Arid	Clay	0.1 m	0.025 m	30 m	100	5	0	3	216420	3
66	Humid	Clay	0.1 m	0.025 m	30 m	100	5	0	3	8539	33
67	Arid	Sand	0.1 m	0.025 m	30 m	100	5	0	3	10432	64
68	Humid	Sand	0.1 m	0.025 m	30 m	100	5	0	3	2184	67

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
69	Arid	Clay	2.0 m	0.025 m	30 m	100	5	0	3	130700	1
70	Humid	Clay	2.0 m	0.025 m	30 m	100	5	0	3	7814	13
71	Arid	Sand	2.0 m	0.025 m	30 m	100	5	0	3	10396	18
72	Humid	Sand	2.0 m	0.025 m	30 m	100	5	0	3	1685	25
73	Arid	Clay	0.1 m	0.6 m	30 m	100	5	0	3	233320	16
74	Humid	Clay	0.1 m	0.6 m	30 m	100	5	0	3	8627	309
75	Arid	Sand	0.1 m	0.6 m	30 m	100	5	0	3	10329	341
76	Humid	Sand	0.1 m	0.6 m	30 m	100	5	0	3	1985	527
77	Arid	Clay	2.0 m	0.6 m	30 m	100	5	0	3	216260	4
78	Humid	Clay	2.0 m	0.6 m	30 m	100	5	0	3	7811	161
79	Arid	Sand	2.0 m	0.6 m	30 m	100	5	0	3	8600	133
80	Humid	Sand	2.0 m	0.6 m	30 m	100	5	0	3	1656	243
81	Arid	Clay	0.1 m	0.025 m	3 m	100	5	0	3	0	0
82	Humid	Clay	0.1 m	0.025 m	3 m	100	5	0	3	1488	73
83	Arid	Sand	0.1 m	0.025 m	3 m	100	5	0	3	643	160
84	Humid	Sand	0.1 m	0.025 m	3 m	100	5	0	3	369	122
85	Arid	Clay	2.0 m	0.025 m	3 m	100	5	0	3	8931	13
86	Humid	Clay	2.0 m	0.025 m	3 m	100	5	0	3	1104	45
87	Arid	Sand	2.0 m	0.025 m	3 m	100	5	0	3	643	67
88	Humid	Sand	2.0 m	0.025 m	3 m	100	5	0	3	169	74
89	Arid	Clay	0.1 m	0.6 m	3 m	100	5	0	3	0	0
90	Humid	Clay	0.1 m	0.6 m	3 m	100	5	0	3	1055	906
91	Arid	Sand	0.1 m	0.6 m	3 m	100	5	0	3	9	2056
92	Humid	Sand	0.1 m	0.6 m	3 m	100	5	0	3	13	1504
93	Arid	Clay	2.0 m	0.6 m	3 m	100	5	0	3	7998	9
94	Humid	Clay	2.0 m	0.6 m	3 m	100	5	0	3	16	748
95	Arid	Sand	2.0 m	0.6 m	3 m	100	5	0	3	11	1068
96	Humid	Sand	2.0 m	0.6 m	3 m	100	5	0	3	19	613
97	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	0	3	217030	14
98	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	0	3	8666	71
99	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	0	3	10660	138
100	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	0	3	2299	136
101	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	0	3	211450	4
102	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	0	3	7807	23
103	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	0	3	10433	51

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
104	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	0	3	1968	54
105	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	0	3	233710	132
106	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	0	3	8657	1074
107	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	0	3	5056	1465
108	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	0	3	2192	22228
109	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	0	3	182300	36
110	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	0	3	7838	407
111	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	0	3	10486	588
112	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	0	3	1693	899
113	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	0	3	0	0
114	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	0	3	1484	137
115	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	0	3	665	222
116	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	0	3	390	197
117	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	0	3	27147	42
118	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	0	3	1106	92
119	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	0	3	653	152
120	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	0	3	365	135
121	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	0	3	0	0
122	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	0	3	1109	2223
123	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	0	3	32	2694
124	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	0	3	178	2971
125	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	0	3	8932	30
126	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	0	3	1108	1206
127	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	0	3	28	1528
128	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	0	3	21	1452
129	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	3	224070	102
130	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	3	0	100
131	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	3	10717	179
132	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	3	2317	157
133	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	3	0	100
134	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	3	0	100
135	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	3	0	100
136	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	3	0	100
137	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	3	23450	479
138	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	3	8665	1785

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
139	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	3	5322	3094
140	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	3	2170	3255
141	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	3	182870	192
142	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	3	7843	595
143	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	3	10523	1259
144	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	3	1857	1344
145	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	3	0	100
146	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	3	1472	1709
147	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	3	692	300
148	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	3	408	255
149	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	3	0	100
150	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	3	1082	136
151	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	3	28470	238
152	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	3	317	197
153	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	3	0	100
154	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	3	1290	3239
155	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	3	3490	3536
156	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	3	315	4191
157	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	3	28470	122
158	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	3	1054	2096
159	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	3	273	2132
160	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	3	103	2024
161	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	3	0	100
162	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	3	0	100
163	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	3	10743	177
164	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	3	2326	157
165	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	3	0	100
166	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	3	0	100
167	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	3	8800	120
168	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	3	0	100
169	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	3	240470	1318
170	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	3	8672	2066
171	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	3	5484	4987
172	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	3	2189	3592
173	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	3	188940	410

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
174	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	3	7819	662
175	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	3	10527	1811
176	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	3	1902	1513
177	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	3	0	100
178	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	3	1463	170
179	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	3	760	304
180	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	3	418	257
181	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	3	0	100
182	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	3	1053	136
183	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	3	689	244
184	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	3	317	199
185	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	3	0	100
186	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	3	1410	3734
187	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	3	629	4480
188	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	3	316	4700
189	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	3	27160	133
190	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	3	1106	2562
191	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	3	465	2617
192	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	3	166	2232
193	Arid	Clay	0.1 m	0.025 m	30 m	100	5	100	3	0	100
194	Humid	Clay	0.1 m	0.025 m	30 m	100	5	100	3	2500	106
195	Arid	Sand	0.1 m	0.025 m	30 m	100	5	100	3	10436	144
196	Humid	Sand	0.1 m	0.025 m	30 m	100	5	100	3	2183	138
197	Arid	Clay	2.0 m	0.025 m	30 m	100	5	100	3	0	100
198	Humid	Clay	2.0 m	0.025 m	30 m	100	5	100	3	6000	104
199	Arid	Sand	2.0 m	0.025 m	30 m	100	5	100	3	0	100
200	Humid	Sand	2.0 m	0.025 m	30 m	100	5	100	3	1800	100
201	Arid	Clay	0.1 m	0.6 m	30 m	100	5	100	3	233430	116
202	Humid	Clay	0.1 m	0.6 m	30 m	100	5	100	3	8627	396
203	Arid	Sand	0.1 m	0.6 m	30 m	100	5	100	3	4958	437
204	Humid	Sand	0.1 m	0.6 m	30 m	100	5	100	3	1984	104
205	Arid	Clay	2.0 m	0.6 m	30 m	100	5	100	3	181940	104
206	Humid	Clay	2.0 m	0.6 m	30 m	100	5	100	3	7810	237
207	Arid	Sand	2.0 m	0.6 m	30 m	100	5	100	3	10329	227
208	Humid	Sand	2.0 m	0.6 m	30 m	100	5	100	3	1654	329

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
209	Arid	Clay	0.1 m	0.025 m	3 m	100	5	100	3	0	100
210	Humid	Clay	0.1 m	0.025 m	3 m	100	5	100	3	1438	136
211	Arid	Sand	0.1 m	0.025 m	3 m	100	5	100	3	640	244
212	Humid	Sand	0.1 m	0.025 m	3 m	100	5	100	3	341	201
213	Arid	Clay	2.0 m	0.025 m	3 m	100	5	100	3	0	100
214	Humid	Clay	2.0 m	0.025 m	3 m	100	5	100	3	735	118
215	Arid	Sand	2.0 m	0.025 m	3 m	100	5	100	3	638	150
216	Humid	Sand	2.0 m	0.025 m	3 m	100	5	100	3	167	152
217	Arid	Clay	0.1 m	0.6 m	3 m	100	5	100	3	0	100
218	Humid	Clay	0.1 m	0.6 m	3 m	100	5	100	3	1055	991
219	Arid	Sand	0.1 m	0.6 m	3 m	100	5	100	3	9	2130
220	Humid	Sand	0.1 m	0.6 m	3 m	100	5	100	3	13	1563
221	Arid	Clay	2.0 m	0.6 m	3 m	100	5	100	3	28470	103
222	Humid	Clay	2.0 m	0.6 m	3 m	100	5	100	3	16	804
223	Arid	Sand	2.0 m	0.6 m	3 m	100	5	100	3	8	1153
224	Humid	Sand	2.0 m	0.6 m	3 m	100	5	100	3	19	804
225	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	100	3	0	100
226	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	100	3	0	100
227	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	100	3	10659	179
228	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	100	3	2298	157
229	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	100	3	0	100
230	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	100	3	0	100
231	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	100	3	0	100
232	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	100	3	0	100
233	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	100	3	233720	227
234	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	100	3	8659	1129
234	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	100	3	5058	1545
236	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	100	3	2085	2280
237	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	100	3	182300	131
238	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	100	3	7836	447
239	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	100	3	10481	660
240	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	100	3	1696	946
241	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	100	3	0	100
242	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	100	3	1458	167
243	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	100	3	659	290

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
244	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	100	3	390	248
245	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	100	3	0	100
246	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	100	3	1080	132
247	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	655	220
248	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	310	188
249	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	0	100
250	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	1109	2283
251	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	32	2762
252	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	178	3036
253	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	10036	110
254	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	1107	1265
255	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	28	1607
256	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	20	1523
257	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	30	220800	5
258	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	30	9252	21
259	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	30	10828	25
260	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	30	2506	26
261	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	30	113930	1
262	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	30	8284	11
263	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	30	10882	15
264	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	30	2699	18
265	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	30	342180	44
266	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	30	8768	375
267	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	30	5671	431
268	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	30	2294	553
269	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	30	547480	12
270	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	30	7921	171
271	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	30	10666	204
272	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	30	2167	331
273	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	30	0	0
274	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	30	1517	27
275	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	30	954	29
276	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	30	513	28
277	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	30	28470	11
278	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	30	1620	23

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
279	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	30	1332	25
280	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	30	586	24
281	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	30	0	0
282	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	30	1489	572
283	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	30	982	475
284	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	30	373	608
285	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	30	27147	11
286	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	30	1489	393
287	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	30	2360	345
288	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	30	336	510
289	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	30	237710	17
290	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	30	9446	24
291	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	30	11092	28
292	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	30	2651	28
293	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	30	181040	8
294	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	30	9203	14
295	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	30	12943	21
296	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	30	3084	21
297	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	30	240610	200
298	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	30	9342	556
299	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	30	5741	677
300	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	30	2415	676
301	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	30	188990	62
302	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	30	9396	317
303	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	30	12989	439
304	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	30	2824	491
305	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	30	0	0
306	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	30	1652	29
307	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	30	949	30
308	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	30	526	29
309	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	30	0	0
310	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	30	1647	3
311	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	30	17109	28
312	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	30	697	26
313	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	30	0	0

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
314	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	30	1621	714
315	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	30	669	625
316	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	30	401	711
317	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	30	28251	19
318	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	30	1720	590
319	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	30	992	474
320	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	30	596	625
321	Arid	Clay	0.1 m	0.025 m	30 m	100	5	0	30	0	0
322	Humid	Clay	0.1 m	0.025 m	30 m	100	5	0	30	8614	4
323	Arid	Sand	0.1 m	0.025 m	30 m	100	5	0	30	10396	7
324	Humid	Sand	0.1 m	0.025 m	30 m	100	5	0	30	2151	8
325	Arid	Clay	2.0 m	0.025 m	30 m	100	5	0	30	0	0
326	Humid	Clay	2.0 m	0.025 m	30 m	100	5	0	30	7802	2
327	Arid	Sand	2.0 m	0.025 m	30 m	100	5	0	30	10327	2
328	Humid	Sand	2.0 m	0.025 m	30 m	100	5	0	30	1630	3
329	Arid	Clay	0.1 m	0.6 m	30 m	100	5	0	30	233280	2
330	Humid	Clay	0.1 m	0.6 m	30 m	100	5	0	30	8624	34
331	Arid	Sand	0.1 m	0.6 m	30 m	100	5	0	30	4950	35
332	Humid	Sand	0.1 m	0.6 m	30 m	100	5	0	30	1979	57
333	Arid	Clay	2.0 m	0.6 m	30 m	100	5	0	30	0	0
334	Humid	Clay	2.0 m	0.6 m	30 m	100	5	0	30	7807	19
335	Arid	Sand	2.0 m	0.6 m	30 m	100	5	0	30	10324	14
336	Humid	Sand	2.0 m	0.6 m	30 m	100	5	0	30	1638	27
337	Arid	Clay	0.1 m	0.025 m	3 m	100	5	0	30	0	0
338	Humid	Clay	0.1 m	0.025 m	3 m	100	5	0	30	1434	10
339	Arid	Sand	0.1 m	0.025 m	3 m	100	5	0	30	637	17
340	Humid	Sand	0.1 m	0.025 m	3 m	100	5	0	30	340	14
341	Arid	Clay	2.0 m	0.025 m	3 m	100	5	0	30	4587	1
342	Humid	Clay	2.0 m	0.025 m	3 m	100	5	0	30	1103	6
343	Arid	Sand	2.0 m	0.025 m	3 m	100	5	0	30	632	7
344	Humid	Sand	2.0 m	0.025 m	3 m	100	5	0	30	172	9
345	Arid	Clay	0.1 m	0.6 m	3 m	100	5	0	30	0	0
346	Humid	Clay	0.1 m	0.6 m	3 m	100	5	0	30	1485	98
347	Arid	Sand	0.1 m	0.6 m	3 m	100	5	0	30	9	228
348	Humid	Sand	0.1 m	0.6 m	3 m	100	5	0	30	11	171

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
349	Arid	Clay	2.0 m	0.6 m	3 m	100	5	0	30	0	0
350	Humid	Clay	2.0 m	0.6 m	3 m	100	5	0	30	1106	87
351	Arid	Sand	2.0 m	0.6 m	3 m	100	5	0	30	9	107
352	Humid	Sand	2.0 m	0.6 m	3 m	100	5	0	30	6	65
353	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	0	30	217120	2
354	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	0	30	8685	14
355	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	0	30	10639	19
356	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	0	30	2318	21
357	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	0	30	0	0
358	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	0	30	7867	7
359	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	0	30	10518	9
360	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	0	30	2298	13
361	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	0	30	233640	14
362	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	0	30	8664	163
363	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	0	30	5099	172
364	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	0	30	2158	314
365	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	0	30	182190	4
366	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	0	30	7848	71
367	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	0	30	182190	74
368	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	0	30	1698	143
369	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	0	30	0	0
370	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	0	30	1487	23
371	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	0	30	652	25
372	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	0	30	512	25
373	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	0	30	25080	6
374	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	0	30	1484	17
375	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	0	30	656	19
376	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	0	30	365	19
377	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	0	30	0	0
378	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	0	30	1139	286
379	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	0	30	32	310
380	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	0	30	181	380
381	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	0	30	1041	4
382	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	0	30	1107	163
383	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	0	30	34218	169

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
384	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	0	30	27	379
385	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	30	0	100
386	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	30	0	100
387	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	30	10933	105
388	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	30	0	100
389	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	30	0	100
390	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	30	0	100
391	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	30	0	100
392	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	30	0	100
393	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	30	234220	142
394	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	30	8747	448
395	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	30	5661	521
396	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	30	2275	626
397	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	30	182600	110
398	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	30	7916	243
399	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	30	10721	295
400	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	30	2178	405
401	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	30	0	100
402	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	30	1472	108
403	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	30	681	123
404	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	30	455	119
405	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	30	0	100
406	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	30	1211	106
407	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	30	944	118
408	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	30	380	114
409	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	30	0	100
410	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	30	1648	656
411	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	30	640	569
412	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	30	369	696
413	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	30	14678	103
414	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	30	3287	476
415	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	30	643	440
416	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	30	332	599
417	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	30	0	100
418	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	30	0	100

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
419	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	30	10764	102
420	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	30	0	100
421	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	30	0	100
422	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	30	0	100
423	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	30	0	100
424	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	30	0	100
425	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	30	240570	291
426	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	30	9332	597
427	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	30	5767	753
428	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	30	2391	731
429	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	30	188820	153
430	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	30	9357	350
431	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	30	12966	511
432	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	30	2759	543
433	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	30	0	100
434	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	30	1461	108
435	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	30	782	124
436	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	30	439	119
437	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	30	0	100
438	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	30	1114	106
439	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	30	1055	120
440	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	30	354	114
441	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	30	0	100
442	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	30	1620	789
443	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	30	654	716
444	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	30	406	801
445	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	30	25740	105
446	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	30	1671	663
447	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	30	991	566
448	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	30	589	712
449	Arid	Clay	0.1 m	0.025 m	30 m	100	5	100	30	0	100
450	Humid	Clay	0.1 m	0.025 m	30 m	100	5	100	30	0	100
451	Arid	Sand	0.1 m	0.025 m	30 m	100	5	100	30	10406	105
452	Humid	Sand	0.1 m	0.025 m	30 m	100	5	100	30	0	100
453	Arid	Clay	2.0 m	0.025 m	30 m	100	5	100	30	0	100

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
453	Humid	Clay	2.0 m	0.025 m	30 m	100	5	100	30	0	100
455	Arid	Sand	2.0 m	0.025 m	30 m	100	5	100	30	10414	105
456	Humid	Sand	2.0 m	0.025 m	30 m	100	5	100	30	2153	104
457	Arid	Clay	0.1 m	0.6 m	30 m	100	5	100	30	233320	102
458	Humid	Clay	0.1 m	0.6 m	30 m	100	5	100	30	8627	133
459	Arid	Sand	0.1 m	0.6 m	30 m	100	5	100	30	4954	135
460	Humid	Sand	0.1 m	0.6 m	30 m	100	5	100	30	1979	156
461	Arid	Clay	2.0 m	0.6 m	30 m	100	5	100	30	164900	101
462	Humid	Clay	2.0 m	0.6 m	30 m	100	5	100	30	7806	116
463	Arid	Sand	2.0 m	0.6 m	30 m	100	5	100	30	10329	113
464	Humid	Sand	2.0 m	0.6 m	30 m	100	5	100	30	1647	126
465	Arid	Clay	0.1 m	0.025 m	3 m	100	5	100	30	0	100
466	Humid	Clay	0.1 m	0.025 m	3 m	100	5	100	30	1484	105
467	Arid	Sand	0.1 m	0.025 m	3 m	100	5	100	30	641	116
468	Humid	Sand	0.1 m	0.025 m	3 m	100	5	100	30	331	111
469	Arid	Clay	2.0 m	0.025 m	3 m	100	5	100	30	0	100
470	Humid	Clay	2.0 m	0.025 m	3 m	100	5	100	30	1053	102
471	Arid	Sand	2.0 m	0.025 m	3 m	100	5	100	30	638	106
472	Humid	Sand	2.0 m	0.025 m	3 m	100	5	100	30	161	106
473	Arid	Clay	0.1 m	0.6 m	3 m	100	5	100	30	0	100
474	Humid	Clay	0.1 m	0.6 m	3 m	100	5	100	30	1485	197
475	Arid	Sand	0.1 m	0.6 m	3 m	100	5	100	30	10	325
476	Humid	Sand	0.1 m	0.6 m	3 m	100	5	100	30	13	271
477	Arid	Clay	2.0 m	0.6 m	3 m	100	5	100	30	0	100
478	Humid	Clay	2.0 m	0.6 m	3 m	100	5	100	30	1080	181
479	Arid	Sand	2.0 m	0.6 m	3 m	100	5	100	30	9	308
480	Humid	Sand	2.0 m	0.6 m	3 m	100	5	100	30	6	164
481	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	100	30	0	100
482	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	100	30	0	100
483	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	100	30	10708	109
484	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	100	30	0	100
485	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	100	30	0	100
486	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	100	30	0	100
487	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	100	30	0	100

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
488	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	100	30	0	100
489	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	100	30	233550	113
490	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	100	30	8666	256
491	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	100	30	5121	270
492	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	100	30	2160	406
493	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	100	30	165110	103
494	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	100	30	7855	161
495	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	100	30	10481	170
496	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	100	30	1699	234
497	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	100	30	0	100
498	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	100	30	1483	109
499	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	100	30	678	122
500	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	100	30	379	117
501	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	100	30	0	100
502	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	100	30	1082	105
503	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	100	30	644	115
504	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	100	30	322	112
505	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	100	30	0	100
506	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	100	30	1140	381
507	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	100	30	31	406
508	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	100	30	179	473
509	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	100	30	7991	101
510	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	100	30	1109	258
511	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	100	30	32	373
512	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	100	30	78	275

Table A.2—Design matrix for the factors that affect chloride movement in the vadose zone and aquifer as well as two response variables in the monitoring well. Brine concentration 100,000 ppm

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
1	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	3	223200	357
2	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	3	8763	821
3	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	3	10777	1634
4	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	3	2339	1506
5	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	3	183150	102
6	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	3	7839	262
7	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	3	10642	684
8	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	3	2100	616
9	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	3	234420	3942
10	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	3	8668	17644
11	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	3	5684	30463
12	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	3	2173	32368
13	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	3	183030	1075
14	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	3	7853	5808
15	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	3	10539	12158
16	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	3	1861	13267
17	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	3	0	0
18	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	3	1766	1517
19	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	3	3501	2364
20	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	3	445	2113
21	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	3	28467	621
22	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	3	2259	1069
23	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	3	8800	1747
24	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	3	374	1501
25	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	3	0	0
26	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	3	1290	32082
27	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	3	3490	34748
28	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	3	315	41569
29	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	3	28256	702
30	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	3	1055	20635
31	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	3	35	20613
32	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	3	105	19426
33	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	3	234760	751

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
34	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	3	8830	853
35	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	3	10803	1709
36	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	3	2348	1543
37	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	3	182180	239
38	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	3	7841	270
39	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	3	10782	745
40	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	3	2116	635
41	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	3	240570	12688
42	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	3	8675	20631
43	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	3	5719	40746
44	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	3	2192	35896
45	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	3	189120	3608
46	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	3	7838	6604
47	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	3	10545	17992
48	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	3	1914	15107
49	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	3	0	0
50	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	3	1482	1554
51	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	3	944	2436
52	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	3	456	2153
53	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	3	28470	688
54	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	3	2259	1104
55	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	3	954	1848
56	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	3	385	1539
57	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	3	10456	3
58	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	3	1708	37221
59	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	3	629	44325
60	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	3	317	46593
61	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	3	28290	1070
62	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	3	2134	25458
63	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	3	482	25596
64	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	3	167	21825
65	Arid	Clay	0.1 m	0.025 m	30 m	100	5	0	3	233480	27
66	Humid	Clay	0.1 m	0.025 m	30 m	100	5	0	3	8655	333
67	Arid	Sand	0.1 m	0.025 m	30 m	100	5	0	3	10448	644
68	Humid	Sand	0.1 m	0.025 m	30 m	100	5	0	3	2188	667

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
69	Arid	Clay	2.0 m	0.025 m	30 m	100	5	0	3	176480	8
70	Humid	Clay	2.0 m	0.025 m	30 m	100	5	0	3	7828	131
71	Arid	Sand	2.0 m	0.025 m	30 m	100	5	0	3	10428	181
72	Humid	Sand	2.0 m	0.025 m	30 m	100	5	0	3	1694	248
73	Arid	Clay	0.1 m	0.6 m	30 m	100	5	0	3	233390	161
74	Humid	Clay	0.1 m	0.6 m	30 m	100	5	0	3	8630	3094
75	Arid	Sand	0.1 m	0.6 m	30 m	100	5	0	3	10334	3414
76	Humid	Sand	0.1 m	0.6 m	30 m	100	5	0	3	1986	5267
77	Arid	Clay	2.0 m	0.6 m	30 m	100	5	0	3	199190	44
78	Humid	Clay	2.0 m	0.6 m	30 m	100	5	0	3	7812	1606
79	Arid	Sand	2.0 m	0.6 m	30 m	100	5	0	3	8600	1334
80	Humid	Sand	2.0 m	0.6 m	30 m	100	5	0	3	1658	2426
81	Arid	Clay	0.1 m	0.025 m	3 m	100	5	0	3	0	0
82	Humid	Clay	0.1 m	0.025 m	3 m	100	5	0	3	1488	727
83	Arid	Sand	0.1 m	0.025 m	3 m	100	5	0	3	3501	1596
84	Humid	Sand	0.1 m	0.025 m	3 m	100	5	0	3	372	1224
85	Arid	Clay	2.0 m	0.025 m	3 m	100	5	0	3	8937	131
86	Humid	Clay	2.0 m	0.025 m	3 m	100	5	0	3	1106	455
87	Arid	Sand	2.0 m	0.025 m	3 m	100	5	0	3	644	666
88	Humid	Sand	2.0 m	0.025 m	3 m	100	5	0	3	173	744
89	Arid	Clay	0.1 m	0.6 m	3 m	100	5	0	3	10034	2
90	Humid	Clay	0.1 m	0.6 m	3 m	100	5	0	3	1055	9063
91	Arid	Sand	0.1 m	0.6 m	3 m	100	5	0	3	9	20557
92	Humid	Sand	0.1 m	0.6 m	3 m	100	5	0	3	13	15043
93	Arid	Clay	2.0 m	0.6 m	3 m	100	5	0	3	8000	86
94	Humid	Clay	2.0 m	0.6 m	3 m	100	5	0	3	16	7479
95	Arid	Sand	2.0 m	0.6 m	3 m	100	5	0	3	8	10680
96	Humid	Sand	2.0 m	0.6 m	3 m	100	5	0	3	19	6131
97	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	0	3	217720	140
98	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	0	3	8709	714
99	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	0	3	10666	1376
100	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	0	3	3213	1360
101	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	0	3	177150	41
102	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	0	3	7854	234
103	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	0	3	10493	515

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
104	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	0	3	2058	544
105	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	0	3	233720	1316
106	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	0	3	8661	10743
107	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	0	3	5061	14653
108	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	0	3	2087	22280
109	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	0	3	182380	360
110	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	0	3	7846	4073
111	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	0	3	10490	5877
112	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	0	3	1699	8995
113	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	0	3	0	0
114	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	0	3	1485	1370
115	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	0	3	676	2221
116	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	0	3	395	1968
117	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	0	3	28256	422
118	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	0	3	1138	920
119	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	0	3	663	1522
120	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	0	3	342	1349
121	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	0	3	10037	2
122	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	0	3	1110	22233
123	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	0	3	33	26941
124	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	0	3	179	29714
125	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	0	3	8940	304
126	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	0	3	1108	12056
127	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	0	3	29	15275
128	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	0	3	22	14515
129	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	3	223280	423
130	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	3	8758	826
131	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	3	10776	1650
132	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	3	2342	1513
133	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	3	166170	167
134	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	3	7850	266
135	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	3	10641	700
136	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	3	2113	621
137	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	3	28470	4027
138	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	3	8667	17664

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
139	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	3	5332	30511
140	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	3	2172	32386
141	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	3	28470	1160
142	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	3	7856	5823
143	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	3	10541	12202
144	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	3	1860	13284
145	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	3	0	100
146	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	3	1484	1535
147	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	3	725	2427
148	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	3	448	2157
149	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	3	24870	652
150	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	3	1139	1089
151	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	3	28470	1810
152	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	3	370	1545
153	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	3	0	100
154	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	3	1290	32113
155	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	3	3490	34809
156	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	3	316	41603
157	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	3	28257	754
158	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	3	1055	20667
159	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	3	276	20683
160	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	3	105	20240
161	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	3	234430	769
162	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	3	8806	853
163	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	3	10797	1715
164	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	3	2349	1546
165	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	3	182330	257
166	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	3	7829	270
167	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	3	8800	750
168	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	3	2114	636
169	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	3	240570	12737
170	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	3	8673	20633
171	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	3	5486	40758
172	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	3	2193	35899
173	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	3	189120	3657

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
174	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	3	7839	6606
175	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	3	10540	18003
176	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	3	1918	15110
177	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	3	0	100
178	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	3	1481	1568
179	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	3	944	2495
180	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	3	450	2194
181	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	3	28470	712
182	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	3	1213	1128
183	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	3	950	1905
184	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	3	374	1581
185	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	3	0	100
186	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	3	1431	37233
187	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	3	630	44372
188	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	3	317	46633
189	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	3	28292	1096
190	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	3	1107	25474
191	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	3	479	25653
192	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	3	167	21874
193	Arid	Clay	0.1 m	0.025 m	30 m	100	5	100	3	233450	124
194	Humid	Clay	0.1 m	0.025 m	30 m	100	5	100	3	8652	400
195	Arid	Sand	0.1 m	0.025 m	30 m	100	5	100	3	10450	724
196	Humid	Sand	0.1 m	0.025 m	30 m	100	5	100	3	2192	739
197	Arid	Clay	2.0 m	0.025 m	30 m	100	5	100	3	147980	105
198	Humid	Clay	2.0 m	0.025 m	30 m	100	5	100	3	7828	184
199	Arid	Sand	2.0 m	0.025 m	30 m	100	5	100	3	10417	260
200	Humid	Sand	2.0 m	0.025 m	30 m	100	5	100	3	1702	310
201	Arid	Clay	0.1 m	0.6 m	30 m	100	5	100	3	233420	261
202	Humid	Clay	0.1 m	0.6 m	30 m	100	5	100	3	8630	3181
203	Arid	Sand	0.1 m	0.6 m	30 m	100	5	100	3	4960	3510
204	Humid	Sand	0.1 m	0.6 m	30 m	100	5	100	3	1986	5357
205	Arid	Clay	2.0 m	0.6 m	30 m	100	5	100	3	182020	143
206	Humid	Clay	2.0 m	0.6 m	30 m	100	5	100	3	7811	1682
207	Arid	Sand	2.0 m	0.6 m	30 m	100	5	100	3	10334	1428
208	Humid	Sand	2.0 m	0.6 m	30 m	100	5	100	3	1657	2512

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
209	Arid	Clay	0.1 m	0.025 m	3 m	100	5	100	3	0	100
210	Humid	Clay	0.1 m	0.025 m	3 m	100	5	100	3	1488	787
211	Arid	Sand	0.1 m	0.025 m	3 m	100	5	100	3	643	1680
212	Humid	Sand	0.1 m	0.025 m	3 m	100	5	100	3	372	1302
213	Arid	Clay	2.0 m	0.025 m	3 m	100	5	100	3	8937	217
214	Humid	Clay	2.0 m	0.025 m	3 m	100	5	100	3	1106	524
215	Arid	Sand	2.0 m	0.025 m	3 m	100	5	100	3	644	750
216	Humid	Sand	2.0 m	0.025 m	3 m	100	5	100	3	173	822
217	Arid	Clay	0.1 m	0.6 m	3 m	100	5	100	3	0	100
218	Humid	Clay	0.1 m	0.6 m	3 m	100	5	100	3	1055	9147
219	Arid	Sand	0.1 m	0.6 m	3 m	100	5	100	3	9	20632
220	Humid	Sand	0.1 m	0.6 m	3 m	100	5	100	3	13	15102
221	Arid	Clay	2.0 m	0.6 m	3 m	100	5	100	3	28470	180
222	Humid	Clay	2.0 m	0.6 m	3 m	100	5	100	3	16	7535
223	Arid	Sand	2.0 m	0.6 m	3 m	100	5	100	3	11	10675
224	Humid	Sand	2.0 m	0.6 m	3 m	100	5	100	3	19	7244
225	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	100	3	217400	227
226	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	100	3	8707	735
227	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	100	3	10666	1417
228	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	100	3	2319	1382
229	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	100	3	177070	127
230	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	100	3	7835	248
231	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	100	3	10476	555
232	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	100	3	2056	562
233	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	100	3	233720	1411
234	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	100	3	8662	10798
234	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	100	3	5060	14732
236	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	100	3	2087	22332
237	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	100	3	182380	455
238	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	100	3	7845	4113
239	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	100	3	10489	5949
240	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	100	3	1698	9041
241	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	100	3	0	100
242	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	100	3	1714	1398
243	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	100	3	674	2289

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
244	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	100	3	396	2019
245	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	100	3	28254	476
246	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	100	3	1771	959
247	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	661	1590
248	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	339	1401
249	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	0	100
250	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	1110	22293
251	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	33	27009
252	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	179	29779
253	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	10045	382
254	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	1108	12115
255	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	29	15354
256	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	22	14586
257	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	222730	48
258	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	100	3	9383	211
259	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	11032	254
260	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	100	3	2589	259
261	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	164940	14
262	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	100	3	9368	114
263	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	12862	151
264	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	100	3	2976	181
265	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	342180	439
266	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	100	3	8762	3745
267	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	30	5674	4306
268	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	0	30	2291	5525
269	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	30	547480	120
270	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	0	30	7916	1705
271	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	30	10731	2044
272	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	0	30	2173	3307
273	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	30	0	0
274	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	0	30	1648	272
275	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	30	973	268
276	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	0	30	585	279
277	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	30	28470	107
278	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	0	30	1777	229

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
279	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	30	1355	247
280	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	0	30	743	245
281	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	30	0	0
282	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	0	30	1491	5723
283	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	30	989	4755
284	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	0	30	373	6075
285	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	30	28258	108
286	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	0	30	1492	3932
287	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	30	2502	3455
288	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	0	30	378	3864
289	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	30	240740	171
290	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	0	30	9480	236
291	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	30	11441	281
292	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	0	30	2684	276
293	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	30	215880	76
294	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	0	30	10331	143
295	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	30	14031	213
296	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	0	30	3459	208
297	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	30	240940	2001
298	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	0	30	9376	5563
299	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	30	5766	6774
300	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	0	30	2431	6757
301	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	30	189280	617
302	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	0	30	9420	3167
303	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	30	13022	4387
304	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	0	30	2846	4901
305	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	30	0	0
306	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	0	30	1713	286
307	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	30	10060	303
308	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	0	30	588	289
309	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	30	0	0
310	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	0	30	2125	253
311	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	30	17109	278
312	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	0	30	753	261
313	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	30	0	0

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
314	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	0	30	1622	7138
315	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	30	672	6246
316	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	0	30	445	7115
317	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	30	28269	187
318	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	0	30	1778	5902
319	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	30	997	4736
320	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	0	30	601	6247
321	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	30	216390	3
322	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	0	30	8651	43
323	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	30	9846	74
324	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	0	30	2186	82
325	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	30	176200	1
326	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	0	30	7824	19
327	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	30	10405	21
328	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	0	30	1699	34
329	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	30	233310	16
330	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	0	30	8631	343
331	Arid	Clay	0.1 m	0.025 m	30 m	100	5	0	30	4958	353
332	Humid	Clay	0.1 m	0.025 m	30 m	100	5	0	30	1985	571
333	Arid	Sand	0.1 m	0.025 m	30 m	100	5	0	30	164900	4
334	Humid	Sand	0.1 m	0.025 m	30 m	100	5	0	30	7812	192
335	Arid	Clay	2.0 m	0.025 m	30 m	100	5	0	30	10334	140
336	Humid	Clay	2.0 m	0.025 m	30 m	100	5	0	30	1655	274
337	Arid	Sand	2.0 m	0.025 m	30 m	100	5	0	30	0	0
338	Humid	Sand	2.0 m	0.025 m	30 m	100	5	0	30	1489	100
339	Arid	Clay	0.1 m	0.6 m	30 m	100	5	0	30	643	174
340	Humid	Clay	0.1 m	0.6 m	30 m	100	5	0	30	372	140
341	Arid	Sand	0.1 m	0.6 m	30 m	100	5	0	30	8938	15
342	Humid	Sand	0.1 m	0.6 m	30 m	100	5	0	30	1107	57
343	Arid	Clay	2.0 m	0.6 m	30 m	100	5	0	30	647	75
344	Humid	Clay	2.0 m	0.6 m	30 m	100	5	0	30	175	86
345	Arid	Sand	2.0 m	0.6 m	30 m	100	5	0	30	342180	0
346	Humid	Sand	2.0 m	0.6 m	30 m	100	5	0	30	1489	984
347	Arid	Clay	0.1 m	0.025 m	3 m	100	5	0	30	9	2282
348	Humid	Clay	0.1 m	0.025 m	3 m	100	5	0	30	13	1713

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
349	Arid	Sand	0.1 m	0.025 m	3 m	100	5	0	30	7996	9
350	Humid	Sand	0.1 m	0.025 m	3 m	100	5	0	30	1105	867
351	Arid	Clay	2.0 m	0.025 m	3 m	100	5	0	30	9	2065
352	Humid	Clay	2.0 m	0.025 m	3 m	100	5	0	30	7	650
353	Arid	Sand	2.0 m	0.025 m	3 m	100	5	0	30	216970	16
354	Humid	Sand	2.0 m	0.025 m	3 m	100	5	0	30	8759	141
355	Arid	Clay	0.1 m	0.6 m	3 m	100	5	0	30	10781	194
356	Humid	Clay	0.1 m	0.6 m	3 m	100	5	0	30	2388	214
357	Arid	Sand	0.1 m	0.6 m	3 m	100	5	0	30	177250	5
358	Humid	Sand	0.1 m	0.6 m	3 m	100	5	0	30	7883	66
359	Arid	Clay	2.0 m	0.6 m	3 m	100	5	0	30	10665	87
360	Humid	Clay	2.0 m	0.6 m	3 m	100	5	0	30	2268	125
361	Arid	Sand	2.0 m	0.6 m	3 m	100	5	0	30	233690	137
362	Humid	Sand	2.0 m	0.6 m	3 m	100	5	0	30	8673	1632
363	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	0	30	5141	1715
364	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	0	30	2164	3139
365	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	0	30	182270	38
366	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	0	30	7860	711
367	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	0	30	182270	735
368	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	0	30	1715	1434
369	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	0	30	0	0
370	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	0	30	1492	232
371	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	0	30	683	254
372	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	0	30	515	246
373	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	0	30	28249	64
374	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	0	30	1489	169
375	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	0	30	665	187
376	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	0	30	599	194
377	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	0	30	0	0
378	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	0	30	1140	2860
379	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	0	30	33	3102
380	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	0	30	180	3795
381	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	0	30	1038	35
382	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	0	30	1109	1629
383	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	0	30	34218	1689

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
384	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	0	30	80	3792
385	Arid	Sand	2.0 m	0.025 m	3 m	10000	5	0	30	223430	144
386	Humid	Sand	2.0 m	0.025 m	3 m	10000	5	0	30	9358	260
387	Arid	Clay	0.1 m	0.6 m	3 m	10000	5	0	30	11007	333
388	Humid	Clay	0.1 m	0.6 m	3 m	10000	5	0	30	2604	329
389	Arid	Sand	0.1 m	0.6 m	3 m	10000	5	0	30	177500	109
390	Humid	Sand	0.1 m	0.6 m	3 m	10000	5	0	30	9272	158
391	Arid	Clay	2.0 m	0.6 m	3 m	10000	5	0	30	12853	228
392	Humid	Clay	2.0 m	0.6 m	3 m	10000	5	0	30	2836	239
393	Arid	Sand	2.0 m	0.6 m	3 m	10000	5	0	30	234400	538
394	Humid	Sand	2.0 m	0.6 m	3 m	10000	5	0	30	8768	3819
395	Arid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	30	5672	4396
396	Humid	Clay	0.1 m	0.025 m	30 m	100	0.1	100	30	2292	5599
397	Arid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	30	182990	218
398	Humid	Sand	0.1 m	0.025 m	30 m	100	0.1	100	30	7916	1777
399	Arid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	30	10752	2135
400	Humid	Clay	2.0 m	0.025 m	30 m	100	0.1	100	30	2174	3381
401	Arid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	30	0	100
402	Humid	Sand	2.0 m	0.025 m	30 m	100	0.1	100	30	1647	352
403	Arid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	30	963	382
404	Humid	Clay	0.1 m	0.6 m	30 m	100	0.1	100	30	527	369
405	Arid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	30	28470	195
406	Humid	Sand	0.1 m	0.6 m	30 m	100	0.1	100	30	1648	307
407	Arid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	30	1356	340
408	Humid	Clay	2.0 m	0.6 m	30 m	100	0.1	100	30	714	331
409	Arid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	30	0	100
410	Humid	Sand	2.0 m	0.6 m	30 m	100	0.1	100	30	1862	5807
411	Arid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	30	644	4849
412	Humid	Clay	0.1 m	0.025 m	3 m	100	0.1	100	30	373	6164
413	Arid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	30	28251	200
414	Humid	Sand	0.1 m	0.025 m	3 m	100	0.1	100	30	3613	4015
415	Arid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	30	651	3549
416	Humid	Clay	2.0 m	0.025 m	3 m	100	0.1	100	30	336	5185
417	Arid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	30	241280	246
418	Humid	Sand	2.0 m	0.025 m	3 m	100	0.1	100	30	9483	272

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
419	Arid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	30	11422	354
420	Humid	Clay	0.1 m	0.6 m	3 m	100	0.1	100	30	2623	341
421	Arid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	30	215400	146
422	Humid	Sand	0.1 m	0.6 m	3 m	100	0.1	100	30	9720	164
423	Arid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	30	13833	276
424	Humid	Clay	2.0 m	0.6 m	3 m	100	0.1	100	30	3042	256
425	Arid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	30	240940	2092
426	Humid	Sand	2.0 m	0.6 m	3 m	100	0.1	100	30	9374	5604
427	Arid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	30	5765	6849
428	Humid	Clay	0.1 m	0.025 m	30 m	10000	0.1	100	30	2421	6812
429	Arid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	30	189240	708
430	Humid	Sand	0.1 m	0.025 m	30 m	10000	0.1	100	30	9441	3201
431	Arid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	30	13021	4459
432	Humid	Clay	2.0 m	0.025 m	30 m	10000	0.1	100	30	2835	4959
433	Arid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	30	0	100
434	Humid	Sand	2.0 m	0.025 m	30 m	10000	0.1	100	30	1650	364
435	Arid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	30	984	396
436	Humid	Clay	0.1 m	0.6 m	30 m	10000	0.1	100	30	589	379
437	Arid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	30	28470	208
438	Humid	Sand	0.1 m	0.6 m	30 m	10000	0.1	100	30	17777	327
439	Arid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	30	1872	368
440	Humid	Clay	2.0 m	0.6 m	30 m	10000	0.1	100	30	725	346
441	Arid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	30	0	100
442	Humid	Sand	2.0 m	0.6 m	30 m	10000	0.1	100	30	1622	7213
443	Arid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	30	674	6338
444	Humid	Clay	0.1 m	0.025 m	3 m	10000	0.1	100	30	442	7204
445	Arid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	30	28289	274
446	Humid	Sand	0.1 m	0.025 m	3 m	10000	0.1	100	30	1780	5975
447	Arid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	30	997	4828
448	Humid	Clay	2.0 m	0.025 m	3 m	10000	0.1	100	30	599	6334
449	Arid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	30	216140	103
450	Humid	Sand	2.0 m	0.025 m	3 m	10000	0.1	100	30	8654	139
451	Arid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	30	10445	172
452	Humid	Clay	0.1 m	0.6 m	3 m	10000	0.1	100	30	2186	178
453	Arid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	30	176460	101

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
453	Humid	Sand	0.1 m	0.6 m	3 m	10000	0.1	100	30	7818	112
455	Arid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	30	10415	119
456	Humid	Clay	2.0 m	0.6 m	3 m	10000	0.1	100	30	1974	129
457	Arid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	30	233320	11
458	Humid	Sand	2.0 m	0.6 m	3 m	10000	0.1	100	30	8630	441
459	Arid	Clay	0.1 m	0.025 m	30 m	100	5	100	30	4959	453
460	Humid	Clay	0.1 m	0.025 m	30 m	100	5	100	30	1985	670
461	Arid	Sand	0.1 m	0.025 m	30 m	100	5	100	30	164920	104
462	Humid	Sand	0.1 m	0.025 m	30 m	100	5	100	30	7814	290
463	Arid	Clay	2.0 m	0.025 m	30 m	100	5	100	30	10332	239
464	Humid	Clay	2.0 m	0.025 m	30 m	100	5	100	30	1658	373
465	Arid	Sand	2.0 m	0.025 m	30 m	100	5	100	30	0	100
466	Humid	Sand	2.0 m	0.025 m	30 m	100	5	100	30	1488	194
467	Arid	Clay	0.1 m	0.6 m	30 m	100	5	100	30	642	272
468	Humid	Clay	0.1 m	0.6 m	30 m	100	5	100	30	371	237
469	Arid	Sand	0.1 m	0.6 m	30 m	100	5	100	30	8933	113
470	Humid	Sand	0.1 m	0.6 m	30 m	100	5	100	30	1106	153
471	Arid	Clay	2.0 m	0.6 m	30 m	100	5	100	30	644	173
472	Humid	Clay	2.0 m	0.6 m	30 m	100	5	100	30	172	183
473	Arid	Sand	2.0 m	0.6 m	30 m	100	5	100	30	0	100
474	Humid	Sand	2.0 m	0.6 m	30 m	100	5	100	30	1489	1082
475	Arid	Clay	0.1 m	0.025 m	3 m	100	5	100	30	9	2379
476	Humid	Clay	0.1 m	0.025 m	3 m	100	5	100	30	13	1813
477	Arid	Sand	0.1 m	0.025 m	3 m	100	5	100	30	7993	108
478	Humid	Sand	0.1 m	0.025 m	3 m	100	5	100	30	1106	961
479	Arid	Clay	2.0 m	0.025 m	3 m	100	5	100	30	9	2166
480	Humid	Clay	2.0 m	0.025 m	3 m	100	5	100	30	7	749
481	Arid	Sand	2.0 m	0.025 m	3 m	100	5	100	30	217110	114
482	Humid	Sand	2.0 m	0.025 m	3 m	100	5	100	30	8776	216
483	Arid	Clay	0.1 m	0.6 m	3 m	100	5	100	30	10765	283
484	Humid	Clay	0.1 m	0.6 m	3 m	100	5	100	30	2389	293
485	Arid	Sand	0.1 m	0.6 m	3 m	100	5	100	30	148420	103
486	Humid	Sand	0.1 m	0.6 m	3 m	100	5	100	30	8194	140
487	Arid	Clay	2.0 m	0.6 m	3 m	100	5	100	30	10600	176
488	Humid	Clay	2.0 m	0.6 m	3 m	100	5	100	30	2300	201

	Factors									Responses	
	Climate	Soil	Dispersion Length	Brine Depth	GW Depth	Release Volume	Flux Aquifer	Cl Concent.	Depth Aquifer	T_{max}	C_{max}
						(bbls)	(cm/d)	(ppm)	(m)	Day #	(ppm)
489	Arid	Sand	2.0 m	0.6 m	3 m	100	5	100	30	233730	237
490	Humid	Sand	2.0 m	0.6 m	3 m	100	5	100	30	8674	1725
491	Arid	Clay	0.1 m	0.025 m	30 m	10000	5	100	30	5138	1812
492	Humid	Clay	0.1 m	0.025 m	30 m	10000	5	100	30	2164	3231
493	Arid	Sand	0.1 m	0.025 m	30 m	10000	5	100	30	182320	137
494	Humid	Sand	0.1 m	0.025 m	30 m	10000	5	100	30	7857	800
495	Arid	Clay	2.0 m	0.025 m	30 m	10000	5	100	30	10506	832
496	Humid	Clay	2.0 m	0.025 m	30 m	10000	5	100	30	1714	1525
497	Arid	Sand	2.0 m	0.025 m	30 m	10000	5	100	30	0	100
498	Humid	Sand	2.0 m	0.025 m	30 m	10000	5	100	30	1489	317
499	Arid	Clay	0.1 m	0.6 m	30 m	10000	5	100	30	681	350
500	Humid	Clay	0.1 m	0.6 m	30 m	10000	5	100	30	512	338
501	Arid	Sand	0.1 m	0.6 m	30 m	10000	5	100	30	28250	157
502	Humid	Sand	0.1 m	0.6 m	30 m	10000	5	100	30	1489	225
503	Arid	Clay	2.0 m	0.6 m	30 m	10000	5	100	30	682	284
504	Humid	Clay	2.0 m	0.6 m	30 m	10000	5	100	30	518	285
505	Arid	Sand	2.0 m	0.6 m	30 m	10000	5	100	30	0	100
506	Humid	Sand	2.0 m	0.6 m	30 m	10000	5	100	30	1140	2954
507	Arid	Clay	0.1 m	0.025 m	3 m	10000	5	100	30	34	3198
508	Humid	Clay	0.1 m	0.025 m	3 m	10000	5	100	30	181	3889
509	Arid	Sand	0.1 m	0.025 m	3 m	10000	5	100	30	10040	133
510	Humid	Sand	0.1 m	0.025 m	3 m	10000	5	100	30	1109	1724
511	Arid	Clay	2.0 m	0.025 m	3 m	10000	5	100	30	33	2844
512	Humid	Clay	2.0 m	0.025 m	3 m	10000	5	100	30	80	1885

Table A3—Design matrix for heterogeneous profiles in Hobbs, as well as two response variables in the monitoring well

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
1	15	15	30	100	0.1	0	3	10442	373
2	3	27	30	100	0.1	0	3	7490	638
3	10	20	30	100	0.1	0	3	10204	448
4	20	10	30	100	0.1	0	3	14162	323
5	0	20	20	100	0.1	0	3	5152	996
6	14	6	20	100	0.1	0	3	10235	379
7	10	10	20	100	0.1	0	3	10125	462
8	6	14	20	100	0.1	0	3	8214	561
9	0	10	10	100	0.1	0	3	2698	1230
10	3	7	10	100	0.1	0	3	4680	814
11	5	5	10	100	0.1	0	3	5396	675
12	7	3	10	100	0.1	0	3	5832	571
13	15	15	30	10000	0.1	0	3	11589	418
14	3	27	30	10000	0.1	0	3	7531	733
15	10	20	30	10000	0.1	0	3	10117	491
16	20	10	30	10000	0.1	0	3	14205	359
17	0	20	20	10000	0.1	0	3	5232	1115
18	14	6	20	10000	0.1	0	3	11933	435
19	10	10	20	10000	0.1	0	3	10068	511
20	6	14	20	10000	0.1	0	3	8312	636
21	0	10	10	10000	0.1	0	3	2719	1400
22	3	7	10	10000	0.1	0	3	4707	417
23	5	5	10	10000	0.1	0	3	5397	754
24	7	3	10	10000	0.1	0	3	6857	658
25	15	15	30	100	5	0	3	10184	119
26	3	27	30	100	5	0	3	8212	108
27	10	20	30	100	5	0	3	10213	126
28	20	10	30	100	5	0	3	10155	67
29	0	20	20	100	5	0	3	4162	186
30	14	6	20	100	5	0	3	10103	125
31	10	10	20	100	5	0	3	10130	130
32	6	14	20	100	5	0	3	8106	118
33	0	10	10	100	5	0	3	844	238

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
34	3	7	10	100	5	0	3	4022	179
35	5	5	10	100	5	0	3	4014	147
36	7	3	10	100	5	0	3	4653	127
37	15	15	30	10000	5	0	3	10203	290
38	3	27	30	10000	5	0	3	6058	424
39	10	20	30	10000	5	0	3	10219	333
40	20	10	30	10000	5	0	3	14202	228
41	0	20	20	10000	5	0	3	4976	666
42	14	6	20	10000	5	0	3	10121	292
43	10	10	20	10000	5	0	3	10137	337
44	6	14	20	10000	5	0	3	8117	372
45	0	10	10	10000	5	0	3	1587	868
46	3	7	10	10000	5	0	3	4114	554
47	5	5	10	10000	5	0	3	4848	460
48	7	3	10	10000	5	0	3	5444	402
49	15	15	30	100	0.1	100	3	10513	385
50	3	27	30	100	0.1	100	3	7442	657
51	10	20	30	100	0.1	100	3	10185	459
52	20	10	30	100	0.1	100	3	14139	335
53	0	20	20	100	0.1	100	3	5147	1023
54	14	6	20	100	0.1	100	3	12225	394
55	10	10	20	100	0.1	100	3	10107	474
56	6	14	20	100	0.1	100	3	8156	579
57	0	10	10	100	0.1	100	3	2672	1268
58	3	7	10	100	0.1	100	3	4674	842
59	5	5	10	100	0.1	100	3	5381	696
60	7	3	10	100	0.1	100	3	5813	592
61	15	15	30	10000	0.1	100	3	11595	420
62	3	27	30	10000	0.1	100	3	7656	739
63	10	20	30	10000	0.1	100	3	10071	493
64	20	10	30	10000	0.1	100	3	14144	360
65	0	20	20	10000	0.1	100	3	5206	1129
66	14	6	20	10000	0.1	100	3	12138	438
67	10	10	20	10000	0.1	100	3	10074	514
68	6	14	20	10000	0.1	100	3	8272	641

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
69	0	10	10	10000	0.1	100	3	2695	1429
70	3	7	10	10000	0.1	100	3	4659	934
71	5	5	10	10000	0.1	100	3	5373	764
72	7	3	10	10000	0.1	100	3	6850	665
73	15	15	30	100	5	100	3	10185	193
74	3	27	30	100	5	100	3	8209	190
75	10	20	30	100	5	100	3	10218	201
76	20	10	30	100	5	100	3	13760	148
77	0	20	20	100	5	100	3	4166	276
78	14	6	20	100	5	100	3	10104	199
79	10	10	20	100	5	100	3	10126	204
80	6	14	20	100	5	100	3	8105	201
81	0	10	10	100	5	100	3	847	327
82	3	7	10	100	5	100	3	4023	265
83	5	5	10	100	5	100	3	4019	233
84	7	3	10	100	5	100	3	4652	211
85	15	15	30	10000	5	100	3	10200	323
86	3	27	30	10000	5	100	3	6066	472
87	10	20	30	10000	5	100	3	10222	368
88	20	10	30	10000	5	100	3	14189	267
89	0	20	20	10000	5	100	3	4971	722
90	14	6	20	10000	5	100	3	10120	328
91	10	10	20	10000	5	100	3	10130	373
92	6	14	20	10000	5	100	3	8109	420
93	0	10	10	10000	5	100	3	1587	929
94	3	7	10	10000	5	100	3	4118	610
95	5	5	10	10000	5	100	3	4840	511
96	7	3	10	10000	5	100	3	5464	451
97	15	15	30	100	0.1	0	30	14154	116
98	3	27	30	100	0.1	0	30	8527	155
99	10	20	30	100	0.1	0	30	12331	124
100	20	10	30	100	0.1	0	30	16296	103
101	0	20	20	100	0.1	0	30	5868	188
102	14	6	20	100	0.1	0	30	14112	113
103	10	10	20	100	0.1	0	30	10373	121

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
104	6	14	20	100	0.1	0	30	10166	144
105	0	10	10	100	0.1	0	30	3083	200
106	3	7	10	100	0.1	0	30	5546	166
107	5	5	10	100	0.1	0	30	8022	145
108	7	3	10	100	0.1	0	30	8016	138
109	15	15	30	10000	0.1	0	30	14981	170
110	3	27	30	10000	0.1	0	30	9985	213
111	10	20	30	10000	0.1	0	30	13753	181
112	20	10	30	10000	0.1	0	30	20165	156
113	0	20	20	10000	0.1	0	30	7361	242
114	14	6	20	10000	0.1	0	30	16128	171
115	10	10	20	10000	0.1	0	30	14046	182
116	6	14	20	10000	0.1	0	30	11563	197
117	0	10	10	10000	0.1	0	30	4110	258
118	3	7	10	10000	0.1	0	30	7551	221
119	5	5	10	10000	0.1	0	30	8714	206
120	7	3	10	10000	0.1	0	30	10044	199
121	15	15	30	100	5	0	30	10189	15
122	3	27	30	100	5	0	30	8199	12
123	10	20	30	100	5	0	30	10199	15
124	20	10	30	100	5	0	30	10139	8
125	0	20	20	100	5	0	30	4156	20
126	14	6	20	100	5	0	30	10096	15
127	10	10	20	100	5	0	30	10127	16
128	6	14	20	100	5	0	30	8095	13
129	0	10	10	100	5	0	30	836	26
130	3	7	10	100	5	0	30	4019	20
131	5	5	10	100	5	0	30	4004	16
132	7	3	10	100	5	0	30	4644	14
133	15	15	30	10000	5	0	30	10201	53
134	3	27	30	10000	5	0	30	8203	70
135	10	20	30	10000	5	0	30	10221	65
136	20	10	30	10000	5	0	30	14141	43
137	0	20	20	10000	5	0	30	5155	98
138	14	6	20	10000	5	0	30	10137	51

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
139	10	10	20	10000	5	0	30	10136	63
140	6	14	20	10000	5	0	30	8307	61
141	0	10	10	10000	5	0	30	1568	108
142	3	7	10	10000	5	0	30	4123	83
143	5	5	10	10000	5	0	30	5452	74
144	7	3	10	10000	5	0	30	5437	62
145	15	15	30	100	0.1	100	30	14154	182
146	3	27	30	100	0.1	100	30	8600	231
147	10	20	30	100	0.1	100	30	10571	194
148	20	10	30	100	0.1	100	30	16218	169
149	0	20	20	100	0.1	100	30	5832	271
150	14	6	20	100	0.1	100	30	14149	183
151	10	10	20	100	0.1	100	30	10259	193
152	6	14	20	100	0.1	100	30	10156	217
153	0	10	10	100	0.1	100	30	3051	288
154	3	7	10	100	0.1	100	30	5541	249
155	5	5	10	100	0.1	100	30	7285	222
156	7	3	10	100	0.1	100	30	8006	215
157	15	15	30	10000	0.1	100	30	14419	214
158	3	27	30	10000	0.1	100	30	9304	273
159	10	20	30	10000	0.1	100	30	12693	230
160	20	10	30	10000	0.1	100	30	18687	198
161	0	20	20	10000	0.1	100	30	7181	316
162	14	6	20	10000	0.1	100	30	15485	218
163	10	10	20	10000	0.1	100	30	13367	233
164	6	14	20	10000	0.1	100	30	10208	256
165	0	10	10	10000	0.1	100	30	3990	339
166	3	7	10	10000	0.1	100	30	6995	293
167	5	5	10	10000	0.1	100	30	8133	272
168	7	3	10	10000	0.1	100	30	9054	259
169	15	15	30	100	5	100	30	10167	111
170	3	27	30	100	5	100	30	5624	110
171	10	20	30	100	5	100	30	10198	112
172	20	10	30	100	5	100	30	10138	105
173	0	20	20	100	5	100	30	4158	119

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
174	14	6	20	100	5	100	30	10097	112
175	10	10	20	100	5	100	30	10128	113
176	6	14	20	100	5	100	30	8092	111
177	0	10	10	100	5	100	30	808	124
178	3	7	10	100	5	100	30	4013	118
179	5	5	10	100	5	100	30	4013	115
180	7	3	10	100	5	100	30	4641	112
181	15	15	30	10000	5	100	30	10226	150
182	3	27	30	10000	5	100	30	8213	161
183	10	20	30	10000	5	100	30	10219	152
184	20	10	30	10000	5	100	30	14218	132
185	0	20	20	10000	5	100	30	5132	191
186	14	6	20	10000	5	100	30	10139	139
187	10	10	20	10000	5	100	30	10132	151
188	6	14	20	10000	5	100	30	8242	152
189	0	10	10	10000	5	100	30	1594	204
190	3	7	10	10000	5	100	30	4740	175
191	5	5	10	10000	5	100	30	5402	165
192	7	3	10	10000	5	100	30	5463	154

Table A4—Design matrix for heterogeneous profiles in Shreveport, as well as two response variables in the monitoring well

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
1	15	15	30	100	0.1	0	3	2542	380
2	10	20	30	100	0.1	0	3	1885	497
3	20	10	30	100	0.1	0	3	3369	335
4	0	20	20	100	0.1	0	3	1036	951
5	6	14	20	100	0.1	0	3	1492	613
6	10	10	20	100	0.1	0	3	1702	511
7	14	6	20	100	0.1	0	3	1902	457
8	20	0	20	100	0.1	0	3	6225	343
9	0	10	10	100	0.1	0	3	543	1246
10	3	7	10	100	0.1	0	3	924	835
11	5	5	10	100	0.1	0	3	1071	709
12	10	0	10	100	0.1	0	3	3336	492
13	15	15	30	100000	0.1	0	3	2593	395
14	10	20	30	100000	0.1	0	3	1904	509
15	20	10	30	100000	0.1	0	3	3357	348
16	0	20	20	100000	0.1	0	3	1033	978
17	6	14	20	100000	0.1	0	3	1478	627
18	10	10	20	100000	0.1	0	3	1717	523
19	14	6	20	100000	0.1	0	3	1858	468
20	20	0	20	100000	0.1	0	3	6085	365
21	0	10	10	100000	0.1	0	3	556	1280
22	3	7	10	100000	0.1	0	3	937	863
23	5	5	10	100000	0.1	0	3	1057	730
24	10	0	10	100000	0.1	0	3	3311	536
25	15	15	30	100	5	0	3	1055	146
26	10	20	30	100	5	0	3	1592	237
27	20	10	30	100	5	0	3	3470	153
28	0	20	20	100	5	0	3	826	405
29	6	14	20	100	5	0	3	1546	284
30	10	10	20	100	5	0	3	1538	265
31	14	6	20	100	5	0	3	1538	220
32	20	0	20	100	5	0	3	7151	109
33	0	10	10	100	5	0	3	400	574

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
34	3	7	10	100	5	0	3	767	365
35	5	5	10	100	5	0	3	763	300
36	10	0	10	100	5	0	3	3431	167
37	15	15	30	100000	5	0	3	2543	327
38	10	20	30	100000	5	0	3	1877	451
39	20	10	30	100000	5	0	3	3471	295
40	0	20	20	100000	5	0	3	1033	841
41	6	14	20	100000	5	0	3	1500	554
42	10	10	20	100000	5	0	3	1671	464
43	14	6	20	100000	5	0	3	1825	412
44	20	0	20	100000	5	0	3	6313	276
45	0	10	10	100000	5	0	3	466	1113
46	3	7	10	100000	5	0	3	800	739
47	5	5	10	100000	5	0	3	1074	624
48	10	0	10	100000	5	0	3	2004	382
49	15	15	30	100	0.1	100	3	2555	385
50	10	20	30	100	0.1	100	3	1888	501
51	20	10	30	100	0.1	100	3	3379	340
52	0	20	20	100	0.1	100	3	1035	962
53	6	14	20	100	0.1	100	3	1473	619
54	10	10	20	100	0.1	100	3	1700	515
55	14	6	20	100	0.1	100	3	1862	461
56	20	0	20	100	0.1	100	3	6093	350
57	0	10	10	100	0.1	100	3	542	1270
58	3	7	10	100	0.1	100	3	913	854
59	5	5	10	100	0.1	100	3	1056	720
60	10	0	10	100	0.1	100	3	3335	504
61	15	15	30	100000	0.1	100	3	2636	396
62	10	20	30	100000	0.1	100	3	1899	510
63	20	10	30	100000	0.1	100	3	3347	348
64	0	20	20	100000	0.1	100	3	1036	986
65	6	14	20	100000	0.1	100	3	1485	632
66	10	10	20	100000	0.1	100	3	1703	524
67	14	6	20	100000	0.1	100	3	1892	470
68	20	0	20	100000	0.1	100	3	6082	366

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
69	0	10	10	100000	0.1	100	3	547	1301
70	3	7	10	100000	0.1	100	3	931	879
71	5	5	10	100000	0.1	100	3	1054	739
72	10	0	10	100000	0.1	100	3	3310	540
73	15	15	30	100	5	100	3	2051	209
74	10	20	30	100	5	100	3	1593	291
75	20	10	30	100	5	100	3	3468	208
76	0	20	20	100	5	100	3	828	475
77	6	14	20	100	5	100	3	1544	338
78	10	10	20	100	5	100	3	1539	319
79	14	6	20	100	5	100	3	1535	273
80	20	0	20	100	5	100	3	6264	174
81	0	10	10	100	5	100	3	400	645
82	3	7	10	100	5	100	3	768	433
83	5	5	10	100	5	100	3	762	367
84	10	0	10	100	5	100	3	3426	234
85	15	15	30	100000	5	100	3	2542	346
86	10	20	30	100000	5	100	3	1876	465
87	20	10	30	100000	5	100	3	3450	309
88	0	20	20	100000	5	100	3	1028	864
89	6	14	20	100000	5	100	3	1490	570
90	10	10	20	100000	5	100	3	1670	478
91	14	6	20	100000	5	100	3	1821	426
92	20	0	20	100000	5	100	3	6258	301
93	0	10	10	100000	5	100	3	466	1148
94	3	7	10	100000	5	100	3	802	770
95	5	5	10	100000	5	100	3	973	649
96	10	0	10	100000	5	100	3	2003	410
97	15	15	30	100	0.1	0	30	3519	150
98	10	20	30	100	0.1	0	30	2714	168
99	20	10	30	100	0.1	0	30	4241	140
100	0	20	20	100	0.1	0	30	1359	221
101	6	14	20	100	0.1	0	30	1984	187
102	10	10	20	100	0.1	0	30	2499	173
103	14	6	20	100	0.1	0	30	2687	159

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
104	20	0	20	100	0.1	0	30	7787	136
105	0	10	10	100	0.1	0	30	815	238
106	3	7	10	100	0.1	0	30	1370	215
107	5	5	10	100	0.1	0	30	1502	195
108	10	0	10	100	0.1	0	30	4823	143
109	15	15	30	100000	0.1	0	30	3650	171
110	10	20	30	100000	0.1	0	30	2916	189
111	20	10	30	100000	0.1	0	30	4397	162
112	0	20	20	100000	0.1	0	30	1422	237
113	6	14	20	100000	0.1	0	30	2025	202
114	10	10	20	100000	0.1	0	30	2672	194
115	14	6	20	100000	0.1	0	30	3111	182
116	20	0	20	100000	0.1	0	30	7779	167
117	0	10	10	100000	0.1	0	30	943	254
118	3	7	10	100000	0.1	0	30	1454	222
119	5	5	10	100000	0.1	0	30	1549	210
120	10	0	10	100000	0.1	0	30	4927	182
121	15	15	30	100	5	0	30	2044	21
122	10	20	30	100	5	0	30	1722	34
123	20	10	30	100	5	0	30	3467	23
124	0	20	20	100	5	0	30	824	51
125	6	14	20	100	5	0	30	1549	45
126	10	10	20	100	5	0	30	1540	40
127	14	6	20	100	5	0	30	1532	32
128	20	0	20	100	5	0	30	7152	15
129	0	10	10	100	5	0	30	399	72
130	3	7	10	100	5	0	30	768	48
131	5	5	10	100	5	0	30	759	38
132	10	0	10	100	5	0	30	3432	22
133	15	15	30	100000	5	0	30	3523	94
134	10	20	30	100000	5	0	30	2074	120
135	20	10	30	100000	5	0	30	3681	90
136	0	20	20	100000	5	0	30	1298	172
137	6	14	20	100000	5	0	30	1735	142
138	10	10	20	100000	5	0	30	2008	127

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
139	14	6	20	100000	5	0	30	2010	110
140	20	0	20	100000	5	0	30	7153	71
141	0	10	10	100000	5	0	30	777	191
142	3	7	10	100000	5	0	30	1165	155
143	5	5	10	100000	5	0	30	1453	145
144	10	0	10	100000	5	0	30	3470	81
145	15	15	30	100	0.1	100	30	3477	198
146	10	20	30	100	0.1	100	30	2563	224
147	20	10	30	100	0.1	100	30	4240	186
148	0	20	20	100	0.1	100	30	1351	292
149	6	14	20	100	0.1	100	30	1848	249
150	10	10	20	100	0.1	100	30	2312	229
151	14	6	20	100	0.1	100	30	2650	215
152	20	0	20	100	0.1	100	30	7166	188
153	0	10	10	100	0.1	100	30	774	318
154	3	7	10	100	0.1	100	30	1306	278
155	5	5	10	100	0.1	100	30	1445	261
156	10	0	10	100	0.1	100	30	3819	212
157	15	15	30	100000	0.1	100	30	3586	210
158	10	20	30	100000	0.1	100	30	2716	237
159	20	10	30	100000	0.1	100	30	4218	196
160	0	20	20	100000	0.1	100	30	1361	304
161	6	14	20	100000	0.1	100	30	1949	260
162	10	10	20	100000	0.1	100	30	2500	243
163	14	6	20	100000	0.1	100	30	2734	228
164	20	0	20	100000	0.1	100	30	7542	205
165	0	10	10	100000	0.1	100	30	904	332
166	3	7	10	100000	0.1	100	30	1341	291
167	5	5	10	100000	0.1	100	30	1474	273
168	10	0	10	100000	0.1	100	30	4919	239
169	15	15	30	100	5	100	30	2033	115
170	10	20	30	100	5	100	30	1752	128
171	20	10	30	100	5	100	30	3461	116
172	0	20	20	100	5	100	30	824	147
173	6	14	20	100	5	100	30	1548	138

	Factors							Responses	
	Total Clay	Total Sand	GW Depth	Release Volume	Flux Aquifer	Cl Concent	Depth Aquifer	T_{max}	C_{max}
	(m)	(m)	(m)	(bbls)	(cm/day)	(ppm)	(m)	Day #	(ppm)
174	10	10	20	100	5	100	30	1543	133
175	14	6	20	100	5	100	30	1532	125
176	20	0	20	100	5	100	30	6320	110
177	0	10	10	100	5	100	30	398	168
178	3	7	10	100	5	100	30	764	143
179	5	5	10	100	5	100	30	760	134
180	10	0	10	100	5	100	30	3420	117
181	15	15	30	100000	5	100	30	3463	163
182	10	20	30	100000	5	100	30	2077	192
183	20	10	30	100000	5	100	30	3679	160
184	0	20	20	100000	5	100	30	1192	251
185	6	14	20	100000	5	100	30	1778	216
186	10	10	20	100000	5	100	30	2015	199
187	14	6	20	100000	5	100	30	2023	183
188	20	0	20	100000	5	100	30	6623	149
189	0	10	10	100000	5	100	30	748	275
190	3	7	10	100000	5	100	30	1162	237
191	5	5	10	100000	5	100	30	1306	223
192	10	0	10	100000	5	100	30	3460	165

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