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PANTEX PLANT

Corrective Measure Study/ Feasibility Study

for the

U.S. Department of Energy/ National Nuclear Security Administration Pantex Plant Amarillo, Texas

June 2006

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BWXT Pantex

30727

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Operations Security

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Department
(PX-2209 Review Located in Administrative Records)

Corrective Measure Study/ Feasibility Study
for the U.S. Department of Energy/National Nuclear Security Administration
Pantex Plant, Amarillo, Texas

June 2006

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LIST OF ATTACHMENTS

(Attachments are provided electronically on CD ROM)

Attachment 1A. Screening Model Alternative Summary Information
Attachment 2A. Key Screening Model Alternatives Results

ACRONYMS AND ABBREVIATIONS

AL	Action level
amsl	Above mean sea level
ARAR	Applicable or Relevant and Appropriate Requirement
AOC	Area of concern
BEG	Bureau of Economic Geology
bgs	Below ground surface
BRA	Baseline Risk Assessment
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLU-IN	Hazardous Waste Cleanup Information
CMI	Corrective Measure Implementation
CMS	Corrective Measures Study
COC	Constituents of concern
COPC	Constituents of potential concern
CPEO	Center for Public Environmental Oversight
CPM	Chemical precipitation/microfiltration
CRP	Conservation Reserve Program
CWA	Clean Water Act
D&D	Deactivation and Decommissioning
DCA	Dichloroethane
DCE	Dichloroethene
DNT	Dinitrotoluene
DNX	Dinitrosoamine
DPE	Dual-phase extraction
DSM	Deep soil mixing
EA	Environmental Assessment
EPA	United States Environmental Protection Agency
ERA	Ecological Risk Assessment
ERDA	United States Energy Research and Development Administration
ERSD	Environmental Remediation Services Department
ESTCP	Environmental Security Technology Certification Program
FGZ	Fine-grained zone
FM	Farm-to-Market
FRTR	Federal Remediation Technologies Roundtable
FS-5	Firing Site 5
FTA	Fire Training Area
FTM	Focused Transport Model
GAC	Granular activated carbon
GHB	General head boundary
GWRTAC	Ground-Water Remediation Technologies Analysis Center
HE	High explosive
HHRA	Human Health Risk Assessment
HI	Hazard index
HMX	High Melting Explosive (cyclotetramethylene tetranitramine)
HQ	Hazard quotient
HSU	Hydrostratigraphic unit
ICM	Interim Corrective Measure
IDW	Investigative derived waste

ACRONYMS AND ABBREVIATIONS

ILCR	Incremental lifetime cancer risk
ISB	*In situ* bioremediation
ISM	Interim stabilization measures
ISRM	*In situ* reduction/oxidation manipulation
ITRC	Interstate Technology Regulatory Council
ITRD	Innovative Technologies for Remediation Demonstration
LNAPL	Light nonaqueous-phase liquid
MCL	Maximum contaminant level
MHC	Mason & Hanger Corporation – Silas Mason Co., Inc.
MNA	Monitored Natural Attenuation
MNX	Mononitrosoamine
MS	MODFLOW-SURFACT
MSC	Media-specific concentration
NA	Natural attenuation
NAPL	Nonaqueous-phase liquid
NEPA	National Environmental Policy Act
NNSA	National Nuclear Security Administration
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NWAR	Nuclear Weapon Accident Residue Storage Unit
NWS	National Weather Service
O&M	Operation and Maintenance
OSTP	Old Sewage Treatment Plant
OU	Operable Unit
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene
PCP	Pentachlorophenol
PGCD	Panhandle Groundwater Conservation District
PGPTS	Perched Groundwater Pump and Treat System
PMU	Playa Management Unit
POTW	Publicly Owned Treatment Works
PPE	Personal protective equipment
PQL	Practical quantitation limit
PRB	Permeable reactive barriers
PRG	Preliminary Remediation Goal
PVC	Polyvinyl chloride
PWPG	Panhandle Water Planning Group
RBSV	Risk-based screening value
RCRA	Resource Conservation and Recovery Act
RDX	Research development explosive (1,3,5-trinitro-1,3,5-triazine)
REACH IT	Remediation and Characterization Innovative Technologies
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RFIR	RCRA Facility Investigation Report
RI	Radiological Investigation
RRR	Risk Reduction Rule
RRRG	Risk Reduction Rule Guidance

ACRONYMS AND ABBREVIATIONS

RRS	Risk Reduction Standards
SAI	Soil-to-air-ingestion
SCADA	Supervisory Control and Data Acquisition
SEED	SERDP Exploratory Development
SERDP	Strategic Environmental Research and Development Program
SITE	Superfund Innovative Technology Evaluation
SLERA	Screening Level Ecological Risk Assessment
SLM	Single layer model
SMCL	Secondary maximum contaminant levels
SRC	Site Relevant Contaminant
SSERA	Site-Specific Ecological Risk Assessment
SVE	Soil vapor extraction
SVOC	Semi-volatile organic compound
SVS	Supplemental Verification Site
SWMU	Solid Waste Management Unit
TAC	Texas Administrative Code
TCE	Trichloroethene
TCEQ	Texas Commission on Environmental Quality
TNRCC	Texas Natural Resource Conservation Commission
TNT	Trinitrotoluene
TNX	Trinitrosoamine
TOC	Total organic carbon
TRRP	Texas Risk Reduction Program
TTRF	Texas Tech Research Farm
TTU	Texas Tech University
UCL	Upper confidence limit
URV	Unit risk value
USACE	United States Army Corps of Engineers
USDOE	United States Department of Energy
USFWS	United States Fish and Wildlife Service
UV	Ultraviolet
VCA	Voluntary corrective action
VOC	Volatile organic compound
WI	Work Instruction
WMG	Waste Management Group
WPA	Work Plan Addendum
WWTF	Wastewater treatment facility

MEASUREMENTS AND CONVERSION

Rounding

Some numbers have been rounded; therefore, sums and products throughout the document may not be consistent. A number was rounded only after all calculations using that number had been made. Numbers that are actual measurements were not rounded.

Metric Conversion Chart

To Convert Into Metric			To Convert Out of Metric		
If You Know	**Multiply By**	**To Get**	**If You Know**	**Multiply By**	**To Get**
Length					
inches	2.54	Centimeters	centimeters	0.3937	inches
feet	0.3048	Meters	meters	3.281	feet
miles	1.60934	Kilometers	kilometers	0.6214	miles
Area					
square feet	0.092903	square meters	square meters	10.7639	square feet
acres	0.40469	Hectares	hectares	2.471	acres
square miles	2.58999	square kilometers	square kilometers	0.3861	square miles
Volume					
gallons	3.7854	Liters	liters	0.26417	gallons
cubic feet	0.028317	cubic meters	cubic meters	35.315	cubic feet
cubic yards	0.76455	cubic meters	cubic meters	1.308	cubic yards
Weight					
pounds	0.45360	Kilograms	kilograms	2.2046	pounds

Units of Measure

°C	degrees Celsius	Lpd	liter per day
°F	degrees Fahrenheit	Lpm	liter per minute
cm	centimeter	L/yr	liter per year
dBA	decibels, A-weighted	m	meter
ft	foot	m^2	square meter
ft^2	square foot	m^3	cubic meter
gal	gallon	mgd	million gallons per day
gpd	gallon per day	mph	miles per hour
gpm	gallon per minute	MW	megawatt
ha	hectare	MWh	megawatt-hour
in	inch	MWhr/yr	megawatt-hour per year
kg	kilogram	PM_{10}	particulate matter with an aerodynamic diameter less than or equal to 10 microns
kph	kilometer per hour	ppb	parts per billion
km	kilometer	ppm	parts per million
lb	pound	yd	yard
L	liters	yd^3	cubic yard

ES.0 EXECUTIVE SUMMARY

This document presents the results of the Corrective Measures Study/Feasibility Study (CMS/FS) conducted for the United States Department of Energy/National Nuclear Security Administration (USDOE/NNSA), Pantex Plant, Amarillo, Texas. The CMS/FS describes how corrective measure alternatives were developed and evaluated for the purpose of proposing a remedial action recommendation. The study focuses on corrective measure alternatives developed to address constituents of concern (COCs) identified in the perched groundwater[1] for a hypothetical current receptor and future protection of the Ogallala Aquifer, a significant and important source of groundwater for the region.

ES.1 SITE INFORMATION AND REGULATORY FRAMEWORK

Pantex Plant is an active facility with a primary mission to: 1) assemble nuclear weapons for the nation's stockpile; 2) disassemble nuclear weapons being retired from the stockpile; 3) evaluate nuclear weapons; 4) develop, fabricate, and test chemical explosives and explosive components for nuclear weapons to support USDOE/NNSA initiatives; and 5) provide storage for plutonium pits from dismantled nuclear weapons. The current mission will continue into the foreseeable future; therefore, land use at Pantex Plant will remain industrial. Further, USDOE/NNSA fully intends to maintain the Pantex Plant for industrial land use under any potential agency mission.

Pantex Plant is also an active permitted hazardous waste facility subject to Resource Conservation and Recovery Act (RCRA) requirements. Following placement on the National Priorities List in 1994, the Plant also became subject to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements. In addition, USDOE/NNSA has issued guidance for integrating National Environmental Policy Act (NEPA) requirements into evaluation of RCRA and CERCLA corrective measures. Therefore, an Environmental Assessment (EA) is being conducted simultaneously with this CMS/FS, completely fulfilling the requirements of NEPA, RCRA, and CERCLA. The EA will be issued as a separate document that provides supporting analysis of the potential impacts associated with implementation of the range of corrective measures represented here.

ES.2 REMEDIAL ACTION OBJECTIVES

Pantex Plant Human Health and Ecological Risk Assessments were conducted to determine the media (soils, groundwater, etc.) and constituents of concern (COCs) that require remedial action. The ecological risk assessment process, including the *Site-Wide Ecological Risk Assessment Report* (BWXT Pantex/SAIC, 2005), did not identify COCs for current and future risks to ecological receptors from exposure at individual corrective action units or on a site-wide basis. Therefore, there was no need to develop corrective measure alternatives for protection of ecological receptors in this CMS/FS.

However, COCs were identified for both perched groundwater and soils, as detailed in the following reports:

- *Baseline Human Health Risk Assessment Report for Zones 10, 11, and 12, Fire Training Area, Ditches and Playas, Independent Sites, and Groundwater for the USDOE/NNSA, Pantex Plant, Amarillo, Texas* (BWXT Pantex/SAIC, 2006)
- *Burning Ground Human Health Risk Assessment Report* (BWXT Pantex, 2005a).

[1] The perched groundwater is the shallowest water-bearing zone in the area and is the first groundwater unit affected by the migration of constituents released from Pantex Plant corrective action units. Vertical flow between the perched groundwater and Ogallala Aquifer is limited by a fine-grained aquitard, referred to as the fine-grained zone.

Specifically, these Human Health Risk Assessment (HHRA) reports identified that the following Pantex Plant media contain COCs requiring further active corrective measures and/or controls:

- Zone 11 soils (polyaromatic hydrocarbons)
- Zone 12 soils (high explosives and polyaromatic hydrocarbons)
- Landfill soils (polyaromatic hydrocarbons)
- Burning Ground soils (high explosives and depleted uranium)
- Perched groundwater (high explosives, volatile organic compounds (VOCs), boron, perchlorate, and total and hexavalent chromium)

A deed recordation will be established for all solid waste management units and areas of concern closing to Risk Reduction Standard 3, including the Nuclear Weapons Accident Residue storage unit that was addressed in a separate HHRA report submitted in January 2006.

Most importantly, the HHRA reports identified that impacted perched groundwater could potentially, in the absence of corrective measures, migrate vertically in areas south and east of Pantex Plant and transport COCs (primarily high explosive compounds) to the Ogallala Aquifer in the future.

Therefore, the Pantex Plant remedial action objectives are:

- Prevent exposure to untreated perched groundwater onsite and offsite to the south and east of Pantex Property.

- Reduce or eliminate the flux of water from the perched groundwater in the southeast area to reduce the potential for COCs to be transported to the Ogallala Aquifer.

- Provide additional monitoring wells in perched groundwater and the Ogallala Aquifer to increase the effectiveness of monitoring for:

    - Changes to nature and extent of COCs in perched groundwater, and;
    - Early detection of perched COCs in the Ogallala Aquifer, should migration occur.

The remedial action objectives were used to develop and evaluate the corrective measure alternatives presented in this CMS/FS.

ES.3 REMEDIES FOR SOIL SOURCES

Voluntary interim corrective measures have been, or are being, implemented to mitigate potential risk to the onsite industrial workers by direct contact primarily through excavation and disposal of impacted soils from the following areas:

- Zone 11
- Zone 12
- Landfills
- Burning Ground.

Potential risk was also identified to the construction worker at Landfill 1, Landfill 13, Burning Ground, and Zone 12. Construction/excavation activities at Pantex Plant are presently managed through the process identified in Pantex Plant work instruction (WI) 02.01.04.03.01, *How to Obtain a Solid Waste Management Unit (SWMU) Interference Notification* (BWXT Pantex, 2005c). If construction activities

are deemed necessary, construction/excavation workers are required to wear proper personal protective equipment appropriate for work performed within the impacted areas, in accordance with the WI. With enforcement of this WI, potential exposure to soil COCs is controlled; therefore, the construction/ excavation worker is protected. A deed record is required in accordance with 30 Texas Administrative Code (TAC) §335.566, *Deed Recordation for Risk Reduction Standard 3*, to provide future notification to others in the unlikely event that the property is sold or transferred.

As a result of the aforementioned factors, additional corrective measure alternatives for soils are not necessary, and technologies to address COCs in soil are not evaluated in this CMS/FS.

ES.4 REMEDIES FOR PERCHED GROUNDWATER

ES.4.1 Alternatives

The COCs identified for perched groundwater are related to its hypothetical potential use as a water source. Although a current direct exposure pathway does not exist from impacted perched groundwater to a receptor, impacted perched groundwater does occur offsite. Risk assessment results also indicate the potential for future migration of impacted perched groundwater to the underlying Ogallala Aquifer. Therefore, perched groundwater COCs were retained for development and assessment of corrective measure alternatives in this CMS/FS. Retained COCs include high explosives, metals (total and hexavalent chromium and boron), perchlorate, and two volatile organic compounds. RDX, a high explosive compound, was identified as the primary risk driver in the HHRA. Evaluation of corrective measures focused on the effectiveness of the remedy to eliminate or reduce, to the greatest extent possible, the migration of impacted perched groundwater to the underlying Ogallala Aquifer. Treatment technologies addressed all perched groundwater COCs in the evaluation of the alternatives.

Several alternatives, both conventional and innovative, were screened on the basis of site, waste, and technical characteristics to focus on the technologies and options that may be feasible to implement to meet the remedial action objectives. Potential groundwater remedial technologies and process options retained through the screening process included land-use controls, monitoring, hydraulic barriers, *in situ/ex situ* biological treatment, *in situ/ex situ* chemical/physical treatment, and onsite and offsite disposal. After analysis of these technologies, alternatives were developed based on experience gained through treatability studies conducted at Pantex Plant, ICMs, ongoing analysis of the existing Perched Groundwater Pump and Treat System (PGPTS), groundwater modeling (Appendix A), site knowledge, and professional engineering judgment. The following alternatives are evaluated for the impacted portions of the perched groundwater:

- Alternative 1: No Action
- Alternative 2: Monitored Natural Attenuation (MNA)
- Alternative 3: Existing Pump and Treat, with MNA
- Alternative 4a: Enhanced Pump and Treat using Horizontal Extraction Wells, with MNA
- Alternative 4b: Enhanced Pump and Treat using Vertical Extraction, with MNA
- Alternative 5: Targeted Treatment with MNA.

Alternatives were evaluated against specific criteria to determine the degree to which each alternative is technologically effective, implementable, and cost-effective. Nine criteria were evaluated to assess the perched groundwater alternatives based on 30 TAC §335.561, *Attainment of Risk Reduction Standard 3: Closure/Remediation with Controls;* 30 TAC §335.562, *Remedy Evaluation Factors for Risk Reduction Standard Number 3;* and 40 CFR §300.430 (e)(9)(iii), *Feasibility Study, Detailed Analysis of Alternatives, Nine Evaluation Criteria.*

The nine evaluation criteria applied for this CMS/FS are:

1. Protection of human health and the environment
2. Attainment of media-specific cleanup standards
3. Control of source releases
4. Compliance with applicable standards for waste management
5. Long-term reliability and effectiveness
6. Reduction in toxicity, mobility, or volume of waste
7. Short-term effectiveness and safety
8. Implementability
9. Cost.

A ranking system was used to compare alternatives against one another. The alternatives are ranked on their ability to meet the first four essential criteria (or threshold criteria) using a "yes" or "no." With the exception of cost, alternatives are ranked on their ability to meet the remaining general decision factors (or balancing criteria) using a scale of 1 to 5. With respect to cost, the present worth for each alternative is listed to allow for a direct comparison of the cost for each alternative.

The alternatives in this CMS/FS are evaluated based on their respective effectiveness in achieving the Pantex Plant remedial action objectives, specifically, reducing the predicted potential migration of RDX-impacted perched groundwater to the underlying Ogallala Aquifer. Each alternative includes controls and measures that break the pathway for potential exposure to impacted groundwater. Alternative 1 requires deed recordation and institutional controls to break the pathway. Alternative 2 relies on monitored natural attenuation, in conjunction with institutional controls, to prevent exposure to impacted groundwater. Alternatives 3 and 4 (4a and 4b) rely on pump and treat to remove perched groundwater and reduce, to the greatest extent possible, the future migration of impacted perched groundwater to the Ogallala Aquifer through a combination of dewatering and enhanced RDX mass removal. The pump and treat alternatives largely target areas where saturated thickness is sufficient to support 30 years of active perched groundwater removal. Alternative 5 focuses *in situ* treatment technologies in areas of thin perched saturation to the south and southeast, where the most significant potential future impacts to the Ogallala Aquifer are predicted.

Following evaluation of the five alternatives to determine if the remedial action objectives could be achieved, additional modeling simulations were conducted to combine the strengths of each alternative and arrive at a recommendation. This recommendation takes into account key features of the site that govern perched groundwater flow. The groundwater mound and greatest saturated thickness beneath and adjacent to Playa 1 represents an area where extraction of large volumes of perched groundwater may be achievable. Reduction of this mound will significantly reduce the upgradient hydraulic head driving the continued migration of impacted perched groundwater to the southeast, thus increasing the long-term effectiveness and reliability of the remedy. However, because of the slope of the fine-grained zone (FGZ) surface and the extent of impacted perched groundwater (especially the large areas of thin saturation offsite to the south and east), additional extraction near Playa 1 alone is not sufficient to meet the RAOs. Similarly, permeability variations in the saturated media indicate areas of higher hydraulic conductivity capable of supporting long-term extraction occurring adjacent to areas of lower hydraulic conductivity. Understanding this heterogeneity is key to effective system design and necessitates the use of exploratory boreholes during the design phase to identify the optimum locations for perched groundwater extraction. Exploratory borings will also be used to further define the variability of the FGZ surface and delineate areas where the FGZ becomes more permeable. The information gained from the exploratory borings may permit a more focused application of *in situ* treatment technologies to mitigate, to the extent possible, the migration of impacted perched groundwater (or any amendments) through the FGZ.

ES.4.2 Recommendation

The recommended alternative consists of enhanced pump and treat with monitored natural attenuation and continued pursuit and periodic reevaluation of targeted *in situ* treatment in the FGZ transition area, southeast of Pantex Plant. This recommendation is based on extensive research, investigation, sampling, analyses, treatability studies, interim corrective measures (such as the perched groundwater pump and treat system), engineering judgment, and fate and transport modeling conducted by Pantex Plant since the late 1980s. In response to community and regulatory concerns expressed during public meetings about groundwater beneath and near Pantex, the recommendation focuses on protecting the Ogallala Aquifer from future impact and increasing the reliability of future detection monitoring in the Ogallala Aquifer as the primary remedial action objectives.

The recommended alternative will eliminate re-injection of treated perched groundwater in the current PGPTS and enhance the extraction capability of the current system with additional wells, using exploratory boreholes to guide their placement. Figure ES-1 depicts the components of the recommended alternative, which are presented as follows:

- Continued use of the current perched groundwater extraction wells for 30 years, with no re-injection
- Installation of 25 new vertical extraction wells to enhance extraction of perched groundwater
- Expansion of the treatment capacity of the current system to 590,000 gpd of perched groundwater
- Irrigation of crops with treated perched groundwater
- Augmentation of the current groundwater monitoring well network with the installation of two additional monitoring wells in perched groundwater and eight additional monitoring wells in the Ogallala Aquifer
- Deed restrictions and other institutional controls to restrict the use of perched groundwater onsite and offsite to the south and east of Pantex Plant
- Natural attenuation processes.

Eliminating re-injection of treated perched groundwater substantially improves the performance of the existing PGPTS by decreasing the hydraulic gradient to the southeast. The reduced gradient decreases the perched groundwater velocity and the rate of COC migration resulting in more time for natural attenuation to occur. Modeling simulations indicate that a two- to three-fold reduction in the mass of COCs exiting the perched groundwater zone can be achieved by enhancing the existing PGPTS with no re-injection. For these reasons, the injection wells for the existing PGPTS will be eliminated from the PGPTS and are not included on Figure ES-1. Also, the additional proposed Ogallala Aquifer monitoring wells are located outside the footprint of the impacted perched groundwater. This proposed placement mitigates the potential for cross-contamination and creation of preferential pathways for migration of COCs to the Ogallala Aquifer during well installation.

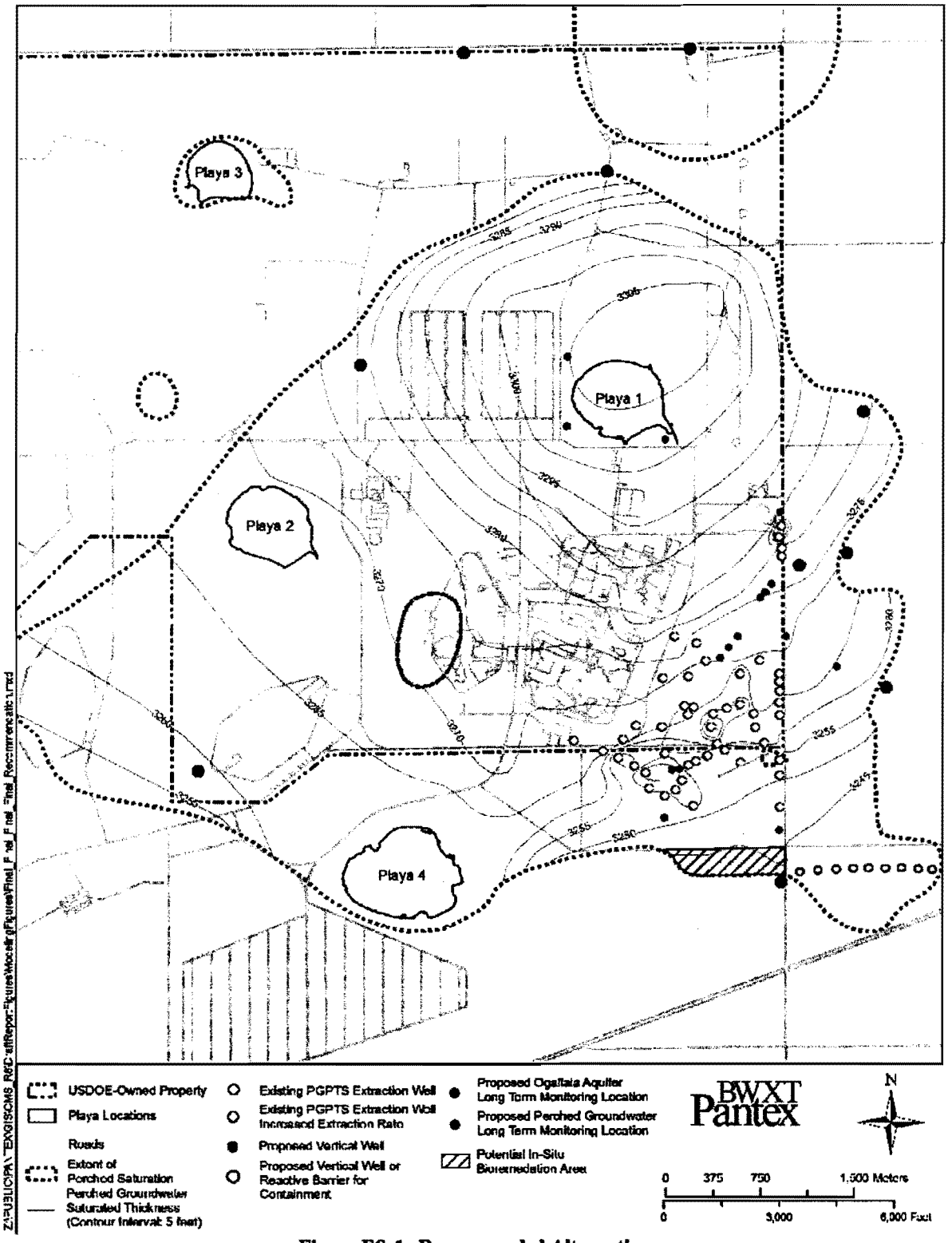


Figure ES-1. Recommended Alternative

1.0 INTRODUCTION

This report documents the Corrective Measure Study/Feasibility Study (CMS/FS) conducted at the United States Department of Energy/National Nuclear Security Administration (USDOE/NNSA) Pantex Plant, Amarillo, Texas (Figure 1-1). This CMS/FS describes the development, screening, and evaluation of corrective measure alternatives.

Soil and groundwater constituents of concern (COCs) were identified in the baseline risk assessments (BRAs) (Section 1.3.3) as posing unacceptable, or potentially unacceptable, risk to current and future receptors. Soils posing these risks are being excavated as part of the voluntary Interim Corrective Measures (ICMs) being implemented; therefore, further evaluation of corrective measures for soil COCs was not conducted and only groundwater COCs were carried forward in this CMS/FS. Media-specific concentrations (MSCs) were calculated for perched groundwater COCs requiring an assessment of corrective action. Alternatives are evaluated in this CMS/FS for site-wide perched groundwater.

The following sections provide brief descriptions of the regulatory initiatives, establish the purpose and scope of this CMS/FS, summarize studies and actions conducted to date, and present the organization of this report.

1.1 REGULATORY INITIATIVES

Pantex Plant is an active permitted hazardous waste facility subject to Resource Conservation and Recovery Act (RCRA) requirements. The United States Environmental Protection Agency (EPA) and the Texas Commission on Environmental Quality (TCEQ) (formerly Texas Natural Resource Conservation Commission [TNRCC]) jointly issued a Hazardous Waste Permit (HW-50284) to Pantex Plant in 1991, which authorized storage and processing of hazardous waste.

In response to receiving authority under the 1984 Hazardous and Solid Waste Amendments to RCRA, EPA conducted a *RCRA Facility Assessment* (RFA) *Visual Site Inspection Report* (EPA, 1989) of Pantex Plant in January 1988, to identify Solid Waste Management Units (SWMUs)/Areas of Concern (AOCs) that may require investigation and possible corrective action. In December 1990, an Administrative Order on Consent was signed by EPA and USDOE that outlined the requirements for ICMs, RCRA Facility Investigations (RFIs), CMSs, and corrective measure implementations (CMIs) at Pantex Plant based on operable units (OUs). The OUs were assigned based on the types of processes previously conducted at the units and expected constituents of potential concern (COPCs). The corrective action process for the OUs was to be implemented on independent schedules. In May 1994, Pantex Plant was added to the National Priorities List (NPL); therefore, Pantex Plant must meet applicable requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and RCRA.

The Hazardous Waste Permit was modified and replaced in 1996 by a Permit for Industrial Solid Waste Management Site issued by TCEQ, as TCEQ received RCRA authority from EPA, and the requirements outlined in the Administrative Order for performing ICMs, RFIs, CMSs, and CMIs were incorporated into the modified permit. In June 2003, TCEQ issued a *Compliance Plan for Industrial Solid Waste* (herein referred to as the *Compliance Plan*) (TCEQ, 2003d) for Pantex Plant under the Hazardous Waste Permit in conjunction with the Permit for Industrial Solid Waste Management Site. The *Compliance Plan* (TCEQ, 2003d) replaced the Hazardous Waste Permit corrective action and groundwater monitoring requirements and included requirements for evaluation of interim stabilization measures (ISMs).

During the initial stages of investigation, RFIs were conducted by OUs, as outlined in the Administrative Order on Consent and the previous Hazardous Waste Permit requirements. Under the current *Compliance*

Plan (TCEQ, 2003d), RFIs, CMSs, and ICMs are conducted according to a zone/Waste Management Group (WMG) approach. Under this approach, the units were grouped into WMGs according to spatial proximity. The WMGs were combined into an RFI Report (RFIR) for each major operational zone at Pantex Plant, where possible (e.g., WMG 1 in Zone 11). The application of the zone/WMG concept is considered a more appropriate approach to the evaluation of SWMUs and AOCs (herein collectively referred to as corrective action units) because it allows for characterization of commingled plumes from corrective action units in close spatial proximity.

1.1.1 State of Texas Risk Reduction Rule

The investigation, cleanup, and closure of corrective action units for chemical COPCs are completed under the Risk Reduction Rule (RRR) found in 30 (Texas Administrative Code) TAC §335, Subchapter S codified in 1993. Although the RRR has been replaced by the Texas Risk Reduction Program (TRRP), which can be applied to remediation projects subsequent to the applicability date of May 1, 2000, Pantex Plant remains grandfathered under the RRR. The RRR provides three Risk Reduction Standards (RRS) (RRS 1, RRS 2, and RRS 3) for closure as described below. Subchapter S contains the regulations to determine and apply the RRS. The TCEQ *Consistency Document for Implementation of the Existing Risk Reduction Rule* (TNRCC, 1998) provides further detailed information for implementing the RRR.

- **RRS 1: Closure/remediation to background or practical quantitation limit (PQL).** Under RRS 1, the most stringent level, all waste and/or contaminated environmental media must be remediated to background concentrations unaffected by waste management or industrial activities, as specified in 30 TAC §335.554. Cleanup levels for RRS 1 are comprised of background concentrations for naturally-occurring constituents determined from media unaffected by waste management, industrial activities, or laboratory PQLs, defined in 30 TAC §335.552, as the lowest concentration of an analyte that can be reliably quantified within specified limits of precision and accuracy during routine laboratory operating conditions for non-naturally-occurring constituents or naturally-occurring constituents with background concentrations lower than the PQL.

- **RRS 2: Closure/remediation to health-based standards and criteria following the procedures specified in 30 TAC §335.555, to provide appropriate protection for human health or the environment.** RRS 2 values are based on promulgated standards (e.g., maximum contaminant levels [MCLs]) or cleanup values established in 30 TAC §335.556 through §335.559. The calculations used to establish the RRS 2 cleanup values are the same for all corrective action units and are based on exposure to one constituent in one exposure medium. Thus, the RRS 2 cleanup values do not account for site-specific factors or the presence of more than one COPC. Closure under RRS 2 also requires an ecological evaluation, starting with the initial ecological screening detailed in TCEQ guidance.

- **RRS 3: Closure/remediation with controls.** RRS 3 compliance requires the remedy to achieve the highest degree of long-term effectiveness possible, considering cleanup objectives and costs, and the remedy must achieve media cleanup requirements specified in 30 TAC §335.563. Under RRS 3, cleanup values can be derived using site-specific information for land use and associated potential receptors, but these cleanup values must consider multiple COPCs within the medium and exposure to multiple contaminated media, when necessary. Furthermore, COPCs can be left in place as long as the risk posed by those COPCs is not greater than the target risk values provided in 30 TAC §335.563. Media cleanup requirements under RRS 3 also allow the use of long-term site controls (e.g., institutional or engineering controls) to attain regulatory compliance.

Unlike RRS 2 closure, RRS 3 closure requires a BRA that addresses both human health and ecological risks to evaluate potential adverse effects under both current and future conditions from COPCs at a site in the absence of any action to control or mitigate the release. When a permanent COPC removal technology (e.g., soil composting or soil removal) has been implemented, current site conditions (i.e., remediated conditions) will serve as the baseline for calculating risks. RRS 3 also requires a CMS to evaluate the abilities and effectiveness of remedial actions and to recommend the remedial action that best achieves the requirement of RRS 3.

Radionuclides fall under EPA authority, and a separate process similar to the RRR was utilized to define the nature and extent of radionuclides and to determine the need for remediation or inclusion in a BRA. Similar to the RRR, backgrounds for naturally-occurring radionuclides were established and used to screen out potential radiological areas that do not contain COPCs. Preliminary remediation goals (PRGs) that are protective of industrial workers and construction/excavation workers were developed using the online EPA PRG calculator. The measured concentrations of radiological site relevant contaminants (SRCs) at potential radiological areas were compared to backgrounds and PRGs to determine areas that required analysis in the BRA. The process and results of the radiological investigation and characterization are included in the *Final Pantex Plant Radiological Investigation (RI) Report* (herein referred to as the *RI Report*) (BWXT Pantex, 2004a).

1.1.2 Comprehensive Environmental Response, Compensation, and Liability Act

In 1994, Pantex Plant was added to the NPL for chemical constituents, requiring compliance with CERCLA through interactions with the EPA (Region VI). Achieving closure under both CERCLA and RCRA required development of an integrated process to ensure objectives mandated by CERCLA were considered with those for RCRA (BPX-MHC, 1996a). Accordingly, this study was conducted with consideration of CERCLA requirements presented in Title 40 of the Code of Federal Regulations, Section 300.430 (e) and is, therefore, recognized as a CMS/FS. In this integrated approach, TCEQ has primary responsibility for RCRA chemical constituents and EPA has primary responsibility for radiological constituents.

1.1.3 National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires Federal agencies to consider the environmental consequences of their proposed actions before decisions are made. The decisions must be based on alternatives that consider, in part, detailed information concerning potential significant environmental impacts. USDOE/NNSA has issued guidance on incorporating NEPA values into documents prepared pursuant to CERCLA and RCRA. Thus, an accompanying Environmental Assessment (EA) that evaluates the alternatives proposed in this CMS/FS is required prior to deciding which alternatives should be implemented. The EA evaluates the corrective measure options for groundwater remediation and identifies whether significant impacts to a broad spectrum of environmental factors are associated with implementation of the options.

1.2 Purpose and Objectives of this Corrective Measure Study/Feasibility Study

The purpose of this CMS/FS is to identify and evaluate alternative technologies and options for attaining the remedial action objectives (RAOs) defined below for the Pantex Plant. Soil COCs are briefly summarized in Section 3; however, since voluntary ICMs are being implemented to remedy soils impacted by COCs, this CMS/FS focuses primarily on COCs in perched groundwater. In general, the perched groundwater beneath Pantex Plant and adjacent to the southern and eastern property boundaries

has been impacted by historical industrial wastewater discharges containing COCs that would pose an unacceptable risk to onsite and offsite receptors if it were used without treatment. Furthermore, this impacted perched groundwater could potentially affect the underlying Ogallala Aquifer in the absence of remedial actions/corrective measures designed to stabilize and control migration of the COCs that it contains. This CMS/FS is designed to balance the requirement for a thorough examination of remedial alternatives with the need to provide expeditious initiation of remedies and corrective action. This CMS/FS evaluates several types of alternative technologies and options including remedial actions, institutional controls, and the No Action alternative to determine which alternative will meet RAOs. The remedial action/corrective measure objectives are:

- Prevent exposure to untreated perched groundwater onsite and offsite to the south and east of Pantex Property.
- Reduce or eliminate the flux of water from the perched groundwater in the southeast area to reduce the potential for COCs to be transported to the Ogallala Aquifer.
- Provide additional monitoring wells in the perched groundwater and Ogallala Aquifer to increase the effectiveness of monitoring for:
    - Nature and extent of COCs in the perched groundwater, and;
    - Detection of perched COCs in the Ogallala Aquifer, should migration occur.

The alternatives are evaluated against specific criteria to determine the degree to which each alternative is technologically effective, implementable, and cost-effective, i.e., capable of achieving the aforementioned remedial action/corrective measure objectives. The specific criteria are:

1. Protection of human health and the environment
2. Attainment of media-specific cleanup standards
3. Control of source releases
4. Compliance with applicable standards for waste management
5. Long-term reliability and effectiveness
6. Reduction in toxicity, mobility, or volume of waste
7. Short-term effectiveness and safety
8. Implementability
9. Cost.

The specific objectives of this CMS/FS are to:

- Identify and screen technologies and options for perched groundwater remediation.
- Identify feasible alternatives for groundwater remediation, analyze selected alternatives, and recommend the alternative which best achieves the criteria presented above.

This CMS/FS uses data describing the site and constituent characteristics collected during RFIs, ICMs, and BRAs (Section 1.3.3) performed at Pantex Plant.

1.3 RESOURCE CONSERVATION AND RECOVERY ACT PROCESS HISTORY

The following sections describe the RCRA process history for corrective action units at Pantex Plant (Table 1-1) including RFIs and BRAs. Requirements mandated under CERCLA are integrated into the RCRA process (BPX/MHC, 1996a). The RCRA corrective action process is illustrated in Figure 1-2. The RFIRs summarized characterization activities and RRS closure recommendations for the corrective action units. Corrective action units closing to RRS 3 were further analyzed in the BRAs to determine whether the constituents at those units posed a potential risk to human or ecological receptors.

1.3.1 Resource Conservation and Recovery Act Facility Investigations

RFIs were conducted for various zones/WMGs and corrective action units at Pantex Plant, as detailed in the RFIRs. The RFIRs summarized site characterization activities, defined sources, described the nature of contamination, and presented the extent of each COPC. The RFIRs identified chemical COPCs to be evaluated in the Pantex Plant BRAs (Section 1.3.3).

The RFIRs were completed following the approach and methodology in 30 TAC §335, Subchapter S, and the *Risk Reduction Rule Guidance* (RRRG) documents for Pantex RFIs (BWXT Pantex, 2002a; BWXT Pantex, 2002b; USDOE, 1999a; USDOE, 1999b). The following RFIRs were completed and approved by TCEQ:

- **Fire Training Area:** *Final RCRA Facility Investigation Report for the Fire Training Area* (FTA) (herein referred to as the *FTA RFIR*) (Stoller, 2002b)
- **Burning Ground:** *Burning Grounds Waste Management Group Final RCRA Facility Investigation Report* (herein referred to as the *Burning Ground RFIR*) (Stoller, 2002a)
- **Zone 10:** *Final RCRA Facility Investigation Report, Zone 10 at DOE Pantex Plant* (herein referred to as the *Zone 10 RFIR*) (Stoller, 2003b)
- **Zone 11:** *Final RCRA Facility Investigation Report for Zone 11 at DOE Pantex Plant* (herein referred to as the *Zone 11 RFIR*) (Stoller, 2003c)
- **Zone 12:** *Final RCRA Facility Investigation Report, Zone 12 at DOE Pantex Plant* (herein referred to as the *Zone 12 RFIR*) (Stoller, 2003d)
- **Ditches and Playas:** *Final RCRA Facility Investigation Report, Ditches and Playas at USDOE Pantex Plant* (herein referred to as the *Ditches and Playas RFIR*) (Stoller, 2003a)
- **Groundwater:** *Pantex Plant Final RCRA Facility Investigation Report, Groundwater, USDOE Pantex Plant* (herein referred to as the *Groundwater RFIR*) (Stoller, 2004b)
- **Independent Sites:** *Final RCRA Facility Investigation Report for Independent Sites at USDOE Pantex Plant* (herein referred to as the *Independent Sites RFIR*) (Stoller, 2004a).

1.3.2 Radiological Investigation Report

The process and results of the RI and characterization are included in the *RI Report* (BWXT Pantex, 2004a). The *RI Report* presents a comprehensive assessment of all radiological issues at Pantex Plant and facilitates site radiological closure. The *RI Report* identified SRCs that are above background screening

criteria as COPCs, which were further evaluated in a BRA. The *RI Report* identified potential radiological sites based on a historical site assessment. Radiological data from the sites identified as potential radiological sites were compared to site-specific background and/or PRGs. The *RI Report* concluded only the Burning Ground required further evaluation for radionuclides in a baseline human health risk assessment (HHRA), since a separate HHRA had already been performed for Firing Site 5. However, as a conservative measure, any RRS 3 site identified as a potential radiological site was further evaluated in a BRA. One additional SWMU, the Building 12-1 Laundry Sump, was not evaluated in a baseline HHRA as the samples indicating the presence of depleted uranium were collected in a sump and the sediment has been removed. Soil samples collected outside and adjacent to the sump provided no indication of a release.

1.3.3 Pantex Plant Baseline Risk Assessments

This CMS/FS utilizes risk evaluation results and conclusions, including the identification of COCs defined for Pantex Plant as COPCs causing potentially unacceptable carcinogenic and noncarcinogenic risks, from the following reports to assist the identification and evaluation of alternative remedial measures:

- *Draft Final Risk Assessment, Firing Site 5* (FS-5), *USDOE, Pantex Plant* (herein referred to as *FS-5 Risk Assessment*) (BPX/MHC, 1999b)
- *Burning Ground Human Health Risk Assessment Report for the USDOE/NNSA, Pantex Plant, Amarillo, Texas* (herein referred to as *Burning Ground HHRA Report*) (BWXT Pantex, 2005a)
- *Nuclear Weapon Accident Residue Storage Unit (NWAR) Human Health Risk Assessment Report* (herein referred to as *NWAR HHRA Report*) (BWXT Pantex, 2005b)
- *Baseline Human Health Risk Assessment Report for Zones 10, 11, and 12, Fire Training Area, Ditches and Playas, Independent Sites, and Groundwater for the USDOE/NNSA, Pantex Plant, Amarillo, Texas* (herein referred to as *Baseline HHRA Report*) (BWXT Pantex/SAIC, 2006)
- *Site-Wide Ecological Risk Assessment (ERA) Report for the USDOE/NNSA, Pantex Plant* (herein referred to as *Site-Wide ERA Report*) (BWXT Pantex/SAIC, 2005).

The Pantex Plant BRAs were conducted in accordance with approved work plans. The *FS-5 Risk Assessment* utilized the *Final Report, BRA Work Plan* (BPX/MHC, 1998b). The remaining BRAs were conducted in accordance with the *Revised Final BRA Work Plan* (BWXT Pantex/SAIC, 2003). The following sections summarize the purpose and scope of the BRA reports. Results from the BRAs are summarized in Section 3.1 of this report.

1.3.3.1 Firing Site 5 Risk Assessment

The *FS-5 Risk Assessment* (BPX/MHC, 1999b) evaluated risk from exposure to depleted uranium under current and future land use scenarios. Carcinogenic risk calculations were performed following the methodology presented in the *Final Report, BRA Work Plan* (BPX/MHC, 1998b) and *Draft-Final BRA Report* (BPX/MHC, 1999a). Risk calculations for onsite mower/groundskeeper and construction/ excavation worker were performed for the current land use conditions, while the onsite resident farmer land use condition was used for future risk calculations. Uranium was not detected above background in groundwater, so this pathway was not evaluated for the current receptor scenarios. However, exposure

parameters used to calculate risk for future land use assumed direct exposure to depleted uranium in soil and potential migration of depleted uranium to groundwater as a result of leaching.

In the *FS-5 Risk Assessment*, risk calculations for future land use were conservatively developed assuming the site would be used for residential purposes (resident farmer). However, the future planned use for the FS-5 site is limited to industrial land use only.

The *FS-5 Risk Assessment* for the current and future receptors showed that the concentrations of isotopic uranium did not exceed the target cancer risk level of one-in-one million (1.0E-06). Noncarcinogenic risk was not evaluated in the *FS-5 Risk Assessment*. The noncarcinogenic risk assessment was completed and presented as Appendix K of the *RI Report* (BWXT Pantex, 2004a). For the current receptors (mower/groundskeeper and construction/excavation worker) the noncarcinogenic risk did not exceed the target hazard index (HI) level of 1. No COCs were identified in soil or groundwater at FS-5.

1.3.3.2 Burning Ground Human Health Risk Assessment

Potential risks to onsite and offsite human receptors that may be exposed to contaminated media at the Burning Ground were evaluated and presented in the *Burning Ground HHRA Report* (BWXT Pantex, 2005a). The following receptors were evaluated, based on the approved *Revised Final BRA Work Plan* (BWXT Pantex/SAIC, 2003):

- Onsite industrial worker under current and future exposure conditions
- Onsite construction/excavation worker under current and future exposure conditions
- Offsite resident farmer under future exposure conditions.

Future exposures were evaluated through fate and transport modeling of subsurface and atmospheric migration pathways. Onsite and offsite future scenarios consider the potential for impacts to groundwater in the Ogallala Aquifer by the way of cross-media migration from constituents in soil, soil gas, perched groundwater, and surface water. Offsite future scenarios also consider potential impacts to offsite receptor locations by atmospheric transport mechanisms from onsite releases of soil gas and soil particulates.

The applicable final RFIRs, the *RI Report* (BWXT Pantex, 2004a), and the TCEQ conditional approval letter (TCEQ, 2003b) for the *Burning Ground RFIR* were used to determine COPCs for evaluation in the Burning Ground HHRA. COPCs were identified in soil, soil gas, surface water, and perched groundwater at the Burning Ground. No COPCs were identified in the Ogallala Aquifer based on the current monitoring network, although non-trending sporadic detections of constituents occur at low, non-actionable concentrations below regulatory screening levels. No COPCs were identified in any offsite media.

The Burning Ground HHRA identified trinitrotoluene (TNT), Research Development Explosive (1,3,5-trinitro-1,3,5-triazine [RDX]), and ^{238}U as COCs in soils (Section 3.1.1). No COCs were identified in groundwater.

1.3.3.3 Nuclear Weapon Accident Residue Storage Unit Human Health Risk Assessment

The *NWAR HHRA Report* (BWXT Pantex, 2005b) documented the results of additional investigations completed to define the nature and extent of residual contamination following completion of ICMs, and presented cumulative risks for all COPCs at NWAR after all ICMs were completed. The NWAR HHRA was conducted in accordance with the methodology described in the approved *Revised Final BRA Work Plan* (BWXT Pantex/SAIC, 2003). The *NWAR HHRA Report* included an evaluation of the soil-to-

groundwater pathway to assess the possibility of COPC migration to potential receptors by way of the groundwater pathway. No COCs were identified in soil (for direct contact or soil-to-groundwater transport) or groundwater.

1.3.3.4 Baseline Human Health Risk Assessment

The *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) evaluated potential risks to onsite and offsite human receptors that may be exposed to contaminated media at Pantex Plant corrective action units closing to RRS 3 including WMGs, SWMUs, Supplemental Verification Sites (SVSs), and AOCs grouped by the following locations:

- Zone 10
- Zone 11
- Zone 12
- FTA
- Ditches
- Playas
- Independent Sites (Landfills).

Risk for each receptor/exposure pathway combination for each corrective action unit was evaluated in the *Baseline HHRA Report* in accordance with the approved *Revised Final BRA Work Plan* (BWXT Pantex/SAIC, 2003). The Baseline HHRA examined COPCs identified in the RFIRs and the *RI Report* (BWXT Pantex, 2004a) for soil, soil gas, and perched groundwater. Additionally, for RFIRs submitted prior to the end of 2003, all metals were re-screened and considered for addition to the list of COPCs because updated background values were derived following completion of those RFIRs. No COPCs were identified in the Ogallala Aquifer based on the current monitoring network, although non-trending sporadic detections of constituents occur at low, non-actionable concentrations below regulatory screening levels.

The Baseline HHRA quantified and evaluated potential risks to the following receptors:

- Onsite industrial worker under current and future exposure conditions
- Onsite construction/excavation worker under current and future exposure conditions
- Offsite resident farmer under future exposure conditions.

Current risks were evaluated using measured COPC concentrations in soils and perched groundwater. As developed in the approved *Revised Final BRA Work Plan* (BWXT Pantex/SAIC, 2003), the soil exposure area for active operational areas of Pantex Plant was 6 acres, and the exposure area for inactive operational areas was 12 acres. Because no current exposure pathways are complete for perched groundwater (there are no water supply wells currently completed in areas of impacted perched groundwater), a hypothetical current exposure to perched groundwater was evaluated.

Evaluation of potential future risk was assessed using fate and transport modeling to determine whether COPCs may migrate to points-of-exposure and to estimate future COPC concentrations at these points-of-exposures. Subsurface and atmospheric migration pathways evaluated in the *Baseline HHRA Report* include:

- Potential impacts to the Ogallala Aquifer from COPCs in soil, soil gas, and perched groundwater for onsite workers and offsite resident farmers.

- Potential impacts to offsite receptor locations by atmospheric transport mechanisms from onsite releases of soil gas and soil particulates using a qualitative approach from the *Burning Ground HHRA Report* (BWXT Pantex, 2005a) for offsite resident farmers.

Soil COCs identified in the *Baseline HHRA Report* include polycyclic aromatic hydrocarbons (PAHs), lead, RDX, and TNT (Section 3.1.2.1). COCs were identified in current and future perched groundwater (boron, TNT, RDX, and degradation products) and future Ogallala Aquifer (2,4-dinitrotoluene [DNT] and RDX) (Section 3.1.2.2).

1.3.3.5 Site-Wide Ecological Risk Assessment

The *Site-Wide ERA Report* (BWXT Pantex/SAIC, 2005) presented the results of the site-wide ERA conducted at Pantex Plant to evaluate potential impacts to ecological receptors. The ERA followed the approach and methodology presented in the approved *Final Site-Wide ERA Work Plan Addendum (WPA) to the BRA Work Plan* (herein referred to as the *Site-Wide ERA WPA*) (BWXT Pantex, 2004b) and includes a summary of all Tier 1 and Tier 2 ERA activities conducted at Pantex Plant.

Tier 1 Exclusion Criteria Checklists are used to evaluate the need for and scope of further ERA activities at corrective action units. For corrective action units requiring further ecological risk evaluation beyond the Tier 1 checklist, a Tier 2 Screening Level Ecological Risk Assessment (SLERA) and/or a Tier 3 Site-Specific Ecological Risk Assessment (SSERA) may be performed (TNRCC, 2001).

Tier 1 Ecological Exclusion Criteria Checklists were completed for each corrective action unit at Pantex Plant and included in the appropriate RFIRs (i.e., Burning Ground, Zone 10, Zone 12, Ditches and Playas, or Independent Sites). The Tier 1 checklists for the playas and associated ditches are included in the *Ditches and Playas RFIR* (Stoller, 2003a) and the *Burning Ground RFIR* (Stoller, 2002a). Corrective action units that passed the Tier 1 Exclusion Criteria Checklist received no further ecological evaluation. Corrective action units that failed the Tier 1 Exclusion Criteria Checklist were evaluated in a Tier 2 SLERA. Tier 2 SLERAs for corrective action units occurring outside the playas were reported in the RFIRs and summarized in the *Site-Wide ERA Report*. As a result of these Tier 2 SLERAs, no further action from an ecological perspective was recommended at these sites.

The Tier 1 checklists identified the need for further ecological assessment (i.e., Tier 2 SLERA) at Playas 1, 2, 3, and 4, Pantex Lake, and associated ditches due to the identification of complete soil, sediment, and surface water exposure pathways. The *Site-Wide ERA Report* (BWXT Pantex/SAIC, 2005) focused on potential current and future risks at Playas 1, 2, 3, and 4, Pantex Lake, and associated ditches, because the playas represent the most significant habitat for ecological receptors and serve as final repositories of surface water drainage from watershed areas containing corrective action units at Pantex Plant.

Individual Tier 2 SLERAs were conducted for Playas 1, 2, 3, and 4, Pantex Lake, and associated ditches. These SLERAs identified whether ecological receptors are potentially at risk from constituents remaining from legacy releases based on default exposure assumptions and literature-based effects levels and, if at risk, identified the constituents and ecological receptors of potential concern for each of these playas. The SLERAs evaluated constituents in surface soil, sediment, and surface water at each of these five playas and their associated ditches.

In addition, four of the playas (Playas 1, 2, 3, and 4) were grouped together for the site-wide evaluation. The site-wide evaluation used the same basic approach as the Tier 2 SLERAs for the individual playas, but focused on higher trophic level receptors capable of foraging at more than one playa. Although Pantex Lake was included in the individual corrective action unit analyses, it was excluded from the site-wide analysis because of its history and distance from the other playas. The benefit of the site-wide

assessment is a more accurate, comprehensive, and realistic evaluation of the risk to wide-ranging receptors that integrates exposure over multiple corrective action units.

Both the individual and cumulative site-wide Tier 2 SLERAs evaluated three scenarios: dry playa, wet playa, and dry/wet playa. The receptors evaluated included representatives from each of the foraging/lifestyle guilds at Pantex Plant, and included surrogate species for threatened and endangered species identified at Pantex Plant. Risks to these receptors were calculated for exposure to COPCs in surface soil, sediment, and surface water.

COPCs evaluated in the Tier 2 SLERAs are chemicals at concentrations that may affect ecological receptors and are considered site-related. Current risk was evaluated using measured concentrations in soils, sediment, and surface water of the ditches and playas. Evaluation of potential future risk was assessed using sediment transport modeling to determine whether contaminated sediments currently in upland source areas and/or ditches are migrating to the playas and if migration could cause COPC concentrations at the playas to increase in the future. Additionally, future water concentrations and risks to aquatic receptors were evaluated using predicted sediment concentrations.

No COCs requiring further evaluation were identified in the *Site-Wide ERA Report* (BWXT Pantex/SAIC, 2005) (Section 3.1).

1.4 ORGANIZATION OF REPORT

This report describes current conditions at Pantex Plant, including COCs contributing risk to human or ecological receptors, and presents the identification, screening, development, assessment, and selection of corrective measure alternatives for impacted media.

This report is organized as follows:

- Section 2 presents the environmental setting for Pantex Plant including facility background, environmental aspects, land use, and potential receptors.
- Section 3 presents the current conditions at Pantex Plant including BRA results, previous ICMs, and nature and extent of contamination.
- Section 4 presents the identification and screening of remedial technologies and development of corrective measure alternatives.
- Section 5 presents summaries of treatability studies previously and currently being performed at Pantex Plant.
- Section 6 presents the methods for assessment of alternatives.
- Section 7 presents the alternative evaluation, analysis, and recommended corrective measure alternative for perched groundwater.
- Section 8 lists references cited in this report.

Detailed supporting information is included in Appendices A and B as follows:

- Appendix A presents the fate and transport modeling for the perched groundwater evaluation.
- Appendix B presents the detailed cost estimates for the corrective measure alternatives.

Table 1-1. Status of Corrective Action Units at Pantex Plant

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 10	WMG 12	SWMU 143 - Former Waste Drum Storage Areas (Buildings 10-9 & 10-7)	--	--	X	N	Y[c]	Y	N	--	--
		SWMU 144 - Zone 10 TNT Settling Pit (Building 10-13)	--	--	X	N	Y	Y	Y	X	--
		SWMU 145 - Zone 10 TNT Settling Pit (Building 10-17)	--	--	X	N	Y	Y	Y	X	--
		SWMU 146 - Zone 10 TNT Settling Pit (Building 10-26)	--	--	X	N	Y[c]	Y	Y	X	--
		SWMU 68d - Sanitary Landfill	--	--	X	Y	Y	Y	Y	--	--
		SVS 8 - Abandoned Zone 10 Landfill	--	--	X	Y	Y	Y	Y	X	--
		SVS 3 (SWMU 67) - Carbon Black Burial Area near Building 10-7	--	--	X	N	N[d]	Y	N	--	--
		SWMU 84 - Scrap, Salvage, and Storage Yard (Building 10-9)	--	--	X	N	Y	Y	N	X	--
		AOC 3a - Zone 10 Former Boiler House Areas	--	--	X	N	N[d]	Y	N	--	--
		AOC 14 - Battery Storage Area (Building 12-18)	--	--	X	N	Y[c]	Y	N	--	--
		Unassigned AOC - Zone 10 Landfills located West and Southwest of SWMU 84 Scrap and Salvage Yard	--	--	X	N	Y	Y	Y	--	--
		Unassigned SWMU - Zone 10 Berms	--	--	X	N	Y	Y	Y	--	--
Zone 11	WMG 1	AOC 8a - Pad 11-12 Solvent Leaks	--	--	X	N	Y	Y	N	--	--
		AOC 8b - Pad 11-13 Solvent Leaks	--	--	X	N	Y	Y	N	--	--
		SVS 2 - Parallel Depressions Near Building 11-26	--	--	X	N	Y	Y	N	--	--
		SVS 5 - Zone 11 Landfill East of Pad 11-13	--	--	X	N	Y	Y	N	--	--
		SWMU 147 – Building 11-13 TNT Settling Pit	--	--	X	N	Y	Y	N	X	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 11 (continued)	WMG 1 (continued)	SWMU 149 – Building 11-26 TNT Settling Pit	--	--	X	N	Y	Y	N	--	--
		SWMU 150 - Building 11-12 TNT Settling Pit	--	--	X	N	Y	Y	N	X	--
		SWMU 60 - Landfill 9	--	--	X	N	Y	Y	N	--	--
		SWMU 61 - Landfill 10	--	--	X	N	Y	Y	N	--	--
	WMG 2	AOC 1 - Transformer Leak (Building 11-14A)	--	--	X	N	Y	Y	N	X	--
		AOC 8c - Building 11-17 Solvent Leaks	--	--	X	N	Y	Y	N	X	--
		Unassigned SWMU - 11-14 Hypalon Pond and Wastewater Line to the 11-14 Hypalon Pond	*Closure Approved 1995*					N	N	X	--
		SWMU 86 - 11-14 Solvent Storage Shed	--	--	X	N	Y	Y	N	--	--
		SWMU 129a - HE Contaminated Sludge Containers, Building 11-44	*Administrative Closure Approved 2001*					N	N	--	--
		Building 11-44 Wastewater Treatment Units:									
		SWMU 117 - High Explosives Settling Tank	*Partial Closure Approved 1994*					Y	N	X	--
		SWMU 118 - Equalization Basin	*Closure Approved 2002*					N	N	X	--
		SWMU 119a - High Explosives Filters	*Partial Closure Approved 1994*					Y	N	X	--
		SWMU 120a - Carbon Filters	*Partial Closure Approved 1994*					Y	N	X	--
		SWMU 148 – Building 11-17 TNT Settling Pits	--	--	X	N	Y	Y	N	X	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 11	WMG 2 (continued)	SWMU 3 - Drainage Ditch (Building 11-44)	–	–	X	N	Y	Y	N	X	--
		SWMU 12 - Drainage Ditch Near Former 11-14 Pond	–	–	X	N	Y	N	N	X	--
	WMG 3	AOC 8d – Pad 11-22 Solvent Leaks	--	–	X	N	Y	Y	N	–	--
		AOC 8e - Building 11-36 Solvent Leaks	–	–	X	N	Y	Y	N	–	--
		AOC 7a - Building 11-36 Sulfuric Acid Spills	–	–	X	N	Y	Y	N	–	--
		SWMU 5-08 - Drainage Ditch (Building 11-36)	–	–	X	N	Y	Y	N	X	--
		SWMU 111 and 112 - Building 11-36 Solvent Tanks	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 113 - Overflows from Building 11-36 Collection System/Sump	–	–	X	N	Y	Y	N	X	--
		SWMU 114 - Building 11-36 Scrubber System	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 115 - Building 11-36 Carbon Filter	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 116 - Building 11-36 Sludge Filters	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 130 - Portable Waste Solvent Tanks	*Closure Approved 2001*					N	N	–	--
		Unassigned - Former Leaching Bed North of Building 11-50 and West of Building 11-36	–	–	X	N	Y	Y	N	–	--
	WMG 4	SWMU 13 - Former Solar Evaporation Pond (Building 11-51)	–	–	X	N	Y	Y	N	–	--
		SWMU 5-09 - Drainage Ditch (Buildings 11-17, 11-20, and 11-51)	–	–	X	N	Y	Y	N	–	--
		SWMU 5-11 Main Perimeter Ditch	–	–	X	N	Y	Y	N	–	--
		SWMU 87 - Building 11-20 Solvent Storage Shed	–	–	X	N	Y	Y	N	–	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 11 (continued)	WMG 4 (continued)	SWMU 88 - 11-41 Compressor Building Waste Accumulation	*Administrative Closure Approved 2003*					N	N	--	--
		Unassigned SWMU - Evaporation Pit East of Bay 3 (Building 11-20)	--	--	X	N	Y	Y	N	X	--
		Unassigned SWMU - Evaporation Pit South of Bay 11/West of Bay 6 (Building 11-20)	--	--	X	N	Y	Y	N	X	--
	Not in WMG	Unit 1/SWMU 79 - Container Storage 11-7N Pad (Permitted Unit)	--	X	--	N	Y[c]	Y	N	--	--
		SWMU 124 - Building 11-50 Wastewater Treatment System	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 134 - Building 11-29 Silver Recovery	*Administrative Closure Approved 2001*					N	N	--	--
		AOC 3b - Zone 11 Former Boiler House Areas	--	--	X	N	Y	Y	N	--	--
		Unassigned - Former 11-15 Pond	--	--	X	N	Y	N	N	--	--
Zone 12	WMG 5	SWMU 56 - Landfill 5	--	--	X	N	Y	Y	Y	--	--
		SWMU 100 - Waste Accumulation Area, Building 12-42	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 103 - Former Battery Storage Area, Building 12-81	--	--	X	N	Y	Y	N	--	--
		SWMU 104 - Waste Accumulation Area, Building 12-82	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 105 -Waste Accumulation Area, Building 12-84	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 68a - Original Landfill	--	--	X	N	Y	Y	N	--	--
		SWMU 135 - Leaching Bed, Building 12-44E	--	--	X	Y[e]	Y	Y	N	--	--
		AOC 7c - Building 12-64 Sulfuric Acid Spills	--	--	X	N[c]	Y	Y	N	X	--
		UST #38 - Building 12-98	*Closure Approved 1999*					N	N	X	--
		UST #39 - North of Building 12-84A	*Closure Approved 1999*					N	N	X	--
		SWMU 5-06 - Drainage Ditch (Buildings 12-44E and 12-81)	--	--	X	N	Y	Y	N	X	--
		SWMU 57 - Landfill 6	--	--	X	Y[e]	Y	Y	N	X	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 12	WMG 6/7	AOC 10a - Building 12-43A Pesticide Rinse Area	–	–	X	N	Y	Y	N	X	Y (GW only)
		AOC 13 - Former Cooling Tower in Zone 12, Pad & Piping/Soil	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 1 - Drainage Ditch (Building 12-17)	–	–	X	N	Y	Y	N	X	Y (GW only)
		Building 12-43 - Wastewater Treatment Unit									
		SWMU 119b - High Explosives Filters	*Partial Closure Approved 1994*				Y[f]	N	N	–	--
		SWMU 120b - Carbon Filters	*Partial Closure Approved 1994*				Y[f]	N	N	–	--
		SWMU 121 High Explosives Settling Tank (soils addressed in SWMU 122b)	*Partial Closure Approved 1994*				Y[f]	N	N	X	--
		SWMU 122a - Equalization Basin (soils addressed in SWMU 122b)	*Partial Closure Approved 2003*				Y[f]	N	N	–	--
		SWMU 122b - Building 12-24N & Building 12-43 Upland Soils	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 123 - Concrete Sump & Wastewater Treatment Unit	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 125 - Building 12-43 HE Contaminated Charcoal Boxes	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 126 - Miscellaneous HE Contaminated Waste Dumpsters	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 129b - HE Contaminated Sludge Containers at Building 12-43	*Administrative Closure Approved 2001*					N	N	–	--
		SWMU 2 - Drainage Ditch (Building 12-43)	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 5-04 - Building 12-19 and 12-73 Drainage Ditches	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 5-05 - Drainage Ditch (Buildings 12-21 & 12-24)	–	–	X	N	Y	Y	N	X	Y (GW only)
		SWMU 5-07 - Building 12-41 Drainage Ditch	–	–	X	N	Y	Y	N	X	--
		SWMU 54 - Landfill 3	--	--	X	N	Y	Y	N	X	–
		SWMU 55 - Landfill 4	--	--	X	N	Y	Y	N	–	--
		SWMU 5-12a - Main Perimeter Ditch	--	–	X	N	Y	Y	N	X	Y (GW only)

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 12 (continued)	WMG 6/7 (continued)	SWMU 96 - Waste Accumulation Area, Building 12-21	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 97 - Waste Accumulation Area, Building 12-34	*Closure Approved 1999*					N	N	--	--
		SWMU 99 - Waste Accumulation Area, Building 12-41	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 137 - Building 12-41, Paint Shop Wastewater Tank	*Administrative Closure Approved 2003*					N	N	--	--
	WMG 8	SWMU 85 - MOCA Waste Accumulation Area, Building 12-16	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 90 - Waste Accumulation Area, Building 12-9	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 91 - Waste Accumulation Area, Building 12-9 Solvent Storage Shed	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 92 - Waste Accumulation Area, Building 12-9 (outside)	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 94 - Waste Accumulation Area, Building 12-R-13 (outside)	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 95 - Waste Accumulation Area, Building 12-18 (outside)	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 102 - Building 12-68 Batch Master, Northeast Corner	*Administrative Closure Approved 1997 & 2003*					N	N	--	--
		SWMU 108 - Building 12-68 Batch Master	*Closure Approved 1997*					N	N	--	--
		SWMU 109 - Concrete Sump (Building 12-68)	--	X	--	N	N	Y	N	X	--
		SWMU 110 - Building 12-68 Electroplating Waste Retention Basin (Moat)	*Closure Approved 1997*					Y	N	--	--
		SWMU 5-03 - Drainage Ditches (Buildings 12-9, 12-10, 12-18, 12-68)	--	X	--	N	N	Y	N	X	--
		SWMU 141 - Classified Waste Incinerator	*Administrative Closure Approved 2001*					N	N	--	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Zone 12 (continued)	WMG 9	AOC 10b - Building 12-51 Pesticide Rinse Area	--	--	X	N	Y	Y	N	--	--
		AOC 12 - Paint Shop Area/Solvent Pit (Building 12-5D)	--	--	X	N	Y	Y	N	--	--
		AOC 5 - Electrical Equipment Bone Yard Near Building 12-5	--	--	X	N	Y	Y	N	--	--
		Unassigned SWMU - Capacitor Bank Rupture	--	--	X	N	Y	Y	N	--	--
		SWMU 5-02 - Drainage Ditch (Buildings 12-51, 12-67, 12-110)	--	--	X	N	Y	Y	N	X	--
		SWMU 93 - Waste Accumulation Area, Building 12-111 Paint Shop Area	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 138 - Zone 12 Paint Shop Sandblaster Collection Cone	*Administrative Closure Approved 2001*					N	N	--	--
	WMG 10	AOC 15 – DDT Release (Building 12-35)	--	--	X	N	Y	Y	N	X	--
		AOC 6a - Gasoline Leaks at Buildings 12-35	*Closure Approved 1999*					N	N	--	--
		UST #7 - Building 12-5B	*Closure Approved 1999*					N	N	X	--
		SWMU 5-01 - Drainage Ditch(es) (Buildings 12-5 and 12-5B)	--	--	X	N	Y	Y	N	X	--
		Unassigned - Concrete Sump (near Building 12-5B)	--	--	X	N	Y	Y	N	--	--
		SWMU 89 - Waste Accumulation Area, Building 12-2 North Hall	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 131 - Portable Waste Oil Storage Tanks (Building 12-35)	*Administrative Closure Approved 2001*					N	N	--	--
	Not Assigned	Unassigned - Building 12-1 Laundry Sump	--	X	--	Y	N[g]	Y	N	--	--
		SWMU 98 - Building 12-38 Solvent Storage	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 101 - Waste Accumulation Area, Building 12-59	*Administrative Closure Approved 2003*					N	N	--	--
		SWMU 136 - Subsurface Leaching Bed (Building 12-59)	--	--	X	N	Y	Y	N	X	--
		AOC 7b - Building 12-4 Sulfuric Acid Spill	--	X	--	N	N	Y	N	--	--
		UST #9 -Building 12-17E	*Closure Approved 2004*					N	N	X	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
FTA Burn Pits and Landfill 7	Not Assigned	AOC 11 - Fire Training Area Burn Pits	--	--	X	Y[h]	Y[h]	Y	N	X	--
		SWMU 58 - Landfill 7	--	--	X	N	Y	Y	N	--	--
Ditches and Playas	WMG 11	SWMU 5-13a - West, Three Main Drainage Ditches to Playa 1	--	--	X	N	Y	Y	Y	X	--
		SWMU 5-13b - Central, Three Main Drainage Ditches to Playa 1	--	--	X	N	Y	Y	Y	--	--
		SWMU 5-13c - East, Three Main Drainage Ditches to Playa 1	--	--	X	N	Y	Y	Y	--	--
		SWMU 6 - Playa 1	--	--	X	Y	Y	Y	Y	--	--
		SWMU 80 - Container Storage Area Conexes (1,2,3, and 4) in Zone 4	*Administrative Closure Approved 2000*					N	N	--	--
		SWMU 82 - Nuclear Weapon Accident Residue Storage	--	--	X	Y	Y - NWAR	Y	Y	X	--
		SWMU 68b - Landfill 1	--	--	X	Y	Y	Y	N	X	--
		SWMU 68c - Landfill 2	--	--	X	Y	Y	Y	N	--	--
		SVS 1 - Denuded Area near Playa 1	--	X	--	N	N	Y	N	--	--
	Misc. Units not in WMGs	AOC 2 – Main Electrical Substation (4-28)	*Closure Approved 1993*					N	N	--	--
		SVS 4 - Old Pistol Range	*Active*					N	N	--	--
		SWMU 5-12b - Perimeter Drainage Ditch from Zone 12 to SWMU 5-14	--	--	X	N	Y	Y	Y	--	--
		SWMU 5-14 - Drainage Ditch from Zone 11 to Playa 2	--	--	X	N	Y	Y	Y	--	--
		SWMU 5-15a - Main Drainage Ditch from Zone 11 to Playa 4	--	--	X	N	Y	Y	Y	--	--
		SWMU 5-15b - Main Drainage Ditch from Zone 12 to Playa 4	--	--	X	N	Y	Y	Y	--	--
		SWMU 4 - Drainage Ditch (Building 11-50)	--	--	X	N	Y	Y	Y	--	--
		SWMU 7 - Playa 2	--	--	X	N	Y	Y	Y	--	--
		SWMU 9 - Playa 4	*No closure decision*[i]			N	N	Y	Y	--	--
		SWMU 10 - Pantex Lake	--	--	X	N	Y	Y	Y	--	--
		SWMU 140 - Old Sewage Treatment Plant/Sludge Beds	--	X	--	N	N	Y	Y	X	--
		SWMU 5-10 - Drainage Ditches near the Old Sewage Treatment Plant	--	X	--	N	N	Y	Y	X	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Burning Ground	WMG 13	SWMUs 14-27 - Explosive Burn Pads (including wash racks)	–	–	X	Y	Y - BO	Y	N	X	--
		SWMUs 28-36 - Active Burn Trays	*Active*					N	N	--	--
		SWMUs 37-44 - Burning Ground Landfills	–	–	X	Y	Y - BO	Y	N	X	--
		SWMUs 45-46 - Explosive Burn Cages	*Closure Approved 2003*					N	N	X	--
		SWMU 47 - Chemical Burn/Evaporation Pits	–	–	X	N		Y	N	–	--
		SWMUs 48-51 - Solvent Evaporation Pans (Pans closed, soils deferred to SWMU 47 investigation)	*Closure Approved 2003*					N	N	–	--
		SWMU 52 - Burn Racks and Flashing Pits	*Closure Approved 2003*					N	N	X	--
		Unassigned SWMU - Demonstration Facilities	–	–	X	N		Y	N	X	--
		SWMU 8 - Playa 3	–	–	X	Y		Y	Y	–	--
Independent Sites	Misc. Units not in WMGs	Unassigned - Dumpster Area near FS-11	–	X	–	N	N	Y	N	–	--
		SVS 6 - Unnumbered Zone 7 Landfills	–	–	X	N	Y	Y	Y	–	--
		SWMU 65 - Landfill 14	*Administrative Closure Approved 2003*					N	N	–	--
		SWMU 53 - Temporary High Explosives Burning Ground	–	X	–	N	N	Y	Y	X	--
		SWMU 62 - Landfill 11	*Administrative Closure Approved 2004*					N	N	–	--
		SWMU 64 - Landfill 13	--	--	X	Y	Y	Y	N	X	–
		SWMU 69 - Firing Site 4	*Active*					N	N	–	--
		SWMU 11 - Surface Impoundment in Zone 5 (Building FS-16)	–	X	–	N	N	Y	Y	X	--
		SVS 7a - Magazine Demolition Debris Landfills, Zone 4	–	–	X	N	Y	Y	Y	–	--
		SVS 7b - Magazine Demolition Debris Landfills, Zone 5	–	–	X	N	Y	Y	Y	–	--
		SWMU 63 - Landfill 12	--	X	–	N	N	Y	N	X	–
		SWMU 66 - Landfill 15	--	--	X	N	Y	Y	Y		–
		SWMU 70 - Firing Site 5	*Closure Approved 1999*					N	N	X	--
		SWMU 71 - Firing Site 6	*Closure Approved 2000*					N	N	–	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Independent Sites (continued)	Misc. Units not in WMGs (continued)	SWMU 72 - Firing Site 10	*Active*					N	N	--	--
		SWMU 73 - Firing Site 15	*Closure Approved 2000*					N	N	--	--
		SWMU 74 - Firing Site 21	*Active*					N	N	--	--
		SWMU 75 - Firing Site 22	*Active*					N	N	--	--
		SWMU 76 - Firing Site 18	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 77 - Firing Site 23, Filter/Exhaust System	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 78 - Firing Site 24, Concrete Sump	*Active*					N	N	--	--
		SWMU 81 - Mixed Waste Storage, Magazine 4-19	*Closure Approved 1993*					N	N	--	--
		SWMU 83 - Building 4-8, Container Storage Building, Asbestos Staging Area	*Administrative Closure Approved 2001*					N	N	--	--
		AOC 6b - Gasoline Leak at Building 16-1	*Closure Approved 1999*					N	N	--	--
		AOC 9 - Site-Wide, Underground Storage Tanks	*Administrative Closure Approved 2003*					N	N	--	--
		Unassigned SWMU - Unlined Landfill (Firing Site 1)	*Administrative Closure Approved 2004*					N	N	--	--
		Unassigned SWMU - Landfill 18 North of Firing Site 10	*Administrative Closure Approved 2004*					N	N	--	--
		Unassigned SWMU – FS-20 UST	*Closure Approved 1991*					N	N	--	--
		Permitted Unit 52 - Magazine 4-46	*Closure Approved 1998*					N	N	--	--
		Permitted Unit 53 - Magazine 4-72	*Active*					N	N	--	--
		Permitted Unit 54 - Magazine 4-74	*Closure Approved 1998*					N	N	--	--
		Permitted Units 8, 9, 10 & 11 - Container Storage Areas (Conexes WM5, WM6, WM7, & WM8)	*Closure Approved 2000*					N	N	--	--
		Permitted Units 36, 37, 38, & 39	*Closure Approved 1999*					N	N	--	--
		Permitted Unit 40 - Building 11-9 Storage	*Closure Approved 2002*					N	N	X	--
		Permitted Units 46, 47, 48, 49 & 50 - Container Storage Area (Conexes WM1-A, WM1-B, WM3-1, WM5-A, & WM5-B)	*Closure Approved 1998*					N	N	--	--
		SWMU 106 - Waste Accumulation Site at Building 16-1	--	X	--	N	N	Y	N	--	--

Table 1-1. Status of Corrective Action Units at Pantex Plant (continued)

RFI Operational Area	WMG	SWMUs, AOCs, and Other Potential Release Sites	RRS 1 Closure[a]	RRS 2 Closure[a]	RRS 3 Closure[a]	Further Evaluation as Potential Radiological Site in *RI Report* (Y/N)	Included in Human Health Risk Assessment (Y/N)[b]	Included in Ecological Risk Assessment Tier 1 (Y/N)	Included in Ecological Risk Assessment Tier 2 SLERA (Y/N)	ICM Conducted	Requires Evaluation in CMS/FS
Independent Sites (continued)	Misc. Units not in WMGs (continued)	SWMU 107 - Building 16-5, Flammable Liquid Storage	*Administrative Closure Approved 2003*					N	N		
		SWMU 127 - Miscellaneous Nonhazardous Waste Dumpsters	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 128 - Portable HE Wastewater Tanks	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 132 - Vacuum Guzzlers	*Administrative Closure Approved 2001*					N	N	--	--
		SWMU 133 - UST #30, Waste Oil Tank at Building 16-1	*Closure Approved 1999*					N	N	--	--
		SWMU 139 - Photo Processing Leaching Bed (Building FS-10)	--	X	--	N	N	Y	N	--	--
		SWMU 142 - Miscellaneous Hood and Filter Systems, 24 Buildings	*Administrative Closure Approved 2001*					N	N	--	--
		AOC 4 - Asbestos Installation (Plant-wide)	*Administrative Closure Approved 2003*					N	N	--	--
		Unassigned SWMU - FS-22 Container Gun Barrels	*Closure Approved 1999*								

[a]Closure status as approved through TCEQ RFIR approval letters.
[b]Sites evaluated in *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).
[c]All or portions of this data included in Exposure Area.
[d]These units were approved for closure to RRS 3 by TCEQ. However, TCEQ agreed these sites were only to be managed as a groundwater uncertainty through a groundwater-monitoring program to be established with consideration of Zone 10. These units were not required to be assessed in a baseline HHRA (TCEQ, 2005).
[e]Uncertainties associated with radionuclides in Zone 12 South area addressed in the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).
[f]Soils are evaluated as part of SWMU 122b in the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).
[g]Solids in sump were impacted with depleted Uranium; however, no release outside of the sump occurred.
[h]FTA was further evaluated as a potential radiological site due to anomalous result for total Uranium and was evaluated in the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).
[i]Pantex Plant portion of site investigation is complete.

AOC - Area of Concern
BG - Site evaluated in *Burning Ground HHRA Report* (BWXT Pantex, 2005a).
CMS/FS - Corrective Measure Study/Feasibility Study
GW - Groundwater
ICM - Interim Corrective Measure
NWAR - Site evaluated in *NWAR HHRA Report* (BWXT Pantex, 2005b).
RFI - RCRA Facility Investigation
RRS - Risk Reduction Standards
SLERA - Screening Level Ecological Risk Assessment
SWMU - Solid Waste Management Group
WMG - Waste Management Group
X - Denotes closure status
-- Not Applicable

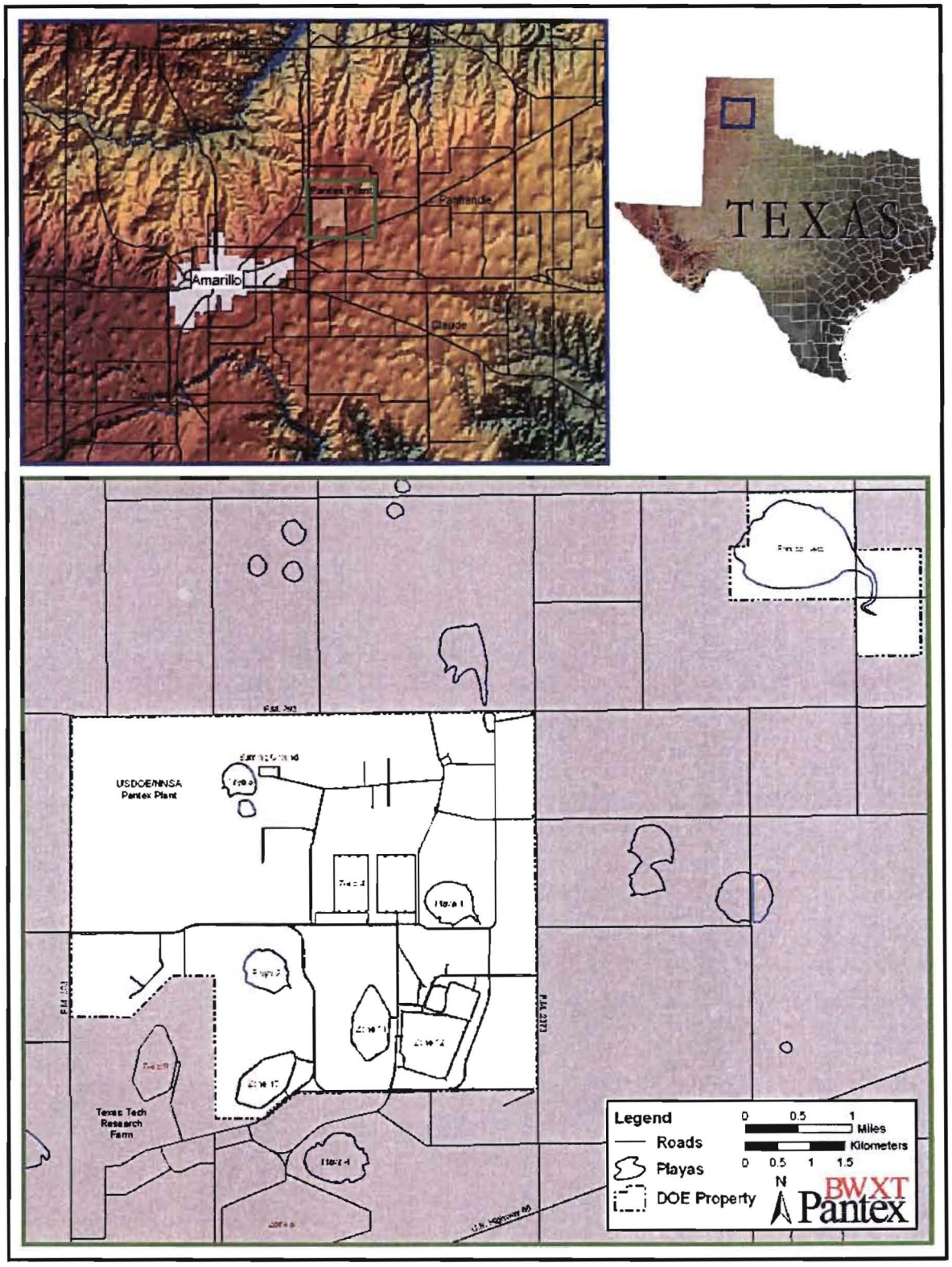
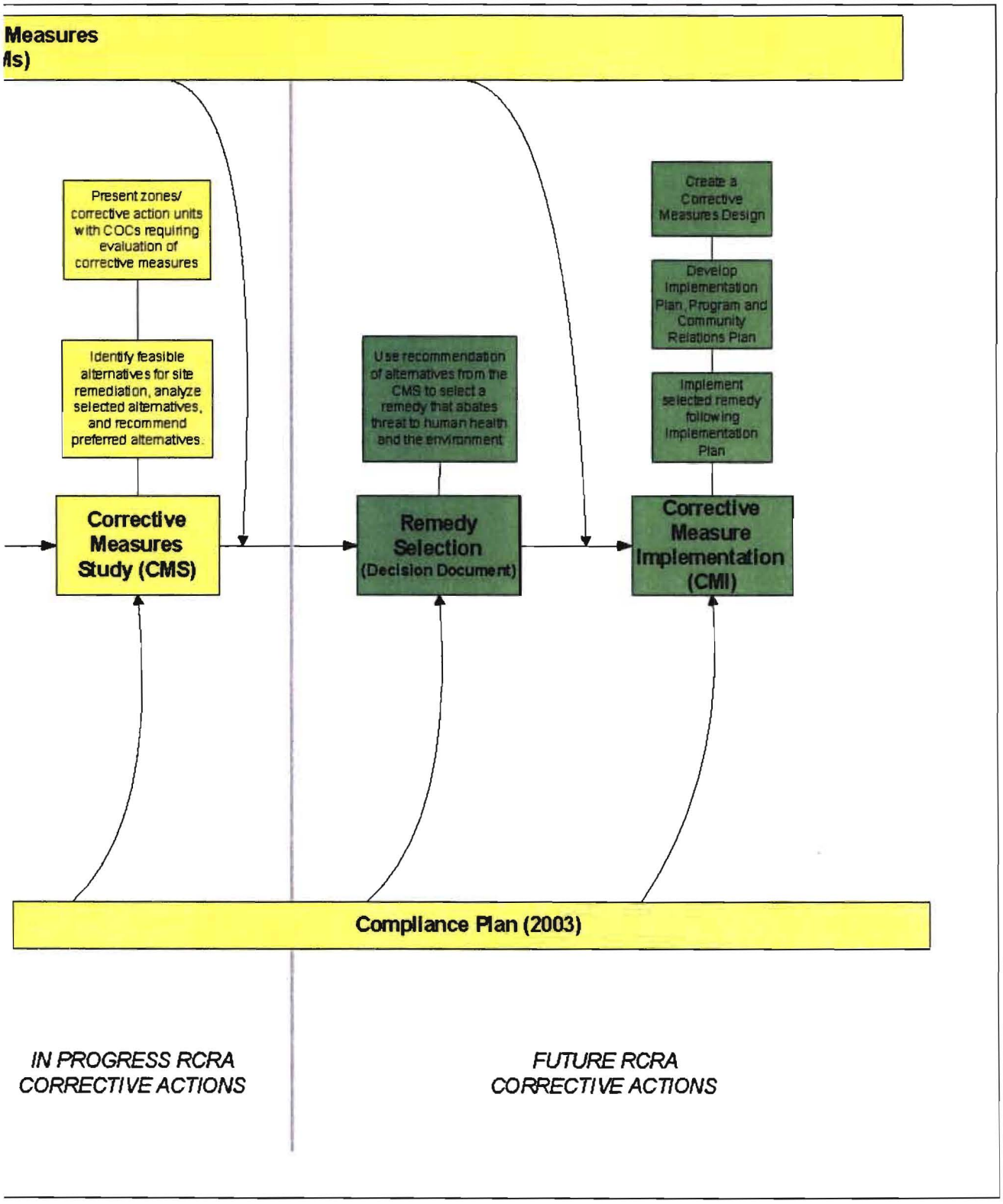


Figure 1-1. Regional Setting of Pantex Plant



ctive Action Process

2.0 ENVIRONMENTAL SETTING

Pantex Plant is located in Carson County in the Texas Panhandle, approximately 17 miles (27 km) northeast of downtown Amarillo (Figure 1-1). Pantex Plant is bounded on the north by Farm-to-Market Road (FM) 293, on the east by FM 2373, and on the west by FM 683. To the south, USDOE/NNSA-owned property extends to within 1 mile of United States Highway 60. Texas Tech University (TTU) owns the land located south of, and contiguous to, the USDOE/NNSA-owned lands.

The site consists of 10,177 acres (4,118 ha) owned by USDOE/NNSA for Plant operations and 5,856 acres (2,370 ha) leased from TTU as a safety and security buffer. This buffer area is managed by Texas Tech Research Farm (TTRF) and is used as rangeland and farmland. Part of the land is in the United States Department of Agriculture Conservation Reserve Program (CRP). TTRF also uses approximately 6,400 acres (2,590 ha) of USDOE/NNSA owned land for agricultural purposes. Industrial operations occur in the central portion of Pantex Plant and encompass approximately 2,000 acres (809 ha) of USDOE/NNSA property. Pantex Plant's primary mission is to:

- Assemble nuclear weapons for the nation's stockpile.
- Disassemble nuclear weapons being retired from the stockpile (including sanitization of components from dismantled nuclear weapons).
- Evaluate nuclear weapons (to include the repair and retrofit of nuclear weapons in the stockpile).
- Develop, fabricate, and test chemical explosives and explosive components for nuclear weapons to support USDOE/NNSA initiatives.
- Provide interim storage for plutonium pits from dismantled weapons.

Pantex Plant is composed of several functional areas, commonly referred to as numbered zones (Figure 1-1). These include a weapons assembly/disassembly area, a weapons staging area, an area for explosive development, a drinking water treatment plant, a sanitary wastewater treatment facility (WWTF), photo shops, vehicle maintenance areas, and administrative areas. Other functional areas include a utilities area for steam and compressed air, an explosive test-firing facility, a burning ground for thermally processing (burning or flashing) explosive materials, and landfills; a portion is currently used only for storage. Overall, there are more than 400 buildings at Pantex Plant.

2.1 FACILITY BACKGROUND

Pantex Plant was constructed during World War II when a number of the Plant's areas were used to develop conventional ordnance and produce high explosive (HE) compounds; TNT was the primary HE produced. The Plant was deactivated after World War II and the entire installation was sold to Texas Technological College (now TTU), subject to recall by the War Assets Administration. TTU used the area for agricultural purposes, such as cattle grazing and small grains production. Many of the original World War II buildings and structures (such as blast walls and berms) remain at the site, and many of the World War II-era structures have historical significance.

The United States Army Ordnance Corps reclaimed the site in 1951, for use by the Atomic Energy Commission as a nuclear weapons assembly facility. Portions of the original conventional weapons plant were renovated, and new facilities were constructed for the manufacture of HEs (i.e., High Melting

Explosive [HMX {cyclotetramethylene tetranitramine}] and RDX) used in nuclear weapons and for final assembly of the weapons. No radioactive materials have been processed at Pantex Plant to fulfill the Plant mission.

Responsibility for Pantex Plant has transitioned among various Government agencies. The United States Army first used the Pantex Ordnance Plant from 1942 to 1945, for loading conventional ammunition shells and bombs. In 1951, the Atomic Energy Commission began to rehabilitate portions of the original Plant and construct new facilities for nuclear weapons operations. In 1974, the United States Energy Research and Development Administration (ERDA) replaced the Atomic Energy Commission and accepted responsibility for operating Pantex Plant. In 1977, USDOE took the place of the ERDA. In 2000, a transition was made by USDOE to NNSA.

Pantex Plant is a government-owned, contractor-operated facility. USDOE/NNSA oversees operation of Pantex Plant through the Pantex Site Office, which reports to the NNSA in Washington D.C. Mason & Hanger - Silas Mason Co., Inc. (MHC) was the operating contractor from 1956 to 2001. BWXT Pantex, L.L.C. (BWXT Pantex) replaced MHC and began operations on February 1, 2001.

From 1991 to present, all environmental programs (i.e., protection, monitoring, and restoration) have been under the operating contractor. The Environmental Projects and Operations Division of BWXT Pantex is responsible for investigation and cleanup of corrective action units.

2.2 GEOLOGY AND HYDROGEOLOGY

This section describes the environmental physical setting of Pantex Plant including climate, geology, and water resources.

2.2.1 Topography

Pantex Plant is located in the Texas Panhandle on the High Plains portion of the Great Plains Physiographic Province. This area is a broad, flat plateau that gently slopes east and south, and is known as the *Llano Estacado* (Spanish for "Staked Plains"). Topographic elevation across Pantex Plant ranges from approximately 3,501 to 3,595 ft (1,067 to 1,096 m) above mean sea level (amsl), with an average elevation of approximately 3,554 ft (1,083 m) amsl (Table 2-1). The topography is relatively flat with slopes ranging from approximately 0.00005 in upland areas to approximately 0.07 near closed drainage basins containing ephemeral lakes (known as playas). The average topographic slope across the Plant area is approximately 0.006 (Table 2-1).

2.2.2 Local Geology

The shallow subsurface stratigraphy in the area of Pantex Plant is comprised of the following geologic units (in order of increasing age of formation and depth below ground surface [bgs]):

- Blackwater Draw Formation (Pleistocene Epoch)
- Ogallala Formation (Pliocene Epoch)
- Dockum Group (Triassic Period)
- Permian Quartermaster Formation (Permian Period) where the Dockum Group is not present.

The vertical dimensions of the geologic units are summarized in Table 2-1. More detailed information regarding the local geology is presented in the *Subsurface Modeling Report* (BWXT Pantex, 2004c).

The Blackwater Draw, the uppermost hydrostratigraphic unit (HSU), consists of eolian silts and sands, with an approximately 20-ft (6-m) thick lower unit composed of silty sand and caliche. The upper surface of the Blackwater Draw is defined by surface topography. Numerous depressions representing the playa basins are apparent on the land surface. These depressions range from a few feet to more than 46 ft (14 m) in relief and from several hundred feet to 1 mile (1.6 km) or more in diameter (ANL and BMI, 1995). Sediments beneath the playas contain thick sequences, roughly 16 to 60 ft (5 to 18 m) of lake sediments that are highly variable in lateral and vertical extent (Hovorka, 1995). The lake sediments intermingle with the Blackwater Draw sediments near the edges of the playa basins. The Blackwater Draw Formation and the availability of water control infiltration and recharge, especially to perched groundwater.

Underlying the Blackwater Draw Formation is the Ogallala Formation. The Ogallala sediments consist of coarse-grained fluvial sequences that fill the floors of paleovalleys and fine upward from gravel to fine sand. The fining-upward sequences contain channel sands and gravels overlain by finer overbank deposits (Gustavson, 1994). Fine-grained eolian deposits overlie the coarse fluvial sediments. Regionally, the thickness of the Ogallala Formation ranges from a few feet to over 900 ft (274 m). A massive Caliche Caprock layer generally defines the top of the Ogallala Formation (and the base of the Blackwater Draw Formation); however, it is not continuous in extent below Pantex Plant. Where present, the Caprock layer consists of a hard, dense, finely crystalline caliche.

Underlying the Ogallala Formation is the Dockum Group. Where present, the Dockum Group is estimated to be approximately 200 ft (61 m) thick in the Plant area. The Dockum Group consists mostly of indurated sediments, these include mudstones, siltstones, sandstones, and minor conglomerates and claystones derived from fluvial, deltaic, and lacustrine depositional systems (Johns, 1989). Identification of the Dockum Group from the Ogallala Formation is more difficult than the identification of the Permian Redbeds or the Quartermaster Formation. The Quartermaster Formation is made up of red shale or clay with sandstone, dolomite, or gypsum. The Permian Redbeds have very low permeability values; therefore, there are limited permeable pathways between the Ogallala and Permian rocks (Nativ, 1988).

2.2.3 Groundwater Resources

The principal source of groundwater for the region is the Ogallala Aquifer, the primary unit of the High Plains Aquifer, comprising the highly permeable basal sediments of the Ogallala Formation throughout the Southern High Plains. The Ogallala Aquifer provides water for municipal water supplies, crop irrigation, livestock operations, and industry, and is the sole water source for Pantex Plant. Groundwater used in the Plant area is discussed further in Section 3 of this report.

The High Plains Aquifer has been developed extensively with more than 96 percent of the total withdrawal used for irrigation (McGuire, 2004). During the year 2000, approximately 121,000 acre-ft of water were pumped from the aquifer in Carson County (PGCD, 2003). Approximately 97,300 acre-ft, or 80 percent, were withdrawn for irrigation (PWPG, 2005). Because this volume of discharge greatly exceeds the amount of recharge, water levels in the aquifer are declining. According to the Panhandle Groundwater Conservation District (PGCD) the average water level in Carson County declined 31 ft (9.4 m) from 1964 to 2004 (PGCD, 2004). Beneath the northern part of Pantex Plant, water levels have dropped more than 130 ft (40 m) since 1942, and are currently declining at rates greater than 1 ft (0.3 m) per year.

Water level declines in the Ogallala Aquifer have resulted in "dry" areas of no saturation where the elevation of the bottom of the aquifer is locally high, such as in the areas to the immediate south and southeast of Pantex Plant as shown in Figure 2-1. The development of local "dry" zones may isolate Ogallala Aquifer groundwater near Pantex Plant from the regional flow regime or otherwise alter local

flow patterns in the Ogallala Aquifer in a manner that would diminish flow of Ogallala Aquifer groundwater away from Pantex Plant.

The Ogallala Aquifer in Carson County was estimated to contain approximately 17.5 million acre-ft of groundwater in 1960 (Knowles, et al., 1984). In 2000, the volume in storage had declined to approximately 15.3 million acre-ft (PWPG, 2005). It is the stated goal of the PGCD to conserve and preserve the limited supply of groundwater in the district, while maintaining the economic viability of all resource user groups. To meet this goal, the PGCD has instituted a conservation management policy to retain 50 percent of the 1998 groundwater supply in 2048 (PGCD, 2003). According to Groundwater Availability Modeling conducted as part of regional water planning, approximately 65 percent of the year 2000 groundwater supply in Carson County is projected to remain in 2050 (PWPG, 2005).

Regionally, the Ogallala Aquifer water table slopes from northwest to southeast, generally following the regional topographic surface. However, in the vicinity of Pantex Plant the water table slopes from southwest to northeast (Figure 2-1) in response to extensive pumping from the City of Amarillo, Carson County well field located north of Pantex Plant. The well field consists of 39 wells and produces an annual average of about 18 million gallons per day (MGD) (68.1 million liters per day [Lpd]). The nearest of these wells to Pantex Plant is 2,100 ft (640 m) north of the Plant boundary. Pantex Plant pumps water from the Ogallala Aquifer at five water supply wells in the northeast section of Pantex Plant. The combined average pumping rate is 0.72 MGD (2.7 million Lpd).

Localized bodies of perched groundwater occur above the Ogallala Aquifer throughout the Southern High Plains (Mullican, et al., 1995). These localized zones occur where focused recharge from playa lakes has ponded on top of an aquitard, referred to as the fine-grained zone (FGZ). Three primary areas of perched groundwater beneath Pantex Plant are shown in Figure 2-2. The largest area of perched groundwater underlying Pantex Plant is associated with natural recharge from Playas 1, 2, and 4; treated wastewater discharge to Playa 1; and historical releases to the ditches draining Zones 11 and 12. Smaller areas of perched groundwater are associated with Playa 3 (near the Burning Ground) and Pratt Playa (near the northeast corner of Pantex Plant).

Perched groundwater does not discharge to the surface, is not a source of drinking water for Pantex Plant, nor is it used for any Pantex Plant industrial operations. Treated effluent from the Perched Groundwater Pump and Treat System (PGPTS), and treated wastewater meeting Pantex Plant permitted discharge requirements, is used for subsurface irrigation onsite. Because it is the shallowest water-bearing zone in the area, it is the first groundwater unit affected by the migration of contaminants released from Pantex Plant corrective action units. Units impacted by COPCs at the surface are separated from groundwater in either the perched groundwater or the Ogallala Aquifer by a 200- to 500-ft (61- to 153-m) thick unsaturated zone. Vertical flow between perched groundwater and the Ogallala Aquifer is limited by the FGZ. In areas where perched groundwater is present, a second unsaturated zone occurs between perched groundwater and the Ogallala Aquifer. Because of the thin saturated thickness of perched groundwater, flow in the perched groundwater is controlled by the topography of the FGZ and by localized sources of recharge, such as Playa 1. As a result, groundwater flow directions in the perched groundwater vary spatially in response to local topography and recharge, and a perched flow divide occurs beneath the Plant.

Table 2-1. Vertical Dimension of Geologic Features Within Pantex Plant Boundary[a]

Geologic Features		High		Low		Average[b]	
		feet	meters	feet	meters	feet	meters
Elevation[c]	Topographic Elevation (Top of Blackwater Draw Formation)	3594.6	1095.6	3501.2	1067.2	3553.6	1083.1
	Topographic Slope (ft/ft)	0.07	0.07	0.00005	0.00005	0.006	0.006
	Elevation of Base of Blackwater Draw Formation (Top of Ogallala Formation and Caprock Caliche)	3532.9	1076.8	3436.9	1047.6	3480.6	1060.9
	Elevation of the Base of the Caprock Caliche	3522.4	1073.6	3426.3	1044.3	3470.5	1057.8
	Elevation of the Perched Water Table Surface	3321.9	1012.5	3257.4	992.8	3283.4	1000.8
	Elevation of the Top of the FGZ	3341.5	1018.5	3111.1	948.3	3277.5	999.0
	Elevation of the Base of the FGZ	3309.6	1008.8	3031.5	924.0	3226.3	983.4
	Top of Ogallala Water Table	3210.4	978.5	2677.2	816.0	3115.6	949.6
	Elevation of the Base of the Ogallala Formation (Top of the Dockum Group and Redbeds)	3152.4	960.9	2679.2	816.6	2895.9	882.7
Depth	Depth bgs to Base of Blackwater Draw Formation (Top of Ogallala Formation and Caprock Caliche)	105.0	32.0	33.6	10.2	72.9	22.2
	Depth bgs to Base of Caprock Caliche	115.0	35.0	43.6	13.3	83.0	25.3
	Depth bgs to Perched Water Table Surface	297.9	90.8	195.1	59.5	256.7	78.2
	Depth bgs to Top of FGZ	321.7	98.1	223.5	68.1	276.0	84.1
	Depth bgs to Base of FGZ	431.1	131.4	267.5	81.5	327.1	99.7
	Depth bgs to Ogallala Water Table Surface	507.5	154.7	343.5	104.7	437.9	133.5
	Depth bgs to Base of Ogallala Formation (Top of the Dockum Group and Redbeds)	888.9	270.9	390.9	119.2	657.6	200.4
Thickness	Thickness of Blackwater Draw Formation	105.5	32.2	33.6	10.2	72.8	22.2
	Thickness of Caprock Caliche	23.2	7.1	0.5	0.2	7.1	2.2
	Saturated Thickness of Perched Groundwater	79.4	24.2	0.0	0.0	22.0	6.7
	Thickness of FGZ	157.1	47.9	8.7	2.6	51.1	15.6
	Lower Ogallala Unsaturated Thickness	221.1	67.4	0.0	0.0	110.8	33.8
	Saturated Thickness of Ogallala Aquifer	406.2	123.8	29.0	8.8	219.7	67.0
	Thickness of Ogallala Formation (Total)	821.6	250.4	316.4	96.5	584.7	178.2

Note: Water surface information is based on April 2000 measurements collected from monitoring, investigation, municipal, private, and extraction wells (See Table 2-3 of *Subsurface Modeling Report* [BWXT Pantex, 2004c] for list of wells included).

[a]Table taken from the *Subsurface Modeling Report* (BWXT Pantex, 2004c).

[b]Averages were calculated as the arithmetic mean of the interpolated surfaces within the Pantex Plant boundary.

[c]Elevation data is above mean sea level (amsl).

2.2.4 Soil Characteristics

The Pullman clay loam series predominately comprises upland surface soils at Pantex Plant. Randall clay dominates the playa bottoms; Lazbuddie and Lofton soils occur on the playa benches; and Pep and Estacado soils occur on the playa side slopes. Subsurface soils are considered part of the Blackwater Draw and Ogallala Formations.

2.3 METEOROLOGY AND CLIMATOLOGY

The climate in the Texas Panhandle is typical of continental interiors. It is mainly semi-arid, with mild winters and hot, dry summers and is characterized by large variations in daily temperature extremes, low relative humidity, and irregular rainfall of moderate amounts. Thunderstorms occur approximately 49 days per year and can produce tornadoes (TTU, 1994). Pantex Plant is in a windy area and in a moderate- to high-hazard zone for tornadoes.

Based on National Weather Service (NWS) records, average annual precipitation for Amarillo is 19.9 in. (50.5 cm). The average annual temperature is 57.1°F (13.9°C) with a normal low temperature in January of 21.2°F (-6.0°C) and a normal high temperature in July of 91.7°F (33.2°C). Average wind speeds at the Amarillo NWS station are 13.1 mph (21.1 kph) based on a 33-year period of record (BPX/MHC, 1998a). The prevailing wind direction is from the south for May through September and from the southwest for the remainder of the year (DOC, 1997). Analysis of NWS meteorological data for 1990 indicates local winds were predominantly from the south and southwest directions approximately 41 percent of the time with an average wind speed of 13.42 mph (21.60 kph). The gross lake-surface evaporation rate averages 73 in (185 cm) per year, as measured from 1950 through 1975 (BPX/MHC, 1997).

2.4 SURFACE WATER

The principal surface water features of the Southern High Plains are the numerous shallow playas and small stream valleys or draws. Stream drainage patterns are poorly developed because of the low relief of the plains. Streams occur as long, shallow draws following the general slope of the land surface at widely spaced intervals. The drainage areas of the streams and draws are limited to narrow belts of land. Playa basins drain the larger, interfluvial areas and generally do not contribute runoff to streams.

The perennial surface water feature closest to Pantex Plant is the Canadian River, located approximately 17 miles (27 km) to the north. The river flows in a generally eastward direction into Lake Meredith, a constructed reservoir. A few smaller streams are located south and east of Pantex Plant along the High Plains Escarpment. These streams are tributaries of the Red River and include: 1) the Salt Fork of the Red River, approximately 20 miles (32 km) southeast of Pantex Plant; 2) the Prairie Dog Town Fork of the Red River, approximately 25 miles (40 km) southwest of Pantex Plant; and 3) Sweetwater Creek, approximately 50 miles (80 km) east of Pantex Plant. During flood events at Pantex Plant, surface water may flow to offsite playas, but runoff from Pantex Plant does not flow into the Canadian River, Lake Meredith, or any of the smaller streams.

Three playas are located at Pantex Plant (Figure 2-3). Playa 1 is north of Zone 12, Playa 2 is west-northwest of Zone 11, and Playa 3 is included in the Burning Ground WMG. Playa 4 is located on TTU property, south of Zone 11. A large playa basin is located on Pantex Lake property, 2.5 miles (4 km) northeast of the Pantex Plant boundary. Other playas are present in the area and each constitutes a separate drainage basin with no surface drainage outlets. Most surface water runoff from Pantex Plant flows into the onsite playas.

2.5 ONSITE ECOLOGY AND LAND USE

Pantex Plant lies on the Southern High Plains portion of the Great Plains at an elevation of approximately 3,554 ft (1,083 m). North of the Plant, the relatively flat plains become rolling breaks that form the escarpment above the Canadian River. The relatively flat plains are characterized by rolling grassy plains and numerous natural playa basins. There are more than 17,000 playas or ephemeral lakes in the Texas Panhandle; the lakes are usually less than 0.6 mile (1 km) in diameter and receive water runoff from the surrounding area.

2.5.1 Onsite Land Use

Four distinct types of land use (Figure 2-4) are identified at the Plant:

- Operations
- Cultivation
- Wetlands
- Grassland.

Operational areas include active and inactive industrial areas. Active operational areas contain a medium-to-high density of buildings, roadways, storage facilities, parking areas, actively disturbed land (landfills and borrow pits), and heavier human utilization. Zones 4, 11, and 12 are enclosed by high security fencing; therefore, are subject to restricted access. Support facilities occur in Zones 10, 11, 12, the Burning Ground, firing ranges, and Firing Sites. The active operational areas are mowed and maintained in shortgrass prairie. Shrubs, trees, and watered lawns are present around some administrative buildings in the operational areas. Denuded areas are also maintained as a safety and security buffer for portions of the operational areas. The inactive operational areas contain mowed/maintained areas around the active operations, and are designed to serve as safety and security buffers in most cases.

Agricultural (cultivation) lands owned by USDOE/NNSA at Pantex Plant and Pantex Lake (i.e., not including the TTU property) are managed by the TTRF through a Service Agreement that allows TTU to use the land for farming and ranching. Approximately 3,817 acres (1,545 ha) are available for cultivation and approximately 1,954 acres (791 ha) are available for grazing. These areas are required to be managed in accordance with the Plant mission, including protection of the environment, safety, and health of employees and the public, and national security. The area available for grazing or farming under the Service Agreement with TTU is shown in Figure 2-4.

Wetland areas, Playas 1, 2, and 3, are formally managed areas under the *Integrated Plan for Playa Management at Pantex Plant* (herein referred to as the *Playa Management Plan*) (BWXT Pantex, 2002c). The areas surrounding each of the playas are designated as Playa Management Units (PMUs). Under the Playa Management Plan, rotational cattle grazing is allowed to promote shortgrass prairie habitat. The goals of the *Playa Management Plan* include cultural resource management and protection, erosion control, shortgrass prairie sustainability, playa wetlands protection, and wildlife management and monitoring. As part of the *Playa Management Plan*, a buffer area was established around each playa to filter runoff from agricultural and industrial operations, decrease sedimentation, and improve overall water quality in the playas. All cultivation practices were discontinued within the buffer area for each playa and the playa itself; however, managed grazing occurs infrequently to meet the above objectives and is included in the *Playa Management Plan*. These formerly cultivated areas were revegetated with native grasses in June 1996. Pantex Lake does not have a formally identified PMU; however, monitoring of resources at this playa is addressed in the *Playa Management Plan*. Pantex Lake differs from the PMUs by not having revegetated areas.

In addition to the agricultural land owned by USDOE/NNSA, most of the buffer zone leased from TTU is used for agriculture. The approximate 5,800-acre (2,347-ha) buffer zone includes rangeland used for grazing cattle (including playas), a small portion of farmland, and land set aside as part of the CRP. Under the terms of the Service Agreement, Pantex Plant provides potable water from the Ogallala Aquifer to the TTRF for watering of livestock and personal consumption.

2.5.2 Vegetation

The Southern High Plains area is semi-arid grassland with very few natural trees. The native vegetation is characterized as shortgrass prairie (USDOE, 1993); however, some of the native prairie has been converted to agricultural crops, and almost all has been affected by cattle grazing and early century cattle drives through the area. The current state of the altered shortgrass prairie at Pantex Plant ranges from unvegetated in the south-central industrial region, to a variety of species elsewhere onsite (USDOE, 1996).

Playa vegetation on the Southern High Plains varies from one playa to another and throughout the changing conditions of the seasons. When water is prevalent within the basins, playa vegetation is usually composed of emergent and submergent aquatic species; however, as available water subsides, the species shift to semi-aquatic annuals. With little moisture present, playa vegetation is commonly made up of characteristic upland species (Haukos and Smith, 1994).

2.5.3 Wetlands

Although the playas are ephemeral water bodies often having water only seasonally, many playas meet the soils, hydrologic, and vegetation criteria for classification as wetlands. Playas 1, 2, 3, and 4, and Pantex Lake have been delineated as wetlands (HEC, 1995) and are closed basins. However, the playas are not subject to federal regulation under the Clean Water Act (CWA) (see Section 2.3.3 of the *Site-Wide ERA* [BWXT Pantex, 2004b]).

2.5.4 Wildlife

As with most of the Southern High Plains, agriculture and industry have changed the biological resources and diversity at Pantex Plant. Land in the Texas Panhandle used for cultivated agricultural purposes does not support extensive populations of endemic, non-migratory wildlife. However, the Plant and Southern High Plains are home to a diversity of wildlife which, varying by species, utilizes cropland, playa lakes, shortgrass prairie, and grasslands established by the CRP. Many species feed in cultivated fields of the Plant and region, although remaining shortgrass prairie is critical for endemic wildlife. Remaining undisturbed playas are "islands" of wildlife habitat allowing the continued existence of many species (Dierauf, 1994; Haukos, 1995; Smith, 1994). The playas are the most ecologically stable areas of wildlife habitat and are critical to the biodiversity of flora and fauna in the area (USDOE, 1996).

A biological assessment of Pantex Plant was completed in April 1996 (BPX/MHC, 1996b). The assessment addressed the impacts of Plant operations on endangered or threatened species and species of concern that occur, may occur, or migrate through the area. The United States Fish and Wildlife Service (USFWS) approved the assessment in May 1996, with the comment that it was "comprehensive and complete." The USFWS concurred with the conclusion that continued Plant operation is not likely to adversely affect any federally-listed threatened or endangered species (BPX/MHC, 1997).

Additionally, several wildlife studies have been completed at Pantex Plant, focusing on mammals, amphibians and reptiles, birds, and invertebrates. Additional studies have been conducted to identify threatened or endangered species, or species that may be candidates for listing. Using the information gathered from these studies, tables have been compiled listing species known to occur, or potentially

occur, within the Pantex Plant area. These tables are found in Appendix A of the *Site-Wide ERA WPA* (BWXT Pantex, 2004b).

2.5.5 Threatened and Endangered Species

The Endangered Species Act of 1973 authorized USFWS to list species that are in danger of becoming extinct and offers protection to these species and, in some cases, to a specific critical habitat that is essential for the survival of these species. In addition to federal designation, Texas maintains a list of species that are designated as endangered or threatened within the state.

No areas on or near Pantex Plant are designated as critical habitats for threatened or endangered species. Listed and candidate animal species have been recorded onsite, and some candidate species are suspected to occur onsite. Table 2-2 presents all species that have recorded occurrences, as well as those suspected to occur, and their state and federal status.

Table 2-2. Endangered, Threatened, and Candidate Species and Species of Concern Known or Expected to Occur in the Vicinity of Pantex Plant, Carson County, Texas

Common Name	Scientific Name	Recorded at Pantex Plant	Federal Status	State Status
Birds				
Arctic peregrine falcon	*Falco peregrinus tundrius*	A	Concern	Threatened
Bald eagle	*Haliaeetus leucocephalus*	B	Threatened	Threatened
Whooping crane	*Grus Americana*	B	Endangered	Endangered
Interior least tern	*Sterna antillarum athalassos*	C	Endangered	Endangered
Baird's sparrow	*Halieetus leucocephalus*	C	Concern	Not listed
Ferruginous hawk	*Buteo regalis*	B	Concern	Not listed
Western burrowing owl	*Athene cunicularia hypugea*	B	Concern	Not listed
Mountain plover	*Charadrius montanus*	B	Concern	Not listed
Snowy plover	*Charadrius alexandrinus*	C	Concern	Not listed
Reptiles				
Texas horned lizard	*Phrynosoma cornutum*	B	Concern	Threatened
Mammals				
Black-tailed prairie dog	*Cynomys ludovicianus*	B	Concern	Not listed
Plains spotted skunk	*Spilogale putorius interrupta*	?	Concern	Not listed
Swift fox	*Vulpes velox*	?	Concern	Not listed
Cave myotis	*Myotis velifer*	B	Concern	Not listed

A - Presence of Arctic or American peregrine species documented at Pantex Plant.
B - Presence documented at Pantex Plant.
C - Presence not documented at Pantex Plant.
? - Questionable record exists for Pantex Plant.

2.5.6 Critical Habitats

According to the *Biological Assessment of the Continued Operation of Pantex Plant and Associated Storage of Nuclear Weapon Components* (BPX/MHC, 1996b), no designated critical habitat for endangered or threatened species is located on or near Pantex Plant. This finding is based on USFWS letter 2-12-95-I-267, dated November 1, 1995, addressed to USDOE/Office of Amarillo Site Operations for Pantex Plant, Texas (USFWS, 1995).

2.6 OFFSITE LAND USE

2.6.1 Land Use Within a 10-Mile Radius

The predominant land use within a 10-mile (16-km) radius of Pantex Plant is agricultural. Grazing is the predominant land use to the west and northwest of Pantex Plant. Cultivated land, with scattered patches of grazing, predominates the areas immediately surrounding Pantex Plant and to the north, northeast, east, southeast, south, and southwest. Some industrial areas are located south and southwest of the Plant. The only urban centers in this area are Highland Park Village to the southwest (on the outskirts of Amarillo), the town of Panhandle to the east, and the town of Washburn to the south. Offsite land use within 10 miles of Pantex Plant is shown in Figure 2-5.

2.6.1.1 Facilities

A 1995 survey identified 24 facilities including schools, daycare centers, nursing homes, industrial areas, grain elevators, recreational facilities, and correctional facilities within the 10-mile (16-km) radius (Burns & McDonnell, 1995). To the east, one daycare facility, three schools, and two nursing homes are located in the town of Panhandle; to the southwest, three schools and two daycare centers are located in or near Highland Park Village. Outside of Pantex Plant, which currently (2005) employs approximately 3,700 staff (Nester, 2005), the facility with the largest employment/enrollment is Iowa Beef Packing, Inc. (now Tyson Foods, Inc.), with 2,700 employees (Pantex, 1998). The only recreational facility within the 10-mile (16-km) radius of Pantex Plant is a city park in the town of Panhandle that has a picnic area and playground.

2.6.1.2 Water Supplies

All water supplies identified within the 10-mile (16-km) radius of Pantex Plant were obtained from groundwater (Burns & McDonnell, 1995). Most water supply wells in the area were completed in the Ogallala Aquifer. Water is used for drinking, irrigation, and livestock watering. Three public water supplies were identified within this area:

- A well field for the City of Amarillo consisting of 39 wells.
- Three wells for the town of Panhandle.
- The Pantex Plant water system consisting of five wells located on Pantex Plant that provides potable and industrial water supply to Pantex Plant, and potable and livestock water supply to the TTRF.

In addition, individual system within the 10-mile radius of Pantex Plant's water system (TWDB, 2006) include:

- Approximately 171 irrigation wells within the 10-mile radius of Pantex Plant's water system (TWDB, 2006).
- Approximately 40 domestic wells have been installed within the 10-mile radius of Pantex Plant's water system (TWDB, 2006).

2.6.1.3 Gardens and Livestock

Gardens grown for personal use are common within the 10-mile (16-km) radius of Pantex Plant (Burns & McDonnell, 1995). Wide varieties of vegetables are grown in these gardens; tomatoes, beans, and squash are among the most common.

Raising beef cattle is one of the major land uses in the area. In 1995, the total number of beef cattle within a 10-mile (16-km) radius of Pantex Plant was approximately 41,000 (Burns & McDonnell, 1995). Very few dairy cattle were identified in the area, and no commercial dairy operations that provide milk or dairy products were found within the 10-mile (16-km) radius. Poultry, swine, and sheep are also raised within the 10-mile (16-km) radius for commercial and personal use.

2.6.2 Land Use Within a 50-Mile Radius

Information presented on land use within the 50-mile (80-km) radius is less detailed than that collected for the 10-mile (16-km) radius. Current land use within the 50-mile (80-km) radius of Pantex Plant is predominantly agricultural. The greatest portion of land is devoted to rangeland, most of which is located along the Canadian River drainage to the north of Pantex Plant and to the south in the drainage of the tributaries of the Red River. Cropland, including both irrigated and dryland farming, accounts for the second largest land use. Carson County was ranked 8th among all Texas counties for production of wheat and grain sorghum and 28th for production of corn (Battelle, 1995).

Commercial, residential, industrial, institutional, and public lands comprise a small percentage of the total land uses within the 50-mile (80-km) radius. Most commercial, residential, industrial, and institutional land uses are associated with the towns and cities in the area; the largest of which is Amarillo. Most urban-related and residential land uses are concentrated near Amarillo. Other major towns include Canyon, Pampa, Borger, and Dumas (Battelle, 1995; Burns & McDonnell, 1995).

2.6.2.1 Agricultural Land Use Patterns

The types of agricultural land within this area include rangeland, cropland, and CRP lands. Corn, cotton, peanuts, sorghum, sugar beets, and soybeans are the primary crops grown in the area during the summer. Oats and wheat are the primary crops grown in the area during the winter (Burns & McDonnell, 1995). Crops may be grown under dryland or irrigated conditions with irrigation water typically from the Ogallala Aquifer or from playas (Battelle, 1995).

Only ten commercial gardens were identified within a 50-mile (80-km) radius of Pantex Plant; most were relatively small operations, totaling only 25 acres (10 ha) altogether (Burns & McDonnell, 1995). Almost all of the commercial gardens are in the southwest and west-southwest quadrants. A variety of vegetables are grown in these gardens. In addition, a few small orchards of 5 acres (2 ha) or less were identified. Twenty cattle feed lots were identified within the 50-mile (80-km) radius, the nearest located approximately 9 miles (14 km) to the southwest. Capacities of these facilities range from 600 to 68,000 head of cattle. Four dairy operations were identified within the 50-mile radius, three to the southwest (SSW, SW, and WSW compass sectors) and one to the west-northwest.

2.6.2.2 Public Water Supplies

Public water supplies serve communities, schools, mobile home parks, and businesses. In 1995, 136 public water supplies were located within a 50-mile (80-km) radius of Pantex Plant (Burns & McDonnell, 1995). Most of these supplies are from wells completed in the Ogallala Aquifer; however, two surface water bodies also serve as public water supplies. Eleven cities including Amarillo, Borger, Brownfield,

Lubbock, Lamesa, Levelland, Odonnell, Pampa, Plainview, Slaton, and Tahoka comprise the Canadian River Municipal Water Authority and obtain some of their water from Lake Meredith. The Greenbelt Reservoir, located approximately 45 miles (72 km) east-southeast of Pantex Plant, is the other surface water supply and is used by Donley County as a sole source drinking water supply.

2.6.2.3 Schools, Hospitals, and Recreation Facilities

In 1995, 146 schools and nine hospitals were identified within the 50-mile (80-km) radius (Burns & McDonnell, 1995). Of the nine hospitals, five are in the Amarillo area and are the closest to Pantex Plant. Recreational facilities within the 50-mile (80-km) radius include several lakes, city parks, sports complexes, swimming pools, one state park (Palo Duro Canyon State Park), and several national areas. The majority of recreational facilities are city parks. National facilities include Buffalo Lake National Wildlife Refuge, Alibates Flint Quarry National Monument, and Lake Meredith National Recreation Area. Lake Meredith has swimming, fishing, and water sports. Several lakes in the Amarillo parks have fishing, and Greenbelt Reservoir has fishing and water sports. Lake McClellan was dry in 1995.

2.6.2.4 Industrial Sites

Currently (2005), Pantex Plant employs 3,730 persons, including management and operating contractors, USDOE and National Laboratory staff, consultants and oversight agency personnel (Nester, 2005b). This employment figure has remained relatively constant over the past 10 years.

Pantex Plant is the major employer in Carson County, and is one of the largest employers within the four county region of influence that includes Carson, Armstrong, Potter and Randall counties, and in the Amarillo metropolitan area. In 2001, Pantex Plant was ranked the third largest employer in the Amarillo metropolitan area. (BWXT Pantex, 2002d)

The largest numbers of industrial facilities are located in the Amarillo area in the west-southwest and southwest compass sectors, and in the Borger area to the north-northeast. Within the 50-mile (80-km) radius, a total of 49 grain elevators were found in all except two compass sectors.

2.6.2.5 Big Game, Game Birds, Small Game, and Fish

Big game in the area consists of mule deer, white-tailed deer, and pronghorn antelope. The Canadian River breaks, located 2 to 4 miles (3 to 6 km) north of Pantex Plant, represent the preferred habitat for the mule deer, white-tailed deer, and pronghorn antelope. Deer and antelope have been sited within the Plant area, but these animals would not be expected to heavily utilize the upland areas surrounding Pantex Plant. Game birds and other small game include the northern bobwhite, ring-necked pheasant, prairie chicken, scaled quail, mourning dove, rabbit, squirrel, and turkey.

Lake Meredith, Greenbelt Reservoir, and five lakes in the city of Amarillo contain fish. Species harvested from Lake Meredith and Greenbelt Reservoir were channel catfish, white bass, smallmouth bass, largemouth bass, white crappie, and walleye. No harvest data were available for the Amarillo lakes.

2.7 POTENTIAL HUMAN RECEPTORS

This section summarizes available information on potential human receptors at Pantex Plant and in the surrounding area. Population data were obtained primarily from the *Revised Land Use Census, Pantex Plant* (Burns & McDonnell, 1995) with supplemental information from the *Environmental Information Documents* (BPX/MHC, 1998a).

2.7.1 Onsite Population

Currently (2005), Pantex Plant employs 3,730 persons, including management and operating contractors, USDOE and National Laboratory staff, consultants and oversight agency personnel (Nester, 2005b). This employment figure has remained relatively constant over the past 10 years.

2.7.2 Offsite Population Within a 10-Mile Radius

The residential population within a 10-mile (16-km) radius of Pantex Plant, including the towns of Panhandle and Washburn that are just beyond the 10-mile circumference, was estimated at 4,816 in 1995 (Burns & McDonnell, 1995). A summary of the population in each 22.5-degree compass sector within the 10-mile radius is given in Table 2-3. The largest number of people are located in the east compass sector associated with the town of Panhandle (population of 2,353), and in the southwest and south-southwest compass sectors associated with Highland Park Village (population of 1,730) on the outskirts of Amarillo.

Table 2-3. Offsite Population Within a 10-Mile Radius of Pantex Plant

Compass Sector	Population
N	8
NNE	23
NE	23
ENE	37
E (includes Panhandle, pop. 2,353)[a]	2,379
ESE	19
SE	17
SSE	22
S (includes Washburn, pop. 123)[a]	245
SSW	280[b]
SW	1,652[c]
WSW	69
W	26
WNW	5
NW	6
NNW	5
Total Population	**4,816**

[a]This city is just outside the 10-mile radius, but was included because it is part of the Emergency Planning Zone for Pantex Plant (Burns & McDonnell, 1995).
[b]130 of the population are in Highland Park Village.
[c]1,600 of the population are in Highland Park Village.

The nearest residences to Pantex Plant are located across the road from the Plant's northern boundary. The nearest two residences in each compass sector and their distances from Pantex Plant are given in Table 2-4.

Table 2-4. Distance to Nearest Residences from Pantex Plant

Sector	Residence	Distance[a]	
		feet	meters
N	1	16,847	5,135
	2	17,618	5,370
NNE	1	7,572	2,308
	2	18,468	5,629
NE	1	10,210	3,112
	2	11,893	3,625
ENE	1	15,669	4,776
	2	17,054	5,198

Table 2-4. Distance to Nearest Residences from Pantex Plant (continued)

Sector	Residence	Distance[a]	
		feet	meters
E	1	39,137	11,929
	2	41,417	12,624
ESE	1	24,111	7,349
	2	25,908	7,897
SE	1	20,085	6,122
	2	22,490	6,855
SSE	1	23,799	7,254
	2	31,706	9,664
S	1	22,916	6,985
	2	23,248	7,086
SSW	1	19,239	5,864
	2	22,300	6,797
SW	1	16,112	4,911
	2	16,302	4,969
WSW	1	15,718	4,791
	2	20,853	6,356
W	1	16,338	4,980
	2	21,411	6,526
WNW	1	11,644	3,549
NW	1	9,232	2,814
	2	19,386	5,909
NNW	1	19,357	5,900
	2	29,918	9,119

[a]Distance from the center of Pantex Plant.
Source: Burns & McDonnell 1995, Table 1.

2.7.3 Offsite Population Within a 50-Mile Radius

The population within a 50-mile (80-km) radius of the Pantex Plant site was estimated at 269,916 in 1995, based on the *Revised Land Use Census, Pantex Plant* (Burns & McDonnell, 1995). The population by compass sector in 5-mile (8-km) increments is shown in Table 2-5.

Table 2-5. Offsite Population Within a 50-Mile Radius of Pantex Plant

Sector	Distance[a] in miles									
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50
N	7	1	60	88	4,530	294	100	114	128	140
NNE	6	17	59	83	8,562	8,686	1,165	1,291	161	177
NE	6	17	59	83	83	766	158	159	137	115
ENE	13	24	59	59	1,182	86	303	20,377	126	128
E	0	26	2,407[b]	48	58	153	335	114	811	349
ESE	5	14	59	55	63	708	171	99	102	334
SE	10	7	56	679	634	55	48	49	77	2,000
SSE	2	20	46	60	70	30	27	31	81	185
S	16	106	201[c]	225	358	248	107	130	111	171
SSW	20	260	902	1,097	879	250	291	336	879	161
SW	38	1,614	10,596	29,663	23,221	2,469	10,378	402	431	555
WSW	12	57	19,920	44,935	31,876	966	1,402	861	551	572
W	10	16	1,274	770	149	183	161	94	107	958
WNW	5	0	83	116	149	183	205	130	98	380

Table 2-5. Offsite Population Within a 50-Mile Radius of Pantex Plant (continued)

Sector	Distance[a] in Miles									
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50
NW	6	0	83	116	152	241	343	423	370	272
NNW	1	4	82	116	224	300	277	349	12,433	2,099
Radius Total	157	2,183	35,946	78,193	72,190	15,618	15,471	24,959	16,603	8,596
Population Total	**269,916**									

[a]Distance from the center of Pantex Plant.
[b]Includes Panhandle, population of 2,353.
[c]Includes Washburn, population of 123.
Source: Burns & McDonnell 1995, Table 11.

Within the 50-mile (80-km) radius, 18 population centers were identified. The largest population center is Amarillo (1995 population of 157,615) located approximately 17 miles (27 km) southwest of Pantex Plant. Other major population centers include Pampa (1995 population of 19,959) approximately 36 miles (58 km) east-northeast; Borger (1995 population of 15,675) approximately 23 miles (37 km) north-northeast; Dumas (1995 population of 12,871) approximately 42 miles (68 km) north-northwest; Canyon (1995 population of 11,365) approximately 30 miles (48 km) southwest; and Panhandle (1995 population of 2,353) approximately 11 miles (18 km) east (Burns & McDonnell, 1995).

2.7.4 Potential Future Conditions

This section discusses available information on potential future populations and land uses both onsite and within the 50-mile (80-km) radius. Information on future conditions is limited and should be considered speculative because many factors, such as the economy, will influence future types and locations of development.

The population at Pantex Plant is expected to remain stable since the mission of Pantex Plant will continue into the foreseeable future. Therefore, it is expected that management and operations personnel at Pantex Plant will remain at the current 3,700 personnel range, and land use at Pantex Plant will remain industrial. Furthermore, USDOE/NNSA fully intends to maintain the Pantex Plant as industrial land use under any potential agency mission.

No future land use has been projected for the majority of the area within a 50-mile (80-km) radius of Pantex Plant (Pantex, 1996). Based on the *City of Amarillo Planning Department Comprehensive Plan* (City of Amarillo, 1989), future land use plans for Amarillo indicated approximately 6,000 acres (2,428 ha) of new land would be needed to accommodate a population of 200,000 (195,000 was forecasted for 2005). The plan only speculates on the location of this new development, and forecasts that two-thirds of this development would occur within the existing city limits and one-third would occur on land to be annexed into the city in the future (Pantex, 1996).

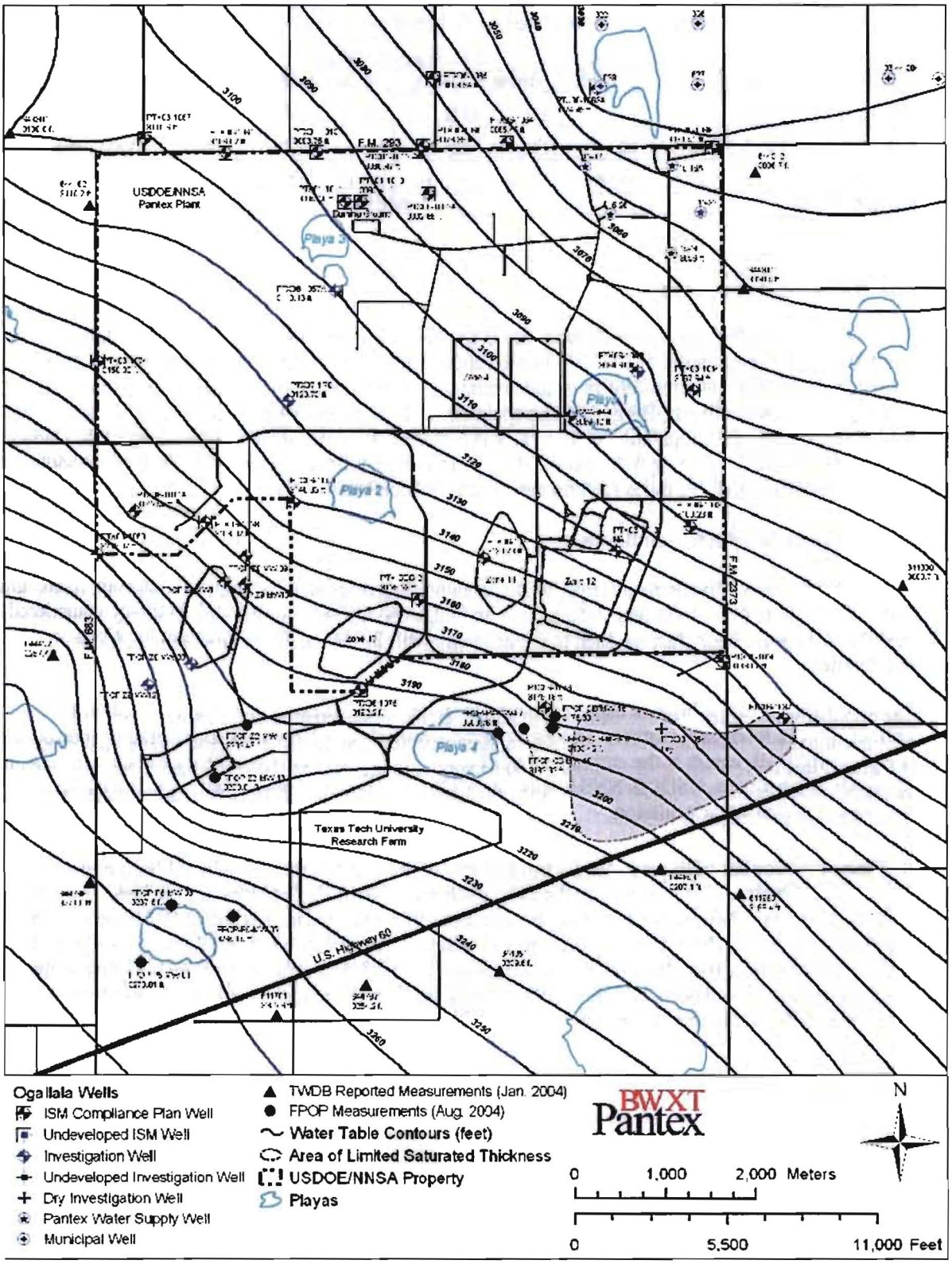


Figure 2-1. Ogallala Aquifer Water Levels at Pantex Plant, December 2004

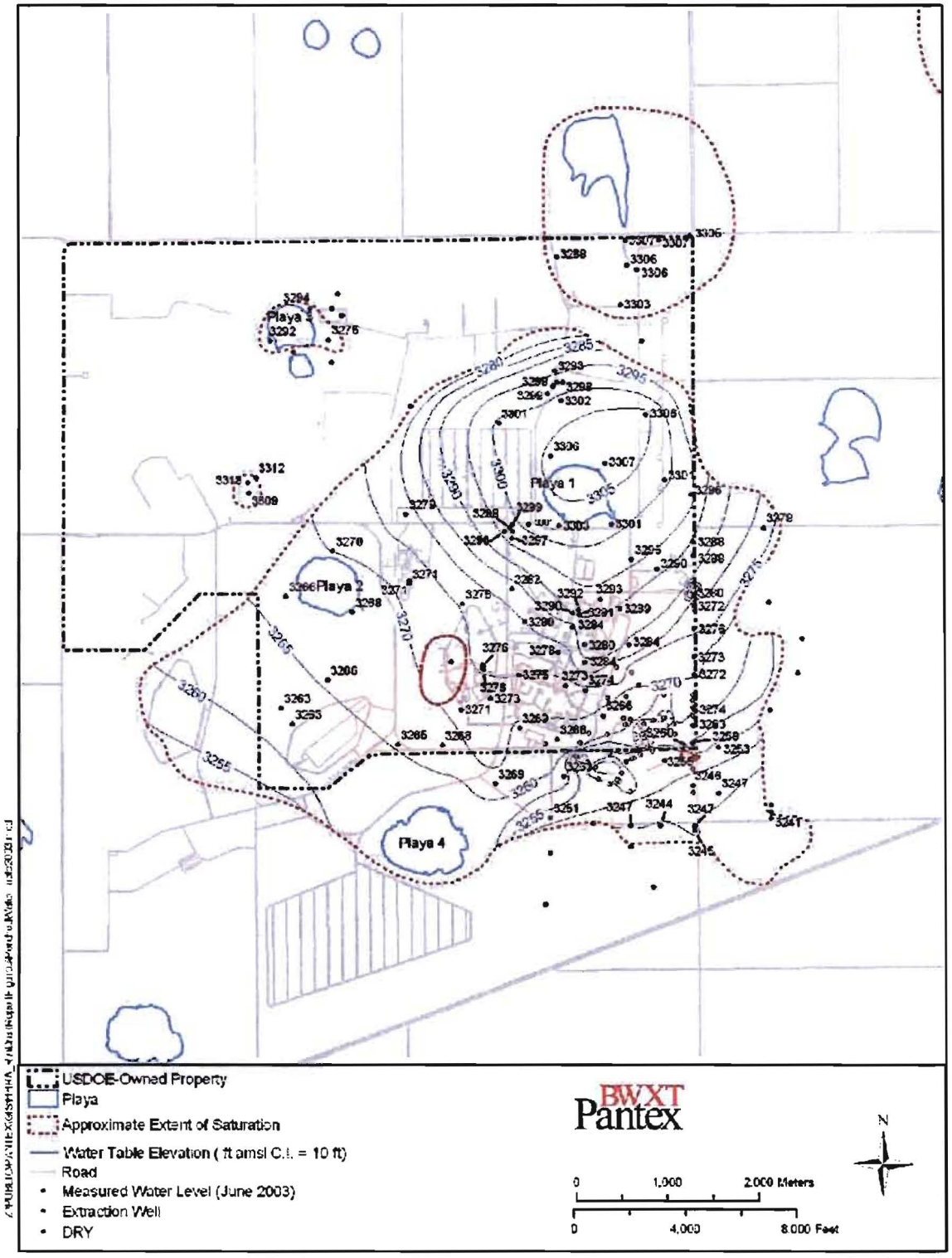


Figure 2-2. Perched Groundwater Water Levels at Pantex Plant, June 2003

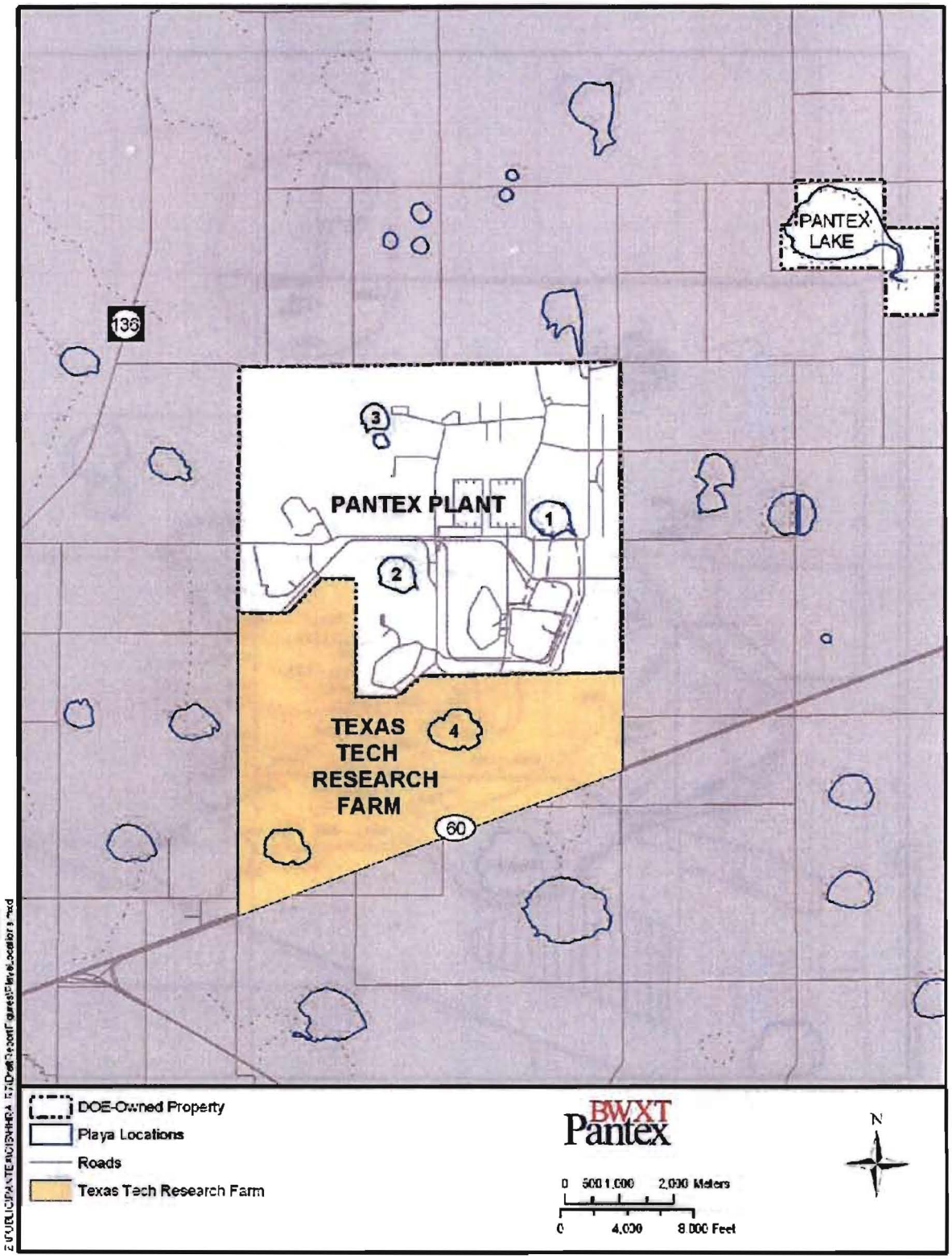


Figure 2-3. Playa Locations at Pantex Plant

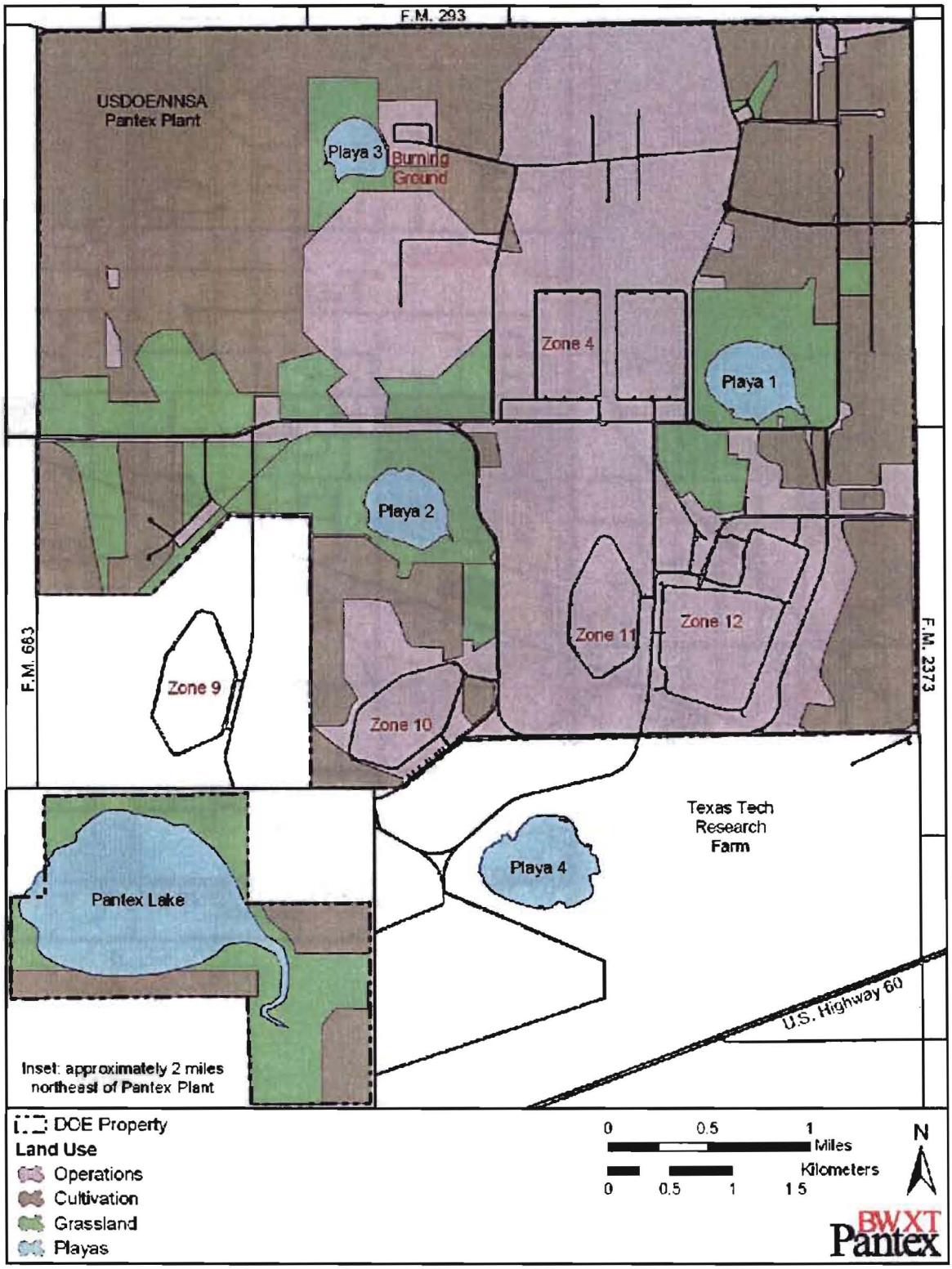


Figure 2-4. Onsite Land Use at Pantex Plant

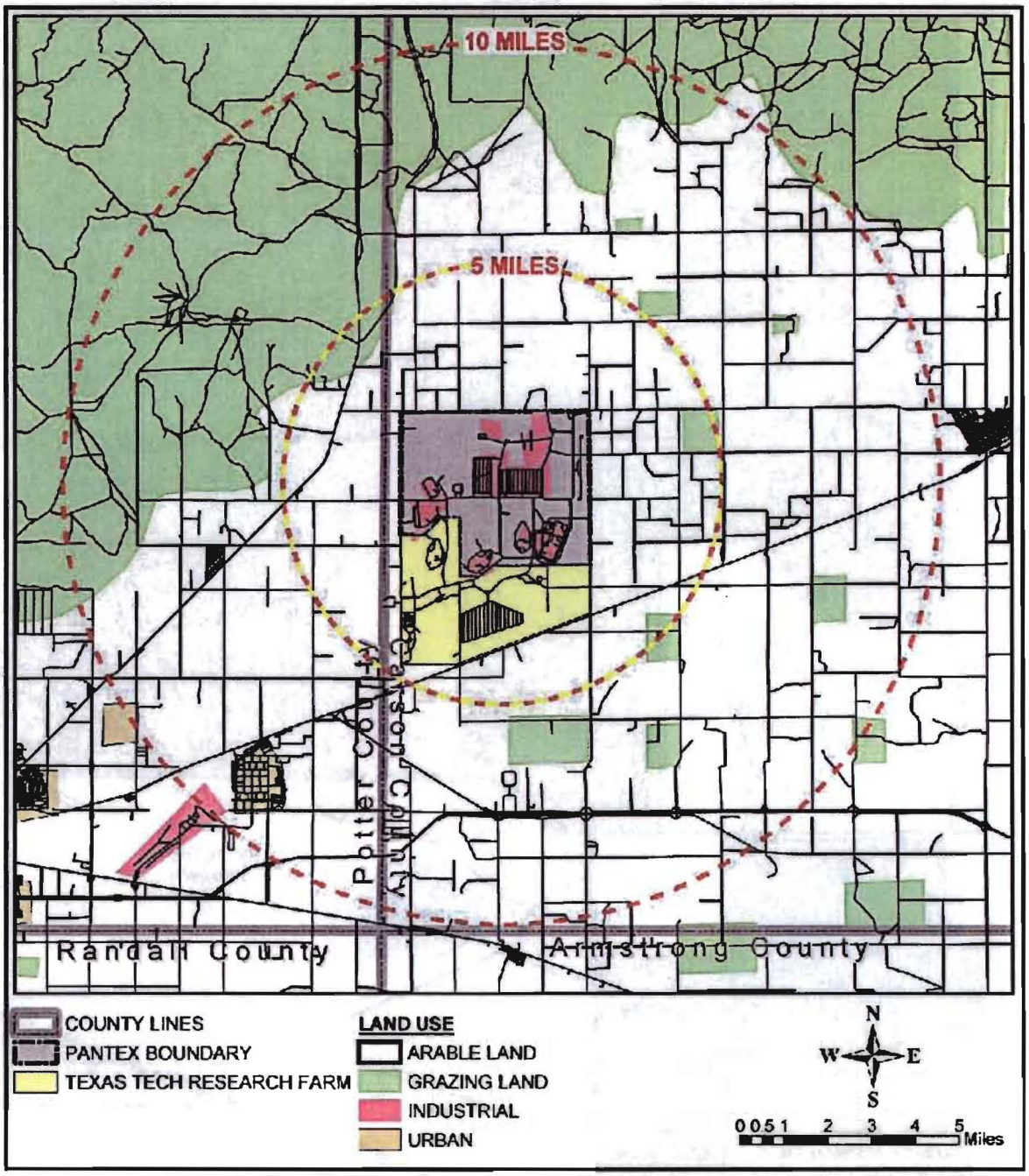


Figure 2-5. Land Use Within a 10-Mile Radius

3.0 CORRECTIVE ACTION UNITS AND CONSTITUENTS OF CONCERN

Corrective action units (Figure 3-1) were included in the HHRAs and the *Site-Wide ERA Report* (BWXT Pantex/SAIC, 2005) based on RRS closure status. The RRRG and 30 TAC §335.551 thru 335.569 were used to determine closure status of each unit. Final closure status is documented in the TCEQ RFI approval letter dated August 26, 2005 (TCEQ, 2005). Closure to RRS 3 required inclusion of the units in a BRA and further evaluation in a CMS. RRS 2 and 3 closures require evaluation of risk to ecological receptors. The results from the risk assessments identified COCs to be addressed in this CMS/FS. The COCs identified and key considerations for their evaluation within this CMS/FS are presented in this Section.

Section 3 is organized as follows:

- Section 3.1 provides a summary of the soil and groundwater COCs identified through completion of risk assessments at Pantex Plant.
- Section 3.2 provides an evaluation of the soil COCs and explains that soil COCs will be addressed through planned ICMs, and therefore, are not evaluated in the remainder of this CMS/FS.
- Section 3.3 provides an evaluation of the perched groundwater COCs, a summary of the extent of groundwater contamination, a summary of the key physical features of the perched groundwater flow system that must be considered in the evaluation of technologies and corrective measures, a summary of source abatement activities conducted at the Plant to address impacted media and to reduce or eliminate continued migration of COCs within or to the perched groundwater, and provides calculated MSCs for the perched groundwater COCs.
- Section 3.4 provides a brief summary of treatability studies completed (or in progress) to evaluate effectiveness and potential for implementation as a comprehensive or portion of a corrective measure for perched groundwater.

3.1 IDENTIFICATION OF CORRECTIVE ACTION UNITS AND COCS CONSIDERED

The risk assessments completed at Pantex Plant identify COCs in the environmental media. The HHRAs (Section 1.3.3) define COCs as COPCs having an individual incremental lifetime cancer risk (ILCR) greater than 1.0E-06 and/or a hazard quotient (HQ) greater than 1.0, or substantially contributing to a cumulative risk greater than 1.0E-06 and/or a HQ greater than 1.0, unless weight of evidence factors indicate the COPC does not represent unacceptable risk. Five separate risk assessments have been conducted for corrective action units at Pantex Plant to identify COCs in environmental media at Pantex Plant. Three of the risk assessments did not identify any COCs in the environmental media associated with the assessments and require no further evaluation in this CMS/FS:

- FS-5 Risk Assessment (BPX/MHC, 1999b)
- *NWAR HHRA Report* (BWXT Pantex, 2005b)
- *Site-Wide ERA Report* (BWXT Pantex/SAIC, 2005).

The following two risk assessments identified COCs in environmental media:

- *Burning Ground HHRA Report* (BWXT Pantex, 2005a)

- *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).

Results from these two risk assessments are summarized below.

3.1.1 Summary of Burning Ground HHRA Results

The risk characterization identified areas of the Burning Ground that result in unacceptable risks/hazards to onsite workers from exposure to soils. The COCs identified in soils at the Burning Ground include RDX, TNT, and ^{238}U (Table 3-1).

Soil and soil gas COPCs evaluated using fate and transport models were found to not impact onsite or offsite receptors evaluated for the Ogallala Aquifer, and no COPCs were currently identified in the Ogallala Aquifer based on the current monitoring network. Evaluation of the sporadic, non-trending detections of constituents in the Ogallala Aquifer that exceed RRS 1 indicated risk from these detections is negligible. Therefore, no COCs were identified for the groundwater pathway. Analysis of volatilization of soil gas COPCs to the air resulted in values lower than conservative risk-based screening levels; therefore, no COCs were identified for this pathway. Evaluation of soil particulate emissions from the Burning Ground to the offsite resident farmer were below acceptable target risk levels; therefore, no COCs were identified for this pathway.

Although the risk assessment does not indicate impacts to the Ogallala Aquifer, long-term monitoring will continue at and downgradient of the Burning Ground area (including Playa 3) to ensure that any potential future impacts to the Ogallala Aquifer would be detected and addressed. This approach provides an additional layer of conservatism intended to address uncertainties common to characterization and assessment of risk associated with historical releases.

3.1.2 Summary of Baseline HHRA Results

The Baseline HHRA risk characterizations are based on an integration of the risk characterization results and uncertainty analysis. The sites included in the Baseline HHRA include:

- Zone 10
- Zone 11
- Zone 12 (including Landfill 3 and SWMUs 5-12a and 5-13c)
- FTA
- Ditches (SWMUs 5-12b, 5-13a and b, 5-14, 5-15a and b, and 4)
- Playas 1, 2, and Pantex Lake
- Landfills 1, 2, 13, 15, SVS 6, and SVS 7a and 7b.

The Baseline HHRA evaluated potential risks from COPCs in soil, soil gas, and groundwater to onsite receptors (industrial worker and construction/excavation worker) under current and future exposure conditions and to an offsite resident farmer under future exposure conditions.

Evaluation of soil gas and groundwater indicated these media do not contribute risk to onsite receptors; therefore, the identification of COCs for onsite worker exposures was focused on COPCs identified in surface soil (0 to 2 ft bgs) and soil (0 to 15 ft bgs). Soil COCs for onsite workers are summarized in Table 3-1. This table identifies exposure areas with calculated risks exceeding the TCEQ and EPA acceptable target risk criteria and the COPCs contributing to any cumulative ILCR>1.0E-06 or HI>1.0.

Evaluation of soil and soil gas indicated these media do not contribute risk to offsite receptors; therefore, the identification of COCs for offsite hypothetical resident farmer exposures was focused on current and future COPCs identified in perched groundwater and the Ogallala Aquifer.

3.1.2.1 Summary of Baseline HHRA COCs for Soil

COPCs identified in surface soil (0 to 2 ft bgs) and soil (0 to 15 ft bgs) in the RFIRs for each of the zones/WMGs/corrective action units were evaluated in the Baseline HHRA:

- Zone 10 is an active operational area. No COCs were identified for soil at Zone 10.

- Zone 11 is an active operational area. Benzo(a)pyrene and dibenz(a,h)anthracene are identified as COCs in surface soil (0 to 2 ft bgs) at Grid Cell 22. Grid Cell 22 is located in the center of Zone 11 and includes a portion of WMG 2 including AOC 8c and SWMUs 117, 118, 119a, 120a, and 148, and part of the Unassigned Former 11-15 Pond. Elevated concentrations of benzo(a)pyrene and dibenz(a,h)anthracene were detected in surface soil around SWMUs 117 to 120a (Building 11-44 Wastewater Treatment Units).

- Zone 12 is an active operational area located in the southeast portion of Pantex Plant. The southern half of Zone 12 (Zone 12 South) including SWMU 5-12a South, WMG 5, and the part of WMG 6/7 west of SWMU 5-12a, is a highly restricted area. Security fences and security police officers prevent entrance by unauthorized personnel and outdoor movement by workers within the security fence is highly restricted. Worker activity outside the Zone 12 South security fence is similar to other inactive operational areas at Pantex Plant. Nine areas were evaluated in Zone 12: SWMU 5-12a (North and South) and SWMU 5-13c, Landfill 3, WMG 5 and WMG 6/7 west of SWMU 5-12a, WMG 9, WMG 10, and SWMU 136.

- SWMUs 5-12a (North and South) and 5-13c comprise the main drainage ditch from the east side of Zone 12 to Playa 1. RDX was identified as a COC in surface soil at SWMU 5-12a South. RDX is a site-related contaminant and is wide-spread along this ditch; however, SWMU 5-12a South is accessed by Pantex Plant personnel even less than other ditches because of its highly restricted location between the security fences on the eastern side of Zone 12; therefore, risks are overestimated in this area. In addition to addressing current COCs identified for the SWMU 5-12a South ditch, deed recordation may be required to address localized work that may occur for future workers.

- Grid Cells 2 and 10 are located adjacent to one another in the northern portion of WMG 6/7 near the former Cooling Tower area. These three grid cells include AOC 13a and 13b, and SWMUs 1, 5-04, and 97. Elevated concentrations of several PAHs are associated with a potential source area at the head of SWMU 1 (Building 12-17 Drainage Ditch). Benzo(a)pyrene is identified as a COC in surface soil for Grid Cells 2 and 10. Other PAHs [benzo(a)anthracene, benzo(b)fluoranthene, indeno(1,2,3-cd)pyrene] also contribute to elevated risk at this location, but were not retained as COCs.

- Grid Cells 17, 18, and 19, located adjacent to one another in the central portion of WMG 6/7, include AOC 10a and SWMUs 2, 122b, 123, and 5-05. Two HEs (RDX and TNT) and five PAHs [benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-c,d)pyrene] were identified as COCs in surface soil (0 to 2 ft bgs); TNT was also identified as a COC in soil (0 to 15 ft bgs). These COCs may have been associated with an elevated wastewater flume system at SWMU 122b, that has now been removed.

- No COCs were identified at Landfill 3, WMG 9, WMG 10, or SWMU 136.
- FTA is an active operational area covering approximately 4.25 acres. COPCs in soil at FTA do not present an unacceptable risk, and no COCs were identified.
- Playa 1, Playa 2, and Pantex Lake were each evaluated separately. COPCs in soil at the playas do not present an unacceptable risk, and no COCs were identified.
- The main ditches draining to playas (SWMUs 5-12b, 5-13a, 5-13b, 5-14, 5-15a, 5-15b, and 4) were each evaluated separately. Other small ditches located completely within a zone/WMG/ SWMU were evaluated as part of that larger unit. Cumulative ILCR and HI results were below TCEQ and EPA acceptable target criteria at all except SWMU 5-13a (with an HI of 1.1). No COCs were identified at any of these ditches.
- Seven landfills (Landfills 1, 2, 13, 15, SVS 6, and SVS 7a and 7b) located outside the main zones were evaluated. Cumulative ILCR and HI results were below TCEQ and EPA acceptable target criteria at Landfill 15, SVS 6, and SVS 7a and 7b. A cumulative ILCR of 1.6E-06 was calculated for surface soil at Landfill 2; however, no COCs were identified at this landfill. COCs were identified at Landfill 1 and Landfill 13:
    - Landfill 1 was a general-purpose sanitary landfill located in the northeast portion of Pantex Plant, north of Playa 1. Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene were identified as COCs in surface soil (0 to 2 ft bgs). Lead was identified as a COC for soil (0 to 15 ft bgs). An administrative cover is in place at Landfill 1; therefore, these risks only apply if the cover is disturbed.
    - Landfill 13, located in the west central portion of Pantex Plant, was used for construction debris. Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene were identified as COCs at Landfill 13. Landfill 13 is located in the impact zone of an active firing range and weapons training facility; therefore, no access is allowed without permission of the range master, so actual risks will be much less than assessed.

COCs in soil are primarily PAHs, with HEs identified as COCs in Zone 12 at SWMU 5-12a South and SWMU 122b and lead (Pb) identified as a COC at Landfill 1. ICMs, including permanent soil removal, have been conducted throughout Pantex Plant. Soil samples from locations where permanent soil removal has occurred were not included in the HHRA dataset. At these locations, confirmation data obtained after excavation were used in place of the removed samples.

3.1.2.2 Summary of Baseline HHRA COCs for Groundwater

The Baseline HHRA evaluated potential risks from the groundwater pathway from potential exposures onsite and offsite. COCs identified in perched groundwater are summarized in Table 3-2.

3.1.2.2.1 Onsite Groundwater

The perched groundwater underlying Pantex Plant is not used for any purpose; therefore, onsite exposure to COPCs in perched groundwater is not currently a complete pathway, nor will it become complete in the future because Pantex Plant will continue to control drilling and water usage. In addition, the Plant will record a restriction on the use of untreated perched groundwater and drilling into and through perched

groundwater in the property deed, in accordance with the requirements for closure to RRS 3 identified in 30 TAC §335.566. Therefore, COPCs in onsite perched groundwater do not represent a risk to onsite receptors.

Groundwater is pumped from the Ogallala Aquifer from five onsite production wells for potable and industrial use at Pantex Plant, as well as the watering of livestock. No COPCs have been identified in the Ogallala Aquifer based on the current monitoring well network. Uncertainties associated with detections above RRS 1 were evaluated in the Baseline HHRA, and no risks were identified. Future exposure would require migration of COPCs from soil, soil gas, or perched groundwater to Pantex Plant production wells in the Ogallala Aquifer; however, subsurface fate and transport modeling indicates no COPCs will reach the Pantex Plant production wells within 1,000 years.

3.1.2.2.2 Offsite Groundwater

Offsite groundwater was assessed as a baseline condition [i.e., in the absence of remediation or measures to control or mitigate risk, in accordance with 30 TAC §335.553(b)(2)]. Additionally, subsurface transport modeling did not consider reactive transport of the COPCs.

All public and most private wells in the vicinity of Pantex Plant are completed in the Ogallala Aquifer; however, one domestic supply well is completed in perched groundwater north of Pantex Plant. The predominant flow directions of perched groundwater beneath Pantex Plant are south and southeast, as discussed in greater detail in Section 3.3.1.1. COPCs are present in the perched groundwater offsite to the east and south of the Pantex Plant boundary. No private wells currently exist in this area; therefore, offsite exposure to COPCs in perched groundwater is not currently a complete pathway.

Perched Groundwater East of Pantex Plant

Although no public or private wells are currently completed in perched groundwater east or south of Pantex Plant, development of a private well in the perched groundwater immediately east of the Plant boundary in the near future could result in exposure to COPC concentrations similar to those currently measured in monitoring wells in this area. Therefore, risks were quantified for a hypothetical future point of exposure along the eastern boundary of Pantex Plant.

COCs identified in perched groundwater east of Pantex Plant include seven HEs (2-amino-4,6-DNT, 4-amino-2,6-DNT, 2,4-DNT, 2,6-DNT, 1,3-dinitrobenzene, RDX, and TNT), one volatile organic carbon (VOC) (1,2-dichloroethane [DCA]), and one metal (boron) in one or more wells.

The primary source areas for these COCs were Zone 12 (SWMU 5-12a [North and South], SWMU 5-13c, and WMG 6/7 west of SWMU 5-12a) and Playa 1. Landfill 3 (SWMU 54) is located in the same upgradient area as these sources, but is not considered a viable source of COPC migration to perched groundwater because it is not associated with focused recharge.

Historic activities resulting in impacts to the perched groundwater have ceased at Pantex Plant (i.e., discharges to ditches, playas, and other areas of focused recharge have been discontinued). Numerous ICMs have also been implemented to reduce potential future impacts to perched groundwater. Measured groundwater concentrations at source areas are lower than in downgradient areas for most COCs (including RDX) and trend analyses do not show increasing COC levels beneath or immediately downgradient of source areas.

Perched Groundwater at Pantex Lake

Pantex Lake is located beyond the extent of perched groundwater underlying Pantex Plant; however, perched groundwater does underlie Pantex Lake. Selenium and nitrate HQs are greater than 1.0 for a resident farmer exposed to concentrations identified in one monitoring well at Pantex Lake. However, nitrate and selenium are not identified as COCs at Pantex Lake because their presence is likely related to agricultural practices in the area rather than past discharges from Pantex Plant.

Perched Groundwater South of Pantex Plant

COCs originating from Zone 11 and Zone 12 have also impacted perched groundwater south of Pantex Plant beneath TTU property at concentrations similar to or higher than in perched groundwater offsite to the east. Southerly groundwater flow beneath Zone 11 and 12 results in a more direct path to the south beneath TTU property. In addition to COCs occurring offsite to the east, COPCs in perched groundwater offsite beneath TTU property include 1,3,5-trinitrobenzene and trichloroethene (TCE) at higher concentrations. Also, groundwater impacted by hexavalent chromium emanating from WMG 5 at the south end of Zone 12 impacts perched groundwater offsite to the south beneath TTU property. Perchlorate, tetrachloroethene (PCE), and chloroform from Zone 11 also may impact perched groundwater offsite to the south beneath TTU property. No water supply wells currently exist in this area; therefore, offsite exposure to COPCs in perched groundwater offsite to the south is not currently a complete pathway because USDOE/NNSA provides water to TTU under the terms of a formal service agreement. This pathway could become complete if a well were placed in this area in the future; however, USDOE/NNSA is currently pursuing an agreement with TTU to formally restrict the use of groundwater and future well drilling in any TTU area that may be impacted by COPCs. This agreement will ensure exposure pathways are eliminated and practices that could potentially contribute to migration of COPCs to the Ogallala Aquifer are controlled.

Ogallala Aquifer

The City of Amarillo operates a well field just north of Pantex Plant containing 39 wells completed in the Ogallala Aquifer; a number of private wells also are installed near Pantex Plant, as shown in Figure 3-2. Perched groundwater underlying portions of Pantex Plant is currently impacted, and COPCs in perched groundwater may migrate to the Ogallala Aquifer by moving downward through the FGZ aquitard, or in areas where the FGZ becomes more permeable. Thus, a hypothetical future groundwater scenario was evaluated for offsite receptors to the east using the Ogallala Aquifer. However, for this exposure pathway to be complete, COPCs in Pantex Plant media must migrate to the Ogallala Aquifer and then to an offsite well location used for potable or agricultural supply.

In accordance with 30 TAC §335.553(b)(2), future concentrations in the Ogallala Aquifer were estimated using subsurface fate and transport modeling. The modeling was conducted as a baseline condition for evaluation of appropriate remedies in the CMS/FS, so the effects of remediation, including the existing PGPTS, are not reflected in the predicted Ogallala Aquifer groundwater concentrations. Furthermore, the effects of sorption and degradation were not considered in the risk calculations for future conditions. However, degradation would likely be a significant factor in reducing risk for COCs that require a long time to reach concentrations above unacceptable risk levels in the Ogallala Aquifer. Finally, the effects of continued decline of water levels in the Ogallala Aquifer were not considered in the risk evaluation. Because the current saturated thickness of the aquifer varies from zero to more than 100 ft in the area southeast of Pantex Plant and some saturated thickness is expected to remain, the decline would likely only affect the timing of potential impacts and size of the associated plume. Current information indicates some areas of the Ogallala Aquifer are already dry beneath the southeastern extent of impacted perched groundwater, thus limiting the potential exposure in this area (water supply wells would not be

completed in this area due to insufficient water availability). Any impacted perched groundwater reaching this dry area could migrate to other areas of the Ogallala Aquifer that still contain water.

Based on the conservative factors discussed above, for a hypothetical future well located just beyond the southeastern plant boundary, 2,4-DNT and RDX are identified as future COCs in the Ogallala Aquifer. As noted above, degradation would likely have a significant impact on 2,4-DNT concentrations; however, RDX risks would likely not be sufficiently reduced by the effects of degradation alone. No other COPCs exceed the risk-based screening value (RBSV) at the point of predicted maximum concentration in the Ogallala Aquifer.

Potential impacts to the Ogallala Aquifer from perched groundwater COPCs may occur in areas near the edge of perched saturation southeast of the Plant, where the FGZ becomes less resistant to downward flow. Maximum concentrations are predicted south of the Plant boundary on TTU property, beneath areas where the FGZ appears to be thinner and more permeable than identified elsewhere beneath Pantex Plant. Potential impacts to the Ogallala Aquifer are predicted in a relatively short timeframe (within approximately 20 years) beneath TTU property where geologic data indicate the fine-grained zone is more permeable. COPCs predicted to reach the Ogallala Aquifer beneath TTU property must migrate northeast across the eastern Plant boundary to reach a hypothetical offsite point-of-exposure. As a result, predicted concentrations in the Ogallala Aquifer beneath TTU property are slightly higher and occur at shorter times in the future than predicted concentrations offsite to the east of Pantex Plant. Offsite Ogallala Aquifer risks southeast of Pantex Plant were predicted within a 40-year timeframe for a hypothetical resident farmer. Currently, only one private well is located in the area southeast of Pantex Plant where potential impacts are predicted in the 40-year timeframe. However, these predicted risks are not expected to actually affect the existing offsite groundwater well because data for this well (obtained after modeling) indicate the Ogallala Aquifer is dry in that area.

3.2 EVALUATION OF SOIL COCS

A summary of the COCs identified in the HHRAs for direct contact with soil is contained in Table 3-1. Based on the results of the HHRAs, voluntary ICMs are currently being implemented for the excavation of impacted soils located within Zone 11, Zone 12, Landfill 1, Landfill 13, and the Burning Ground to address the risk to the industrial worker. Therefore, technologies to develop alternatives for soil to address risk to the industrial worker at these units were not evaluated or discussed in this CMS/FS. The results of these voluntary ICMs and the effects on the resulting risk to the industrial worker posed by the soil COCs identified in the HHRAs will be discussed in individual ICM closure reports for Zone 11, Zone 12, Landfill 1, Landfill 13, and the Burning Ground. The final ICM closure reports will be provided to the regulatory agencies following implementation and evaluation of the impact of the voluntary corrective measures. The ICM closure reports will include a re-evaluation of risk to demonstrate the voluntary corrective measures sufficiently mitigate risk to the industrial worker.

Risk was identified for the construction worker in Landfill 1, Landfill 13, the Burning Ground, and Zone 12. However, construction/excavation activities at Pantex Plant are restricted under the Pantex Plant Work Instruction (WI) 02.01.04.03.01, *How to Obtain a Solid Waste Management Unit (SWMU) Interference Notification* (BWXT Pantex, 2005c). If construction activities are deemed necessary, construction/excavation workers are required to wear proper personal protective equipment (PPE) that is appropriate for work performed within the potentially contaminated areas, in accordance with the WI. With enforcement of this WI, potential exposure to soil COCs is controlled; therefore, the construction/ excavation worker is protected. A deed record is required in accordance with 30 TAC §335.566, *Deed Recordation for RRS 3*, to provide future notification to others in the unlikely event that the property is

ever sold or transferred. Therefore, technologies to develop alternatives for soil to address risk to the construction worker at these units were not evaluated or discussed in this CMS/FS.

Table 3-1. Summary of Human Health Risk Assessment Results at Pantex Plant

		COCs for Direct Contact with Soil[a]	
		Industrial Worker	Construction/ Excavation Worker
Zone/WMG/Corrective Action Unit	**Location**	**Surface Soil (0 to 2 ft)**	**Soil (0 to 15 ft)**
Burning Ground (SWMUs 8, 14 - 52, and Unassigned SWMU)			
SWMUs 14-27 (Explosive Burn Pads) and SWMUs 37-44 (Burning Ground Landfills)	Outside loop Grid Cell 12	RDX	TNT
		TNT	
		^{238}U	
SWMUs 14-27 (Explosive Burn Pads)	Outside loop Grid Cell 13	RDX	RDX
		TNT	TNT
	Inside loop Grid Cell 18	RDX TNT	RDX TNT
Compliance Sampling Location inside Burning Ground fenceline	Grid Cell 17	^{238}U	--
SWMUs 14-27 (Explosive Burn Pads)	Outside loop Grid Cell 22	^{238}U	--
SWMUs 14-27 (Wash Rack within Explosive Burn Pads)	Outside loop Grid Cell 23	RDX	--
Zone 11			
WMG 2: AOC 8c, SWMUs 117-120a, 148, and part of Former 11-15 Pond	Grid Cell 22	Benzo(a)pyrene	--
		Dibenz(a,h)anthracene	
Zone 12			
Inside Zone 12 South security fence	SWMU 5-12a South	RDX	--
Zone 12 South, Former Cooling Tower Area WMG 6/7: AOC 13a and 13b; SWMUs 1, 5-04, 11, and 97	Grid Cell 2	Benzo(a)pyrene	--
	Grid Cell 10	Benzo(a)pyrene	--
Zone 12 South, WMG 6/7: AOC 10a, SWMUs 2, 122b, 123, 5-05[b]	Grid Cell 17	RDX	--
		Benzo(a)anthracene	
		Benzo(a)pyrene	
		Benzo(b)fluoranthene	
		Dibenz(a,h)anthracene	
		Indeno(1,2,3-c,d)pyrene	
	Grid Cell 18	RDX	TNT
		TNT	
		Benzo(a)anthracene	
		Benzo(a)pyrene	
		Benzo(b)fluoranthene	
		Dibenz(a,h)anthracene	
	Grid Cell 19	RDX	--
		Benzo(a)pyrene	

Table 3-1. Summary of Human Health Risk Assessment Results at Pantex Plant (continued)

Zone/WMG/Corrective Action Unit	Location	COCs for Direct Contact with Soil[a]	
		Industrial Worker	Construction/ Excavation Worker
		Surface Soil (0 to 2 ft)	Soil (0 to 15 ft)
Landfills (1, 2, 13, 15; SVS 6, 7a, and 7b)			
Landfill 1 (SWMU 68b)	General purpose sanitary landfill north of Playa 1	Benzo(a)anthracene	Lead
		Benzo(a)pyrene	
		Benzo(b)fluoranthene	
		Dibenz(a,h)anthracene	
Landfill 13 (SWMU 64)	Construction debris landfill in west central portion of Pantex Plant	Benzo(a)pyrene	Benzo(a)anthracene
			Benzo(a)pyrene
			Benzo(b)fluoranthene
			Dibenz(a,h)anthracene
			Indeno(1,2,3-c,d)pyrene

[a]*Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) and the *Burning Ground HHRA Report* (BWXT Pantex, 2005a).
[b]Risks conservatively evaluated considering ditch lining ICM.
COC - constituent of concern
-- No COCs identified

Table 3-2. Summary of Constituents of Concern for Groundwater[a]

Location	COCs		Potential Source
	Current Perched Groundwater[b]		
Offsite East of Pantex Plant boundary	Boron (HQ = 1.5)	2,4-Dinitrotoluene (4.4E-04) (HQ = 1.1)	The primary source areas for these COCs are Zone 12 (SWMU 5-12a (North and South), SWMU 5-13c, and WMG 6/7 west of SWMU 5-12a) and Playa 1.
	2-Amino-4,6-dinitrotoluene (1.1E-05) (HQ = 23)	2,6-Dinitrotoluene (1.9E-05)	
	4-Amino-2,6-dinitrotoluene (6.1E-06) (HQ = 12)	RDX (6.5E-03) (HQ = 41)	
	1,2-Dichloroethane (5.7E-05)	TNT (7.5E-05) (HQ = 17)	
	1,3-Dinitrobenzene (HQ = 1.2)		
Offsite South of Pantex Plant	Boron, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, 1,2-dichloroethane, 1,3-dinitrobenzene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, RDX, and TNT are also present in perched groundwater offsite to the south of the Plant boundary on the TTU property at concentrations similar to those reported at the eastern boundary. Total and hexavalent chromium, HMX, 1,3,5-trinitrotoluene, TCE, and perchlorate have also been detected at the southern boundary but are not COCs at the eastern boundary. Because Pantex Plant supplies all water to the TTU property according to terms of a Service Agreement, no wells currently exist in this area; therefore, offsite exposure to COPCs in perched groundwater is not currently a complete pathway. USDOE/NNSA is pursuing an agreement with TTU to formally restrict groundwater use in this area.		
Offsite at Pantex Lake	None Retained		
	Future Perched Groundwater[c]		
Offsite East of Pantex Plant boundary	Boron (HQ = 1.5)	2,4-Dinitrotoluene (4.4E-04) (HQ = 1.1)	Impacts to perched groundwater will persist in the future as residual pore water from past industrial wastewater releases drains from the overlying partially saturated formation. Potential future impacts are predicted to continue in the future, but at lower levels than those currently observed in downgradient areas.
	2-Amino-4,6-dinitrotoluene (1.1E-05) (HQ = 23)	2,6-Dinitrotoluene (1.9E-05)	
	4-Amino-2,6-dinitrotoluene (6.1E-06) (HQ = 12)	RDX (4.0E-03) (HQ = 41)	
	1,2-Dichloroethane (5.7E-05)	TNT (7.5E-05) (HQ = 1.7)	
	1,3-Dinitrobenzene (HQ = 1.2)		
Offsite South of Pantex Plant	Boron, total and hexavalent chromium, 2-amino-4,6-dinitrotoluene, 4-amino-2,6-dinitrotoluene, 1,2-dichloroethane, 1,3-dinitrobenzene, 1,3,5-trinitrotoluene, 2,4-dinitrotoluene, 2,6-dinitrotoluene, HMX, RDX, TCE, and TNT present in perched groundwater offsite to the south of the Plant boundary are also expected to persist in the future. Perchlorate, tetrachloroethene, and chloroform from Zone 11 may also impact the perched groundwater on the TTU property to the south in the future. USDOE/NNSA is pursuing an agreement with TTU to formally restrict groundwater use in this area. In the absence of this agreement, risks would be similar to those reported offsite to the east, if a well is installed in the future.		
Offsite at Pantex Lake	None Retained		

Table 3-2. Summary of Constituents of Concern for Groundwater (continued)

Location	COCs		Potential Source
	Future Ogallala Aquifer[c]		
Onsite Production Wells	None Retained		
Offsite at Pantex Plant	2,4-dinitrotoluene (2.5E-06)	RDX (2.2E-04) (HQ = 2.2)	COPCs in perched groundwater may migrate to the Ogallala Aquifer.
Offsite at Pantex Lake	None Retained		

[a] *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006), *NWAR HHRA* (BWXT Pantex, 2005c), and the *Burning Ground HHRA* (BWXT Pantex, 2005b).
[b] No domestic supply wells are currently completed in the area of perched groundwater impacted by COPCs. Current risks are calculated using current measured concentrations for a hypothetical future well completed in perched groundwater.
[c] Future risks are calculated for a hypothetical future well completed in perched groundwater or the Ogallala Aquifer at the location of maximum offsite future concentration predicted using subsurface modeling
COC - constituent of concern

3.3 EVALUATION OF GROUNDWATER COCs

As part of the groundwater evaluation, a fate and transport groundwater flow model was developed that focused on migration of COPCs to assess "potential adverse effects under future conditions caused by the release of contaminants in the absence of any actions to control or mitigate the release" [30 TAC §335.553(b)(2)]. Results of the subsurface transport modeling indicate receptor exposure to impacted groundwater is an incomplete pathway for FS-5, NWAR, Zone 10, Zone 11, FTA, ditches, landfills, and the Burning Ground. Therefore, groundwater does not contribute to risk to receptors at these units.

A level of uncertainty is associated with the analysis of potential groundwater migration to the south at Zone 10. This uncertainty will be managed through a groundwater-monitoring program to be established with consideration of Zone 10. An uncertainty is also associated with the conclusion that COPCs in perched groundwater at Zone 11 will not migrate south of Pantex Plant within 1,000 years (i.e., beneath TTU property) because little is known of the perched groundwater influence from Playa 4. Perched groundwater COPCs have been detected in offsite perched groundwater in monitoring wells located south of the Plant assigned to SWMU 5-15b (ditch). However, no supply wells currently exist in this area, and USDOE/NNSA is currently pursuing an agreement with TTU to formally restrict the use of groundwater and future well drilling in any TTU area that may be impacted by COPCs.

COPCs in perched groundwater beneath and downgradient of Zone 12 are the only significant potential source to the Ogallala Aquifer. The historical processes that resulted in the formation of impacted perched groundwater no longer occur. Because the amount of recharge to perched groundwater has been greatly reduced, COPCs currently in soil and soil gas at Zone 12 are not significant sources for future potential impacts to the Ogallala Aquifer southeast of the Plant. Monitoring data beneath and immediately downgradient of source areas indicate stable or decreasing constituent concentrations in the perched groundwater. Soil and soil gas COPCs in Zones 10 and 11 and other areas of the Plant are not significant sources to the Ogallala Aquifer because of the lack of recharge mechanisms, presence of perched groundwater and the FGZ, and distance to a receptor location in the Ogallala Aquifer.

As discussed previously, predictions of future potential impacts to the Ogallala Aquifer were assessed under baseline conditions, i.e., in the absence of remediation or measures to control or mitigate risk, in accordance with 30 TAC §335.553(b)(2). This baseline condition is used to evaluate the need for remedial measures to be evaluated in this CMS/FS.

USDOE/NNSA has adopted and implemented a proactive strategy to reduce the potential for COPCs in perched groundwater to impact the Ogallala Aquifer. This strategy includes interim measures such as the PGPTS, remediation pilot studies such as a permeable reactive barrier and *in situ* bioremediation, and institutional controls such as use of treated wastewater for irrigation instead of discharge to Playa 1 to reduce the continuing recharge to perched groundwater. Supporting information concerning groundwater resources, source locations, source abatement activities, and Innovative Technologies for Remediation Demonstration (ITRD) evaluations, as well as results and conclusions of the RFIR and HHRA with respect to onsite and offsite groundwater are presented in the remainder of this section.

3.3.1 Groundwater Strategy

As noted in Section 2.2.3, three primary areas of perched groundwater occur beneath Pantex Plant. The largest area of perched groundwater underlying Pantex Plant is associated with natural recharge from Playas 1, 2, and 4, treated wastewater discharge to Playa 1, and historical releases to the ditches draining Zones 11 and 12. Smaller areas of perched groundwater are associated with Playa 3 (near the Burning Ground) and Pratt Playa (near the northeast corner of Pantex Plant). Impacted perched groundwater south and east of Playa 1 includes the COCs that currently exceed regulatory limits or may exceed them in the

future. Key features of the perched groundwater flow system pertinent to corrective measures evaluation include:

- Perched groundwater flow conditions
- Depth to perched groundwater and saturated thickness
- FGZ character
- Perched groundwater flux across the FGZ.

3.3.1.1 Perched Groundwater Flow Conditions

Flow in the perched groundwater is governed by the topography of the FGZ and localized sources of groundwater recharge. The *Groundwater RFIR* (Stoller, 2004) noted that several depressions or possible paleochannels on the FGZ surface have been shown to be laterally continuous over relatively short distances (generally less than 0.5 mile). These fluvial channels are braided with one another or cross-cut by other channels; they provide no distinct control on groundwater flow. Instead, the general flow direction is thought to be the result of an overall south-southeast dip of the FGZ surface beneath the eastern portion of the Plant. This dip, along with perched groundwater mounding associated with infiltration of past industrial discharges in Playa 1, appears to have the most significant effect on flow direction. Figure 3-3 illustrates the south-southeast dip of the FGZ surface beneath the Plant.

There is a prominent flow divide (Figure 3-4) that runs generally north and south through Playas 1 and 4. On the western side of the divide beneath much of Pantex Plant, perched groundwater flows westward, but the main perched groundwater does not extend beyond the western boundary of Pantex Plant. On the eastern side of the divide, perched groundwater generally flows eastward towards the Plant boundary, with portions also flowing south onto TTU property.

The flow divide is important in understanding both the results of the risk assessment and the evaluation of corrective measure alternatives. COCs in perched groundwater west of the flow divide have a much longer travel path to a potential point of exposure. As a result, many constituents identified in perched groundwater west of this flow divide are not retained as COCs, because travel times to potential points of exposure are in excess of 1,000 years. ICMs or other corrective measures implemented west of this flow divide will have less value than similar activities implemented east of the flow divide.

3.3.1.2 Depth to Perched Groundwater and Saturated Thickness

The depth to perched groundwater varies, and ranges from about 213 ft near Playa 1 to 280 ft at the southern edge beneath Texas Tech property. Figure 3-5 depicts the perched groundwater saturated thickness. Saturated thickness ranges from zero or no perched groundwater at the perched groundwater fringe to nearly 80 ft beneath Playa 1, with an average saturated thickness of 22 ft. Most of the areas to the south and east of the Plant have saturated thicknesses ranging from 0 to 15 ft. Saturated thicknesses less than 10 to 15 ft are not amenable to groundwater extraction. The thin saturated thickness and depth to perched groundwater present a significant challenge to conventional pump and treat or other technologies relying upon hydraulics (to either remove impacted groundwater or to deliver amendments).

3.3.1.3 FGZ Character

The character of the FGZ has been documented in the *Groundwater RFIR* (Stoller, 2004) and in subsurface modeling efforts (BWXT Pantex/SAIC, 2004). The FGZ consists of several fining upward sequences capped by 1 to 2 ft clays. During the RFI, over 100 additional permeability measurements were collected from the upper surface of the FGZ. Site investigation efforts during the RFI also identified

areas to the south and east of the Plant where the FGZ transitions into coarser-grained, more permeable materials. These areas occur near the extent of perched groundwater saturation and are generally depicted in Figure 3-6. These transition areas are based upon the increase in permeability at the top of the FGZ. ICMs or corrective measures implemented in these areas need to consider the potential impacts to flux across these areas to the underlying Ogallala Aquifer. Adding significant volumes of amendment will increase hydraulic gradients and flux across the FGZ, unless efforts to remove a similar quantity of perched groundwater are implemented concurrently.

3.3.1.4 Perched Groundwater Evolution and Flux

The main perched groundwater covers an area of 14.85 square miles with a current volume of water of approximately 15 billion gallons (BWXT Pantex/SAIC, 2006). The modeling completed for the Baseline HHRA indicated pre-Pantex Plant operation perched groundwater volumes at approximately 8 billion gallons. The simulation of 40 years of Pantex Plant operations, including the effects of significant discharges (from mid to late 1950s to mid to late 1990s) resulted in both the expansion and increase in perched groundwater footprint and volume. Modeling results also indicate pore water retained in the vadose zone will continue to drain, increasing the perched groundwater volume to approximately 17.5 billion gallons over the next 150 to 200 years. The majority of drainage beneath source areas is predicted to occur within the next 50 to 100 years. As the volume of perched groundwater increases, the flux of perched groundwater across the FGZ can also be expected to increase. Modeling results indicate the flux across the FGZ (from the entire perched groundwater footprint) will increase from approximately 142 gpm (currently) to 190 gpm (150 to 200 years into the future) as the volume of perched groundwater increases. In the southeast area of the Plant, including areas offsite to both the east and south, the flux across the FGZ increases from 44 gpm to 62 gpm for the same time intervals.

3.3.2 Extent of Contamination

The *Groundwater RFIR* (Stoller, 2004) provides a complete discussion of the nature and extent of COPCs in perched groundwater. The Baseline HHRA identified nine COCs (seven HEs: 2-amino-4,6-DNT; 4-amino-2,6-DNT; 2,4-DNT; 2,6-DNT; 1,3-dinitrobenzene; RDX; and TNT; one VOC: 1,2-DCA; and one metal: boron) for perched groundwater south and east of Pantex Plant. Of these, RDX is the most prevalent COC in perched groundwater. The approximate extent of RDX impacts in perched groundwater at Pantex Plant is shown in Figure 3-7. The highest concentrations of RDX are observed south of the Plant boundary on TTU property and along the eastern Plant boundary. Current concentrations observed near the known source areas (WMG 6/7, SWMU 5-13c, and Playa 1) are much lower. The lower concentrations near the source areas indicate influx of RDX to the perched groundwater was much greater in the past, the observed nature and extent of RDX impacts are a result of historical releases, and improved waste management practices have mitigated continuing influx of RDX to the perched groundwater.

Corrective measures presented in Section 7 of this document are evaluated based on the effectiveness of remediating RDX in perched groundwater. However, the presence not only of the eight other COCs identified in the perched groundwater, but all perched groundwater COPCs are considered in the evaluation of the various alternatives. As a result, the selected alternative must address HEs, metals, and VOCs simultaneously due to commingling of contaminant plumes.

As shown in Figure 3-7, areas of RDX-impacted perched groundwater occur offsite to both the south and east, in areas of low saturated thickness and adjacent to or overlying areas where the FGZ may be more permeable. Using water levels from June 2003, porosity of 0.40, and RDX initial conditions from the Baseline HHRA (BWXT Pantex/SAIC, 2006), the volume of perched groundwater impacted by RDX at concentrations greater than 7.7 µg/L (RRS 2 residential standard) is calculated at 4.45 billion gallons.

The volume of impacted perched groundwater (>7.7 µg/L RDX) offsite to the south on TTU property is estimated at 250 million gallons; the calculated volume offsite to the east is 640 million gallons. Using these numbers, approximately 20% of the impacted perched groundwater occurs offsite to the south and east of Pantex Plant, in areas of low saturated thickness (generally less than 15 ft of saturated thickness).

3.3.2.1 Source Locations

The impacts from known historical source areas at the surface are still apparent in the perched groundwater beneath them. The primary sources of perched groundwater COPCs occurred in Zone 12, the ditches draining Zone 12, and Playa 1 (BWXT Pantex/SAIC, 2006). Complete historical migration pathways for HEs, metals, and VOCs resulting in impacts to perched groundwater have been identified for Zone 12. Runoff pathways from Zone 12 include the SWMU 5-13 ditch draining to Playa 1 and the SWMU 5-12b and 5-15b ditches draining to Playa 4. The only active pathways to perched groundwater are gaseous diffusion and leaching at ditches and Playa 1 as residual contamination in the subsurface continues to drain to underlying perched groundwater.

Examination of the current distribution of COPCs associated with the source areas in Zone 12 suggest ongoing impacts, but at a reduced level compared to historical conditions. The majority of COPCs exhibit higher concentrations downgradient from the source areas. Therefore, concentrations reaching the perched groundwater must have been historically higher than those currently observed. The time frame for these continued, but lower, impacts to the perched groundwater is approximately 50 to 100 years, based on the predicted time frame for drainage of historical discharges from the vadose zone above the perched groundwater.

The source areas for HEs, metals, and VOCs, as evaluated in the fate and transport groundwater flow model, are more fully described below.

3.3.2.2 High Explosives

The main source of HEs in Zone 12 was the Building 12-43 wastewater treatment unit in WMG 6/7 (SWMU 122b) and associated industrial wastewater discharges. Industrial wastewater discharges entered the SWMU 2 and 5-05 ditches that connect with the SWMU 5-12a main drainage ditch for Zone 12, then drained to the SWMU 5-13c ditch, and finally drained to Playa 1. The water provided the driving force for HEs to leach into the subsurface. Industrial discharges that released constituents to the ditches were discontinued in the late 1980s. Four HE compounds (HMX, RDX, 1,3,5-trinitrobenzene, and TNT), detected in both soil and perched groundwater, have complete historical leaching pathways to the FGZ, as identified through soil sampling. Other HE compounds detected in perched groundwater beneath Zone 12 either reached the groundwater as a result of wastewater discharges or are degradation byproducts of other HE compounds. Fifteen HE compounds were detected in perched groundwater beneath and downgradient of Zone 12. The HE plume occurs beneath a large portion of Zone 12 and extends south and east of Zone 12 beyond the Pantex Plant property line and to the north beyond Playa 1. The extent of the HE plume is affected by radial flow from Playa 1 and is indicative of sources in Zone 12, along the SWMU 5-12a and 5-13c ditches, and Playa 1. Non-contact cooling water and condensate discharges to the ditches were eliminated by 1999. Source locations for perched groundwater HEs evaluated in the Baseline HHRA include:

- WMG 6/7
- SWMU 5-13c ditch
- Playa 1 area.

3.3.2.3 Metals (Inorganics)

Six metals/inorganics (boron, cyanide, total chromium, hexavalent chromium, nickel, and strontium) are identified in perched groundwater resulting from Zone 12 activities. The six metals/inorganics have historically leached to the perched groundwater similar to HEs. The metals/inorganics were included in industrial wastewater discharged to the ditches and ultimately to Playa 1. Total chromium and hexavalent chromium originate from chromate solutions that were added to cooling tower water to control algae growth. In addition to metals on the eastern side of Zone 12, a hexavalent chromium plume originates from WMG 5 in southern Zone 12, where ditches were used to convey discharges to Playa 4. This chromium plume is localized to a small source area, indicating the ditch was not a major contributor to this plume. Source locations for perched groundwater metals evaluated in the Baseline HHRA include:

- WMG 6/7
- SWMU 5-13c ditch
- Playa 1 area
- AOC 13 (Former Cooling Tower).

3.3.2.4 VOCs

VOCs are migrating by gaseous diffusion to perched groundwater beneath Zone 12. Historical VOC migration pathways include leaching and runoff. VOCs in soil gas have been detected at WMG 6/7, WMG 10, and SWMU 136. Five compounds (1,2-DCA, trichlorofluoromethane, Freon-113, TCE, and chloroform) exceed their RRS 1 action levels (ALs). Other VOCs have been detected in groundwater at levels below RRS 1. The WMG 6/7 VOCs originated from the SWMU 122b HE wastewater processing facility. The SWMU 136 VOCs originated from a chemical laboratory and dry well. The WMG 10 VOCs originated from a wastewater sump near the old vehicle maintenance facility. Historical runoff pathways from VOC source areas in Zone 12 to Playa 1 no longer exist. The extent of VOCs in perched groundwater indicates discharges to Playa 1 were not a main contributor to the perched groundwater VOC plumes. The main contributors were soil gas and point source discharges to dry wells, sumps, and possibly ditches. Industrial discharges to these point sources and the ditches have been eliminated. Source locations for perched groundwater VOCs evaluated in the Baseline HHRA include:

- AOC 13 Former Cooling Tower area
- WMG 6/7
- WMG 10.

3.3.3 Source Abatement

Several types of ICMs have been, and continue to be, conducted at Pantex Plant to eliminate exposure pathways to current onsite workers and groundwater, minimize exposures to offsite receptors, and minimize impacts to the environment (i.e., transport through the ditches to the playas or through the soil column to groundwater). ICMs completed at Pantex Plant include excavations, landfill administrative covers, deactivation and decommissioning (D&D), ditch lining, bioremediation/ozone pilot system installation and monitoring, SVE systems, and PGPTS installation, expansion, and continuing operation (Stoller, 2004b):

- **Excavations:** During RFI efforts to delineate COPC extent, "hot spot" locations were identified and ICMs subsequently conducted. ICMs generally included excavation and removal of near-surface soils impacted above RRS 2 ALs. Soil samples were collected and analyzed from all excavations to confirm the effectiveness of the removal action.

- **Administrative Landfill Covers:** Administrative maintenance covers were constructed over several landfills (Landfills 1, 2, 3, 12, and 13) to eliminate fugitive dust emissions, promote runoff rather than infiltration, and eliminate COPCs in runoff.

- **D&D:** Facilities at Pantex Plant that are no longer being used undergo D&D. In 2003, the Old Sewage Treatment Plant (OSTP), the HE synthesis complex, including Building 11-36, and the Building 12-10 HE preparation complex underwent D&D. Plans for removal of other unused facilities are ongoing.

- **Ditch Lining:** Ditches are lined to reduce infiltration from natural runoff in the industrial zones of the facility. Recently, two ditches were lined: SWMU 5-05 and SWMU 2 located in WMG 6/7 in Zone 12.

- **Bioremediation/Ozone Pilot System Installation and Monitoring:** The *in situ* HE Biodegradation Expansion Site was constructed in 2001. The expansion site was designed and built as a larger pilot-scale demonstration of the *in situ* nitrogen gas injection technique for treatment of HE in the shallow, unsaturated soils at SWMU 122b. Rates of degradation were not sufficient to continue the demonstration and the system was converted to ozone injection in 2004. Rates of degradation through oxidation of HEs induced by the ozone appear to be greater than observed through the bioremediation efforts. Monitoring of the effects of ozone injection is continuing.

- **SVE:** SVE is an *in situ* unsaturated (vadose) zone soil remediation technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile COPCs from the soil. Construction of a full scale SVE system for the former Building 11-36 area was completed and became operational in June 2005. An SVE system is also located at the Burning Ground.

- **PGPTS:** The PGPTS is located southeast of Zone 12. The system was installed in 1995 and updated several times (most recently in 2006) and currently consists of 52 extraction wells and 5 injection wells. The system is designed to remove impacted perched groundwater, precipitate out the hexavalent chromium, remove HEs and VOCs by pumping the water through granular activated carbon (GAC), and re-inject the water into the perched groundwater. The system treats approximately 7.5 million gallons of water per month, and has treated over 459 million gallons as of March 2006. A conveyance line was constructed in 2005 to allow discharge of the treated water from the PGPTS to the new subsurface irrigation system installed as part of the Pantex Plant WWTF upgrades. Also, modeling simulations of corrective measure alternatives present in this CMS/FS considered the PGPTS before addition of the three most recent extraction wells; i.e., with 49 extraction wells and 5 injection wells.

In addition to these source abatement activities, Pantex Plant improved waste handling practices in accordance with the Pantex Plant Hazardous Waste Permit (HW-50284) and, beginning in the late 1980s, eliminated the release of industrial wastewater discharges to the ditches. Figure 3-8 presents a timeline summarizing the history of discharges from Zone 12 to the ditch system and Playa 1. During Cold War operations, industrial process wastewaters were discharged directly to the ditches that were used to carry water from effluent sources (industrial wastewater, treated sanitary wastewater, cooling water discharge, and stormwater runoff) at Pantex Plant to Playas 1, 2, and 4. The majority of the wastewaters from the production facilities and their supporting operations were generated on the east side of Zone 12, flowed into the eastern ditch system, and either infiltrated into the ditch soils or flowed into Playa 1. The volume of wastewater discharged on the east side averaged approximately 224,000 gpd up to an estimated maximum of 314,000 gpd (Ramsey et al., 1995). Wastewater from operations in Zone 11 produced

relatively small amounts of wastewater (66,000 gpd average to a maximum of 95,000 gpd) that entered the Zone 11 ditch system, but most infiltrated into the ditch soils rather than flowing to the playas. Most of the Zone 11 discharge was released to Playa 1 through the SWMUs 3, 12, and 5-13a ditches, with smaller amounts entering the ditches that lead to Playas 2 and 4. The high volume of treated and untreated wastewater discharge, primarily from Zone 12 with smaller amounts from Zone 11, that entered Playa 1 and its ditch system, created the impacted portion of the main perched groundwater beneath Pantex Plant. Other smaller source areas (e.g., FTA, WMG 10, SWMU 136, evaporation pits in Zone 11) contribute to the perched groundwater, but impacts are localized in extent.

Discharges of untreated industrial wastewater to the ditch system were eliminated in the 1980s to implement improved environmental controls and to comply with permit requirements. During the 1990s, the Plant began reducing the discharge of treated wastewater to the ditches, and by 1999 even non-contact cooling water and condensate discharges to the ditches were discontinued (MHC, 2000). Since 1999, wastewaters have been discharged to the sanitary sewer system and directed to the Pantex Plant WWTF.

Until 2005, treated effluent from the WWTF was released into a ditch approximately 350 ft from Playa 1. Flow in the other ditches since 1999 has comprised only stormwater runoff and infrequent releases of potable water related to maintenance and testing of the Plant's fire protection systems.

A new subsurface irrigation system for the beneficial reuse of treated wastewater has been constructed and routine discharge to Playa 1 has been eliminated. With the elimination of regular discharge to the playa, Playa 1 is expected to once again be an ephemeral water body. The reduction or elimination of discharge to the ditches and Playa 1 has eliminated the primary driving force for further movement of COPCs through the ditches and Playa 1 soils, as well as the driving force that caused the expansion of the perched groundwater to its current extent. The effects of reduced wastewater discharge were considered in the evaluation of future groundwater plume movement.

3.3.4 Media-Specific Concentrations

Under RRS 3, MSCs can be derived using site-specific information for land use and associated potential receptors, but these cleanup values must consider multiple contaminants within the medium and exposure to multiple contaminated media, when necessary. Media cleanup requirements under RRS 3 also allow the use of long-term site controls (e.g., institutional or engineering controls) to attain regulatory compliance.

The risk-based MSCs for groundwater are the MCLs (when available), which are promulgated by the Safe Drinking Water Act. Otherwise, groundwater MSCs are calculated by dividing the target risk level by the unit risk value (URV) established in the HHRAs (documented in Appendix H of the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]) without adjustment. Due to the presence of multiple chemicals, the target risk level is adjusted to ensure the cumulative cancer risk does not exceed 1.0E-04 and the HI does not exceed 1.0. A target risk level of 1.0E-05 for carcinogens and 0.1 for noncarcinogens accounts for the potential for cumulative effects. This is consistent with the development of RRS 2 MSCs, as the primary risk driver for groundwater (RDX) is a Class C carcinogen, which is calculated at a 1.0E-5 risk level for RRS 2 MSCs. For COCs with both cancer and noncancer endpoints, both cancer and noncancer MSCs are calculated; whichever yields a lower value is retained as the MSC. The offsite resident farmer is the only receptor and the resulting MSCs for the COCs identified in Table 3-2 are summarized in Table 3-3.

Table 3-3. Risk-Based Groundwater Media-Specific Concentrations

COC	Cancer URV	Noncancer URV_{child}	Cancer MSC	Noncancer MSC	MSC[a] (mg/L)	COC	RRS 2 AL (mg/L)
1,2-Dichloroethane	9.2E-03	2.0E-01	1.09E-03	5.0E-01	5.00E-03	MCL	5.00E-03
1,3-Dinitrobenzene	--	7.6E+02	--	1.3E-04	1.3E-04	NC	3.65E-03
2,4-Dinitrotoluene	1.6E-02	3.9E+01	6.37E-04	2.6E-03	6.37E-04	C	1.00E-03
2,6-Dinitrotoluene	1.6E-02	7.7E+01	6.37E-04	1.3E-03	6.37E-04	C	1.00E-03
2-Amino-4,6-dinitrotoluene	2.7E-04	5.4E+02	3.72E-02	1.9E-04	1.9E-04	NC	6.10E-03
4-Amino-2,6-dinitrotoluene	2.6E-04	5.2E+02	3.89E-02	1.9E-04	1.9E-04	NC	6.10E-03
Boron	--	9.0E-01	--	1.1E-01	1.1E-01	NC	3.29E+00
RDX	2.4E-03	2.4E+01	4.15E-03	4.2E-03	4.15E-03	C	7.74E-03
TNT	6.8E-04	1.5E+02	1.46E-02	6.7E-04	6.7E-04	NC	1.83E-02

[a] Media-specific concentration (MSC) based on MCL when available, or the lowest MSC developed from a chemical-specific HQ of 0.1 for noncarcinogens and chemical-specific ILCR of 1.0E-05 for carcinogens.
-- not applicable
AL - action level
C - MSC based on cancer endpoint
COC - constituent of concern
MCL - MSC is the maximum contaminant level
NC - MSC based on noncancer endpoint
RRS - risk reduction standard
URV - unit risk value

3.3.5 Summary of COCs Requiring Evaluation in Perched Groundwater

Risk characterization results from the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) identified nine COCs as posing a potential risk to an offsite receptor. Because groundwater remediation will require remediation of the perched groundwater within Pantex Plant boundaries, the onsite perched groundwater was re-evaluated to identify all COPCs that will need to be addressed through a treatment option in this CMS/FS.

The evaluation of data for perched groundwater in this CMS/FS assumed a current land use scenario (industrial). Based on this evaluation, 1,3,5-trinitrobenzene, hexavalent chromium, total chromium, TCE, and TNT will be included with the nine COCs previously identified in the Baseline HHRA as posing potential risk to an offsite receptor. Thus, the following 14 COCs will need to be addressed for treatment options within this CMS/FS:

- 1,2-DCA
- 1,3,5-Trinitrobenzene
- 1,3-Dinitrobenzene
- 2,4-DNT
- 2,6-DNT
- 2-Amino-4,6-DNT
- 4-Amino-2,6-DNT
- Boron
- Chromium (hexavalent)
- Chromium (total)
- HMX
- RDX
- TCE
- TNT.

3.4 TREATBILITY TESTING

BWXT Pantex has completed and is continuing to conduct numerous laboratory bench scale and field treatability studies to evaluate potential technologies for the remediation of perched groundwater. Appendix A provides a summary of selected treatability testing completed to date. Large areas of thin (<15 ft) perched groundwater saturation are impacted. Conventional pump and treat technology is not feasible in these areas. Technology screening (IT and Stoller, 2000) identified hydraulic barriers, reactive barriers, *in situ* plume treatment, and monitored natural attenuation (MNA) as potential approaches for areas of thin saturation. The technologies retained for further consideration include:

- Hydraulic barrier using vertical wells for groundwater injection
- Hydraulic barrier using vertical extraction wells in areas less than 15 ft thick
- Reactive barrier using vertical or horizontal wells and either chemical oxidation, enhanced bioremediation, or chemical reduction processes
- Groundwater extraction, *ex situ* treatment, and reinjection with vertical or horizontal wells
- *In situ* chemical oxidation
- *In situ* chemical reduction
- *In situ* enhanced biodegradation
- MNA.

The treatability studies documented in the *Draft Final Implementation Report of Remediation Technology Screening and Treatability Testing of Possible Remediation Technologies for the Pantex Perched Aquifer* (IT and Stoller, 2000) focused on *in situ* chemical oxidation using potassium permanganate, *in situ* enhanced bioremediation, and MNA. Documentation of field treatability testing of *in situ* chemical oxidation and MNA sampling are presented, along with bench scale laboratory studies. Two additional field treatability studies are ongoing consisting of *in situ* redox manipulation to create a permeable reactive barrier (MKM et al, 2005), and *in situ* enhanced bioremediation (Llano-Permian Environmental et al., 2006).

Baseline sampling for these studies indicate oxidizing to slightly reducing conditions exist within the perched groundwater flow system. MNA sampling results yielded an average dissolved oxygen level of 8.7 mg/L. Nitrate was present in all water samples, and dissolved iron was not detectable in any well. ORP ranged from 188 to 261 mV. This corresponds to slightly reducing conditions.

Background sampling for the *in situ* bioremediation pilot study detected dissolved oxygen ranging from 8 to 9 mg/L. ORP was in the range of 120 to 200 mV indicating slightly oxidizing conditions at the beginning of the study. Background sampling for the *in situ* reactive barrier by injection of sodium dithionite solution indicated pH of 7.5 to 7.6, dissolved oxygen at 9.8 to 10 mg/L, and ORP ranging from -21.5 mV to -302.9 mV. Pre-injection sulfate concentrations averaged 31.3 mg/L.

Results from each of these evaluations indicate the technologies shows potential for remediation of perched groundwater. However, none by themselves will be effective at remediating the entire perched groundwater.

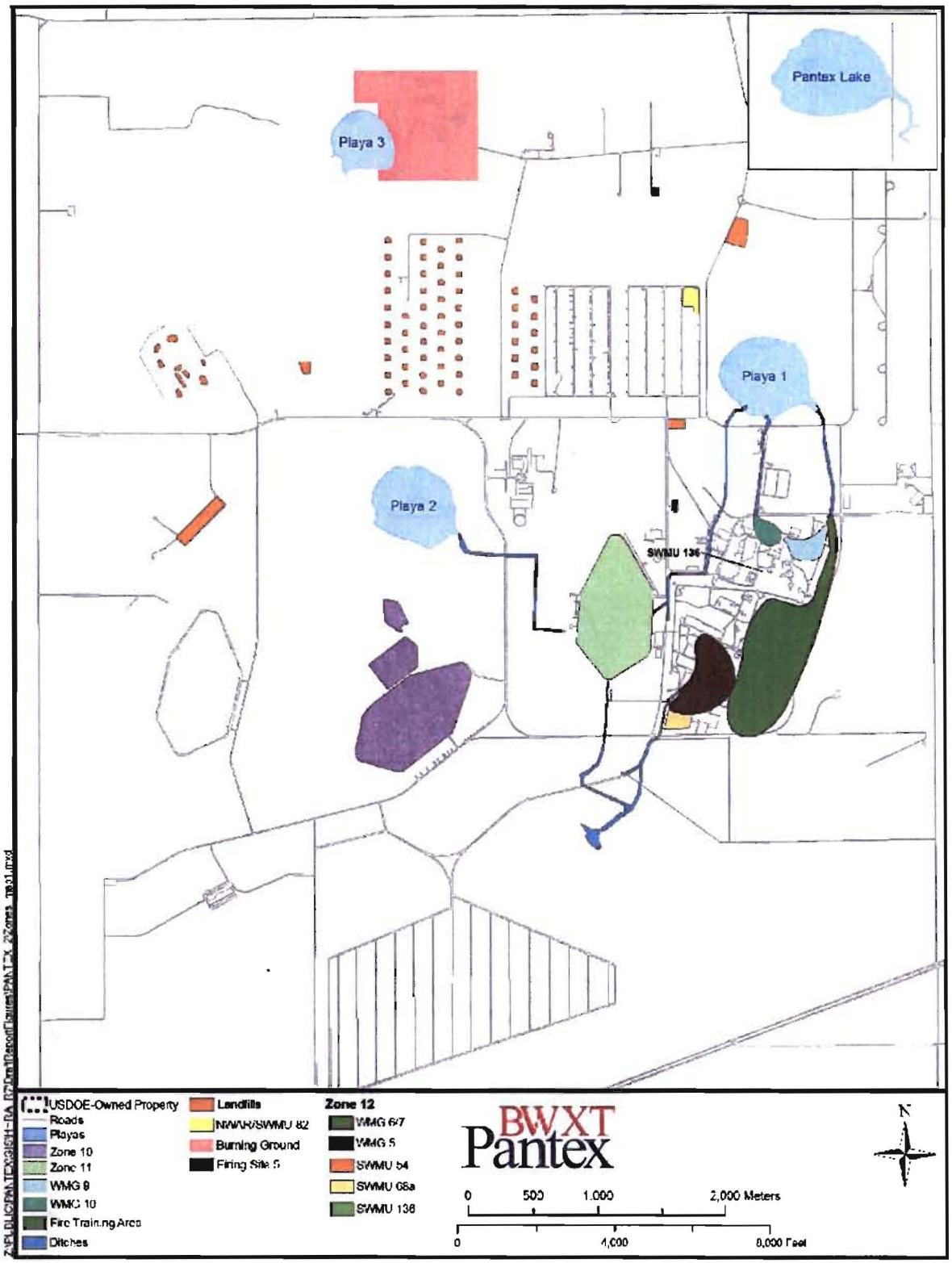


Figure 3-1. Zones and Corrective Action Units Evaluated in the Human Health Risk Assessments

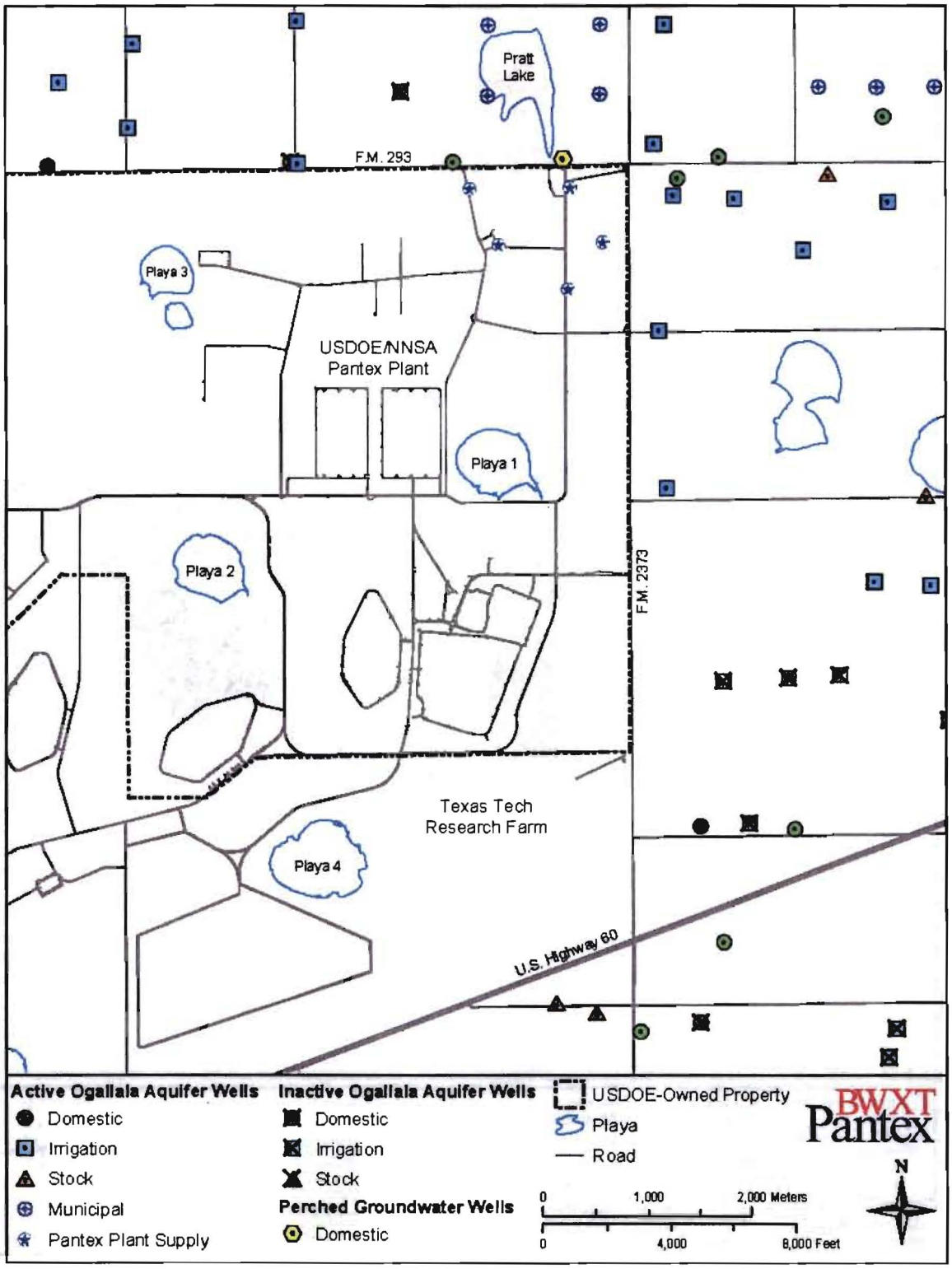
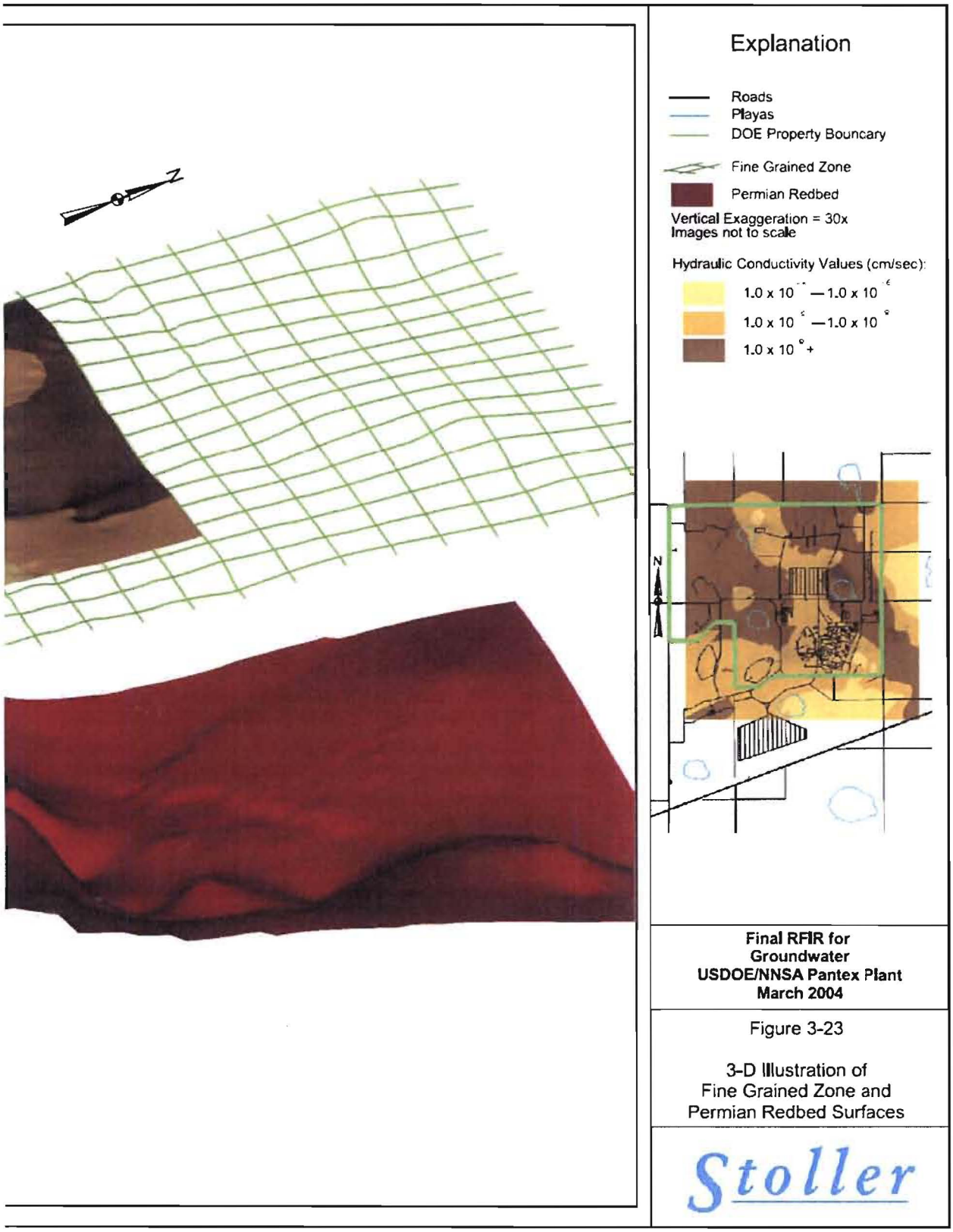


Figure 3-2. Groundwater Use North and East of Pantex Plant



and Permian Redbed Surface (Stoller, 2004b)

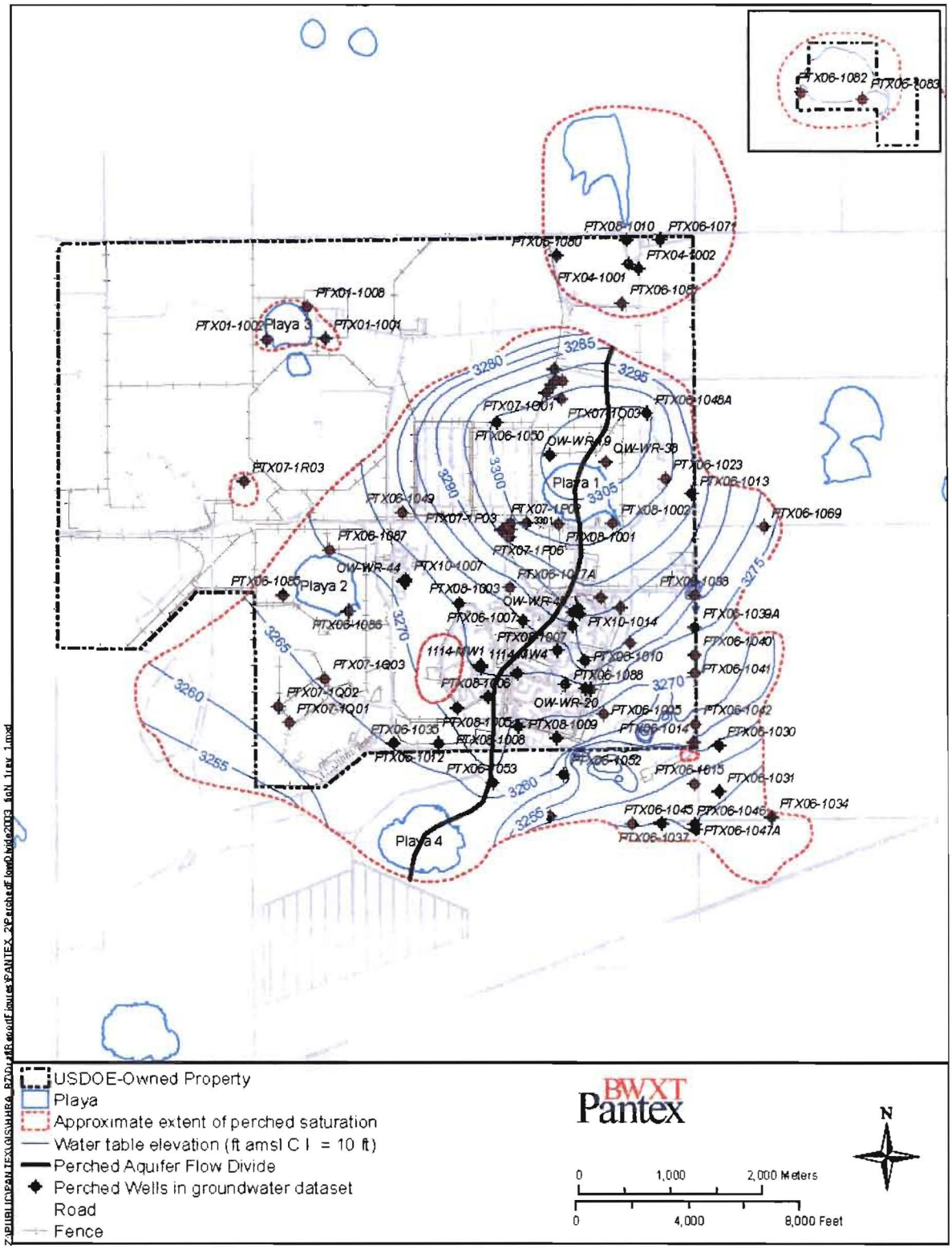


Figure 3-4. Groundwater Flow Divide

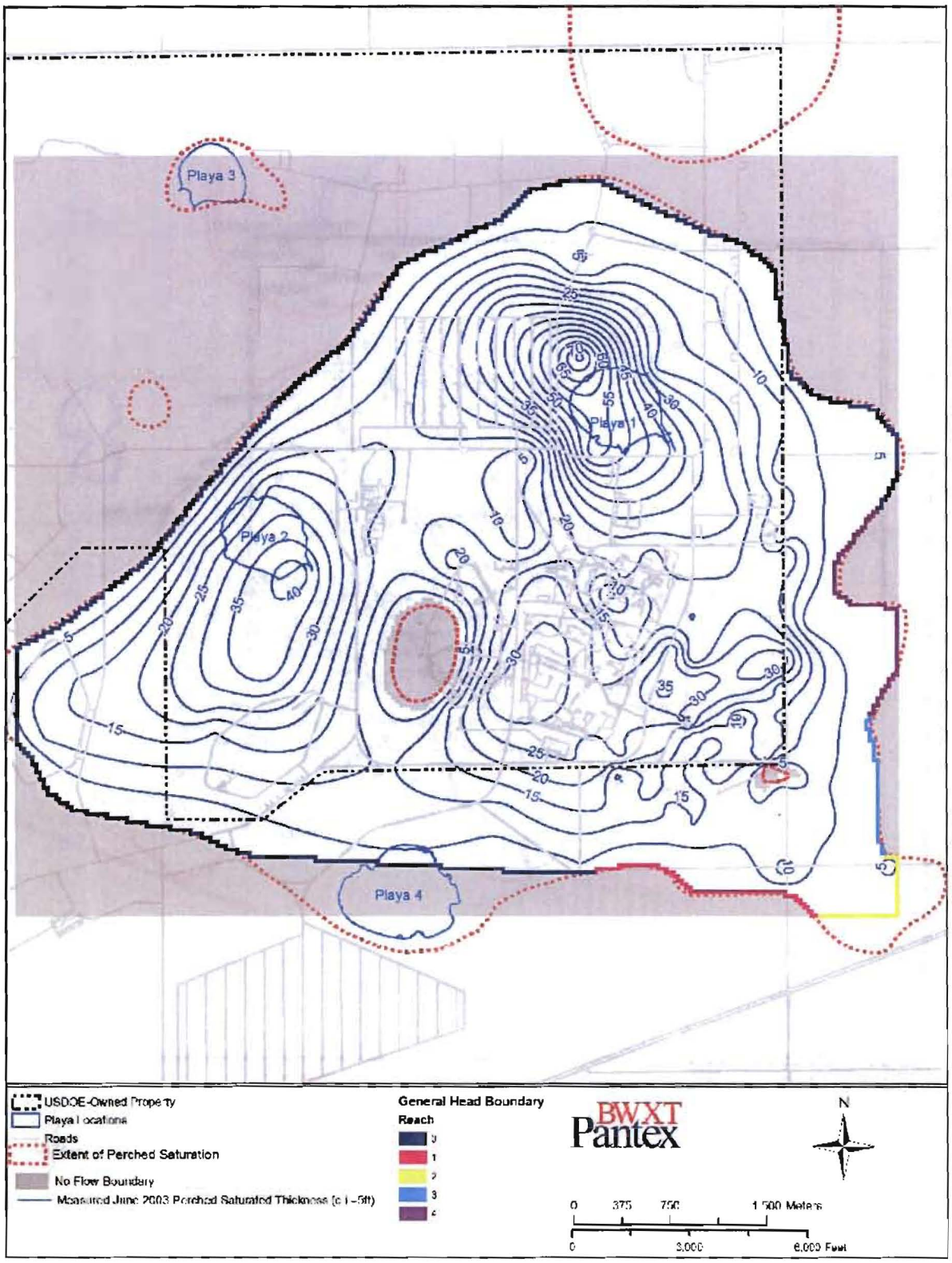
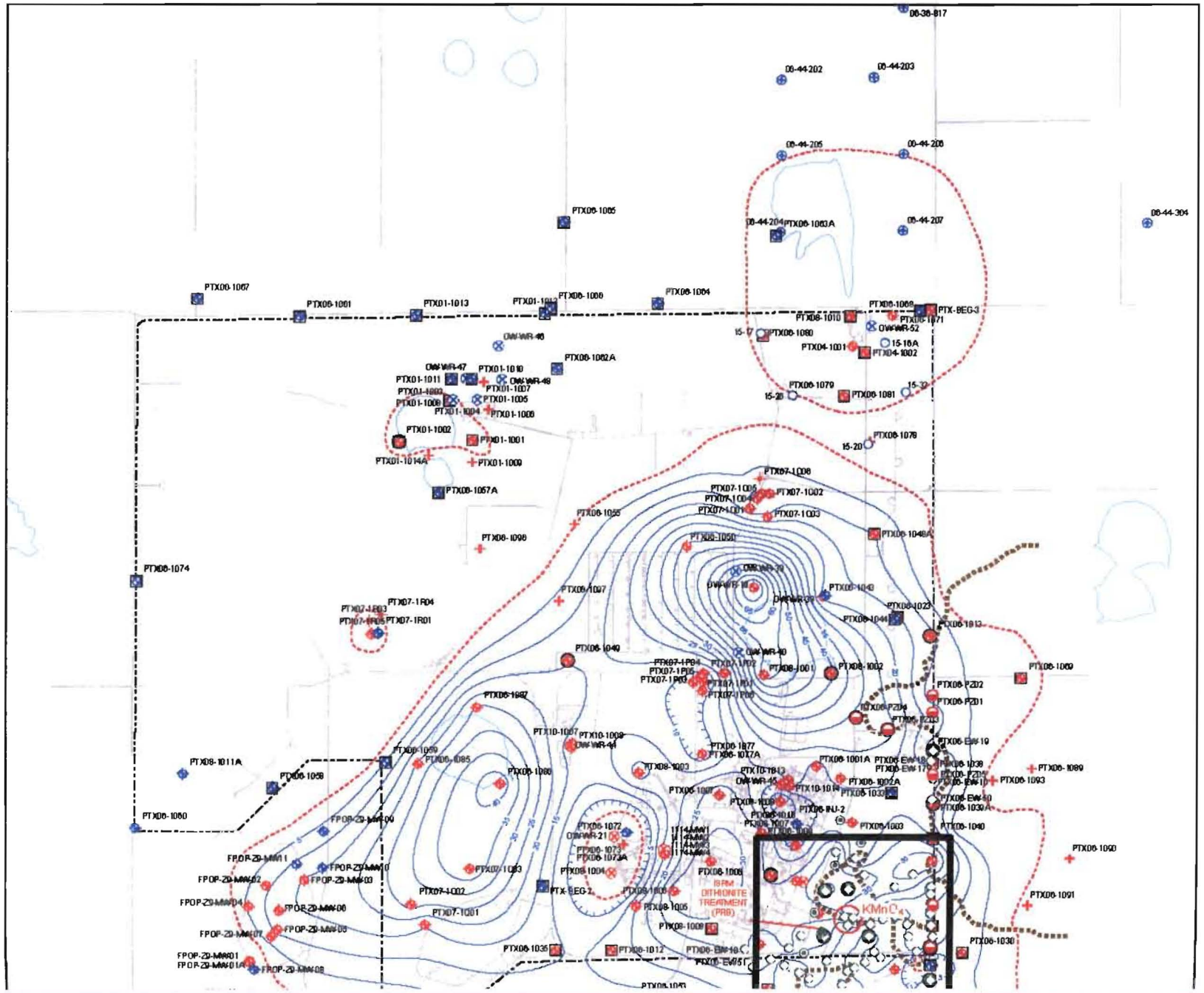


Figure 3-5. June 2003 Perched Groundwater Saturated Thickness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00-44-203
00-44-205
00-44-206
00-44-207
00-44-204
00-44-304
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PTX06-1003A
PTX06-1007
PTX06-1001
PTX01-1013
PTX01-1012
PTX06-1006
PTX06-1004
PTX06-1008
PTX-BEG-3
PTX06-1010
PTX06-1071
OW-WR-52
15-16A
PTX04-1001
PTX04-1002
PTX06-1080
15-17
OW-WR-46
PTX06-1002A
OW-WR-47
PTX01-1010
PTX01-1011
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PTX01-1002
PTX01-1001
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15-23
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PTX06-1005
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PTX07-1001
PTX06-1009
FPOP-ZD-MW-07
FPOP-ZD-MW-05
PTX06-1030
PTX06-1035
PTX06-1012
PTX06-EW-16
PTX06-EW-15
FPOP-ZD-MW-01
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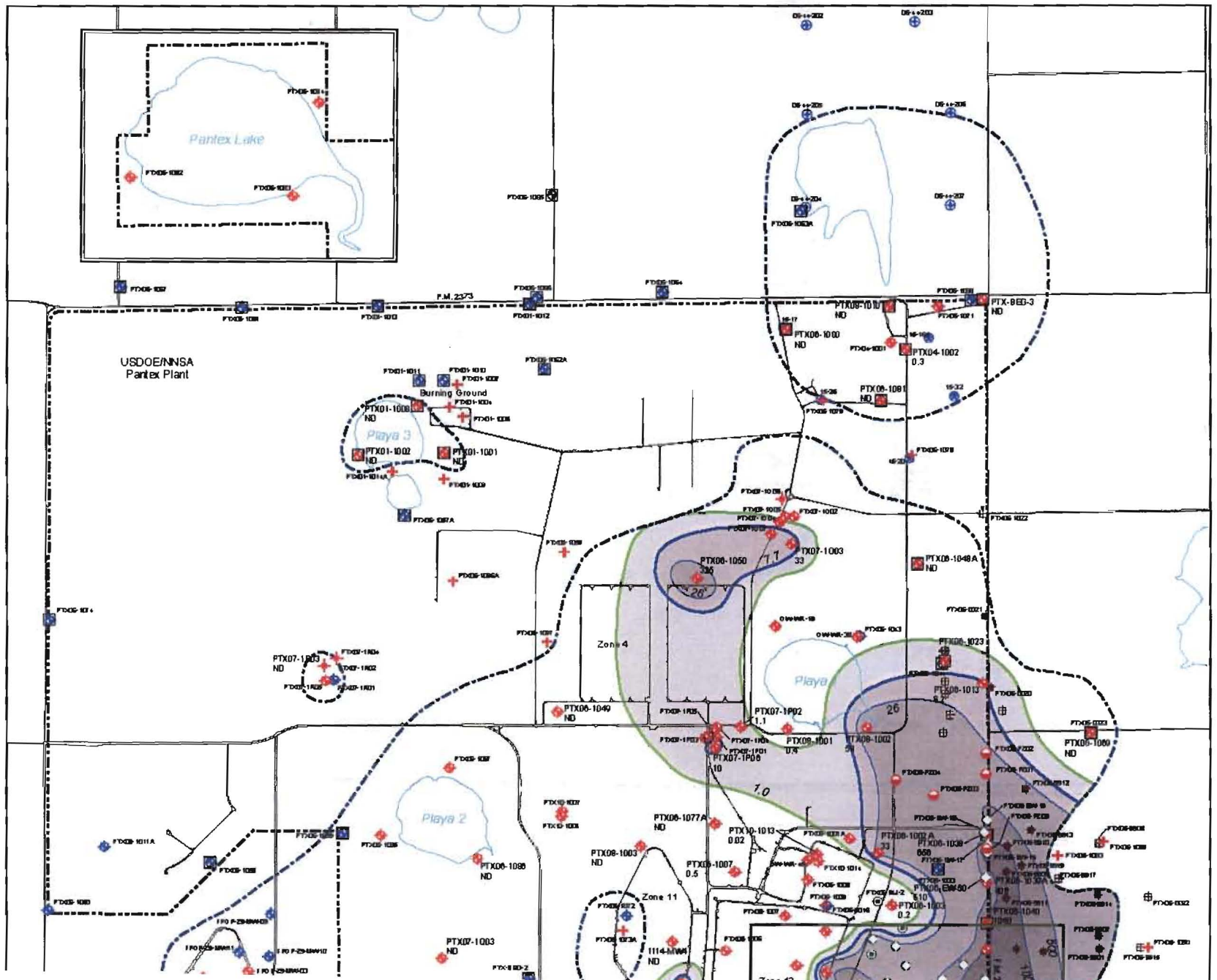
ISRM
DITHIONITE
TREATMENT
(PRB)
KMnO4


Pantex Lake
USDOE/NNSA
Pantex Plant
F.M. 2373
Burning Ground
Playa 3
Playa 2
Playa
Zone 4
Zone 11
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ND
PTX04-1002
0.3
PTX01-1000
ND
PTX01-1002
ND
PTX01-1001
ND
PTX06-1050
335
PTX07-1003
33
PTX06-1048A
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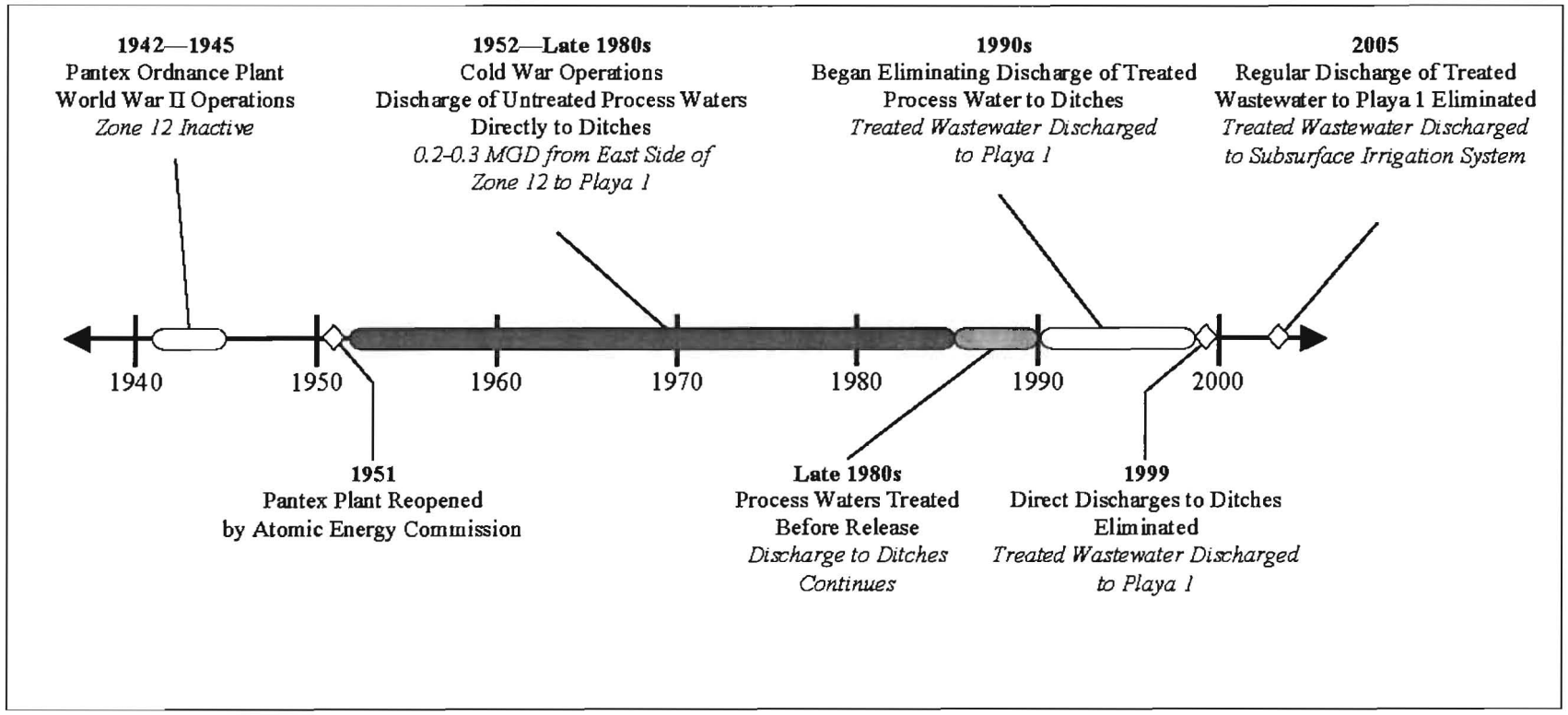

Figure 3-8. Discharge Timeline for Zone 12

4.0 IDENTIFICATION, SCREENING, AND DEVELOPMENT OF CORRECTIVE MEASURE ALTERNATIVES

This section describes options and technologies that were considered for remediation of perched groundwater at Pantex Plant, and summarizes the screening process used to select candidate options and technologies as viable alternatives for further evaluation. Section 4.1 presents the informational sources reviewed to compile the initial list of potential remedial technologies and process options. Section 4.2 presents a discussion of the initial screening process and a summary of the screening results for the remedial technologies and process options.

4.1 IDENTIFICATION OF TECHNOLOGIES

Several online sources of remedial technologies and information were reviewed to ensure the identification and screening of available conventional and innovative remedial technologies and process options. The following websites, in addition to previous Pantex Plant reports, comprise the primary sources reviewed to compile the list of potential remedial technologies and process options:

- Federal Remediation Technologies Roundtable (FRTR): Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, online: http://www.frtr.gov/matrix2/top_page.html
- Superfund Innovative Technology Evaluation (SITE), online: http://www.epa.gov/ORD/SITE
- Remediation and Characterization Innovative Technologies (REACH IT), online: http://www.epareachit.org
- Hazardous Waste Cleanup Information (CLU-IN), online: http://clu-in.org
- Ground-Water Remediation Technologies Analysis Center (GWRTAC), online: http://www.gwrtac.org/Default.htm
- Strategic Environmental Research and Development Program (SERDP), online: http://www.serdp.org/general
- Center for Public Environmental Oversight (CPEO): Technology Tree, online: http://www.cpeo.org/tree.html

These sources provide an extensive listing of conventional and innovative remedial technologies, process descriptions, and process applicability and limitations.

The term "remedial technology" refers to general categories of technologies (e.g., biological treatment and chemical/physical treatment). The term "process options" refers to specific processes within each remedial technology type (e.g., bioventing, bioremediation, and phytoremediation are process options for biological treatment).

4.2 INITIAL SCREENING OF TECHNOLOGIES

Prior to the development of remedial alternatives, the potentially applicable remedial technologies were screened to eliminate those remedial technologies and process options that may be infeasible to implement due to inherent limitations for the site-specific COCs and conditions, or would not achieve the remedial action objectives within a reasonable timeframe or cost. The impact of site, waste, and technology characteristics on the effectiveness, implementation, and cost of each technology established the basis for consideration in corrective measure alternatives in this CMS/FS.

Site characteristics are site-specific factors that limit or favor use of a technology. Technologies that are unfavorable for application under existing conditions at Pantex Plant are eliminated from further consideration. The following elements are considered in the evaluation of limitations imposed by site characteristics:

- Accessibility
- Utility and resource availability
- Surface topography
- Geology and hydrogeology
- Climate.

Waste characteristics are COC and/or media characteristics that limit or favor the use of a technology. Technologies that are unfavorable for application to the COC/media combination at Pantex Plant are eliminated from further consideration. The following elements are considered in the evaluation of limitations imposed by waste characteristics:

- Ability to meet required cleanup levels for COC/media combinations
- Volume of material requiring remediation
- Vertical extent of contamination
- COC/matrix complexity.

Technology characteristics are factors inherent in the technology that limit or favor its use for remediation at Pantex Plant. Technologies with constraints that significantly limit the implementation at Pantex Plant are eliminated from further consideration. The following elements are considered in the evaluation of limitations imposed by technology characteristics:

- Ability to comply with regulatory requirements
- Protection of human health and the environment during and after remediation
- Reduction of toxicity, mobility, or volume
- Permanence of remediation results (useful life)
- Maturity and commercial availability of the technology
- Established performance in full-scale operation treating materials similar to site wastes
- Cost.

The remainder of this section presents the results of the screening of the remedial technologies and process options for perched groundwater (Section 4.2.1).

Table 4-1 presents a summary of the remedial technologies and process options initially identified as candidates to remediate perched groundwater at Pantex Plant, including the standard *No Action* alternative. Those technologies eliminated by the screening process are shaded in gray in the table; those considered further during the development of alternatives are not shaded.

4.2.1 Initial Screening of Remedial Technologies and Process Options for Groundwater COCs

Several remedial technologies and process options initially compiled were removed as potential remedial candidates due to site characteristics and the specific COCs to be addressed.

Localized bodies of perched groundwater occur below portions of Pantex Plant at depths ranging from approximately 190 to 300 ft. The perched groundwater exceeds the maximum proven application depth for several of the remedial technologies and process options initially compiled. Due to limitations associated with application depth, the following remedial technologies and process options were removed from further consideration:

- Vertical engineered barriers
    - Deep soil mixing (DSM)
    - Geosynthetic membrane
    - Jet grouting
    - Sheet pile
    - Slurry walls
    - Soil freezing
- Collection trenches
- *In situ* phytoremediation.

Flow between perched groundwater and the Ogallala Aquifer is limited by the FGZ. Therefore, due to the potential for creating a pathway between the perched groundwater and Ogallala Aquifer, the use of hydrofracturing enhancement was removed from consideration.

As noted in Section 3.3, perched groundwater COCs include various HEs (e.g., RDX, TNT), metals (boron, hexavalent chromium, and total chromium), and VOCs (TCE and 1,2-DCA). Due to the potential hazards associated with thermal treatment of HEs, *in situ* thermal treatment technologies and *ex situ* separation by distillation were removed from further consideration.

The remainder of this section presents the initial screening of potential remedial technologies for perched groundwater.

4.2.1.1 Land Use Controls

This section describes the basis for evaluating land use controls as an alternative for preventing exposure to perched groundwater.

4.2.1.1.1 Description

Land use controls are generally institutional controls or engineered controls that are used to limit human activities at or near a contaminated site, or to ensure effectiveness of the remedial action when COCs remain onsite at concentrations above a standard that would allow unrestricted use of the site.

Institutional Controls

Institutional mechanisms to record and preserve land and resource use constraints and to provide safety have been used extensively throughout the United States. Examples of institutional controls include structure use restrictions, land use restrictions, natural resource restrictions, well restriction areas, deed restrictions, deed notices, property purchases, restrictive covenants, declaration of environmental restrictions, and information distribution.

Engineered Controls

Engineered controls include capping or closing abandoned wells to reduce the potential for adverse effects on human health by reducing opportunities for unnecessary direct contact with contaminated materials.

4.2.1.1.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of land use control technologies for consideration in this CMS/FS.

Institutional Controls

Site Characteristics: Site characteristics would not limit the use of institutional controls.

Waste Characteristics: Institutional controls alone would not meet cleanup objectives. The volume and vertical extent of contamination would not limit the use of institutional controls to supplement selected corrective action technology.

Technology Characteristics: Institutional controls are expected to provide protection of human health by limiting perched groundwater use. However, institutional controls alone would not reduce the toxicity, mobility, or volume of COCs in groundwater.

Institutional controls are retained as possible technologies to supplement selected corrective measure alternatives.

Engineered Controls

Site Characteristics: Site characteristics would not limit the use of engineered controls as a remedial technology.

Waste Characteristics: No particular group of constituents is targeted by engineered controls. Engineered controls alone would not meet cleanup objectives.

Technology Characteristics: Fencing and barriers are constructed using existing equipment and methods. Engineered controls can effectively limit human traffic and potential exposure. However, engineered controls alone would not reduce the toxicity, mobility, or volume of COCs in groundwater.

Engineered controls are retained as possible technology to supplement selected corrective measure alternatives.

4.2.1.2 Monitoring

This section describes the basis for evaluating monitoring as an alternative for perched groundwater.

4.2.1.2.1 *Description*

Monitoring is the collection, analysis, and interpretation of analytical results from environmental samples. The information collected is used to determine COC status or measure matrix properties. Groundwater samples are collected and analyzed for COCs to assess changes to concentration and migration.

4.2.1.2.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of groundwater monitoring as an alternative for consideration in this CMS/FS.

Site Characteristics: Site characteristics would not limit environmental monitoring.

Waste Characteristics: Waste characteristics would not limit the use of environmental monitoring.

Technology Characteristics: Environmental monitoring is not a remedial action, but may be used to select a remedial action or determine the effectiveness of an alternative. Environmental monitoring is implemented using established methods.

Monitoring is retained to assist with COC control during remedial activities and to track performance of the corrective measure alternative after corrective action objectives are met.

4.2.1.3 Containment

This section describes the basis for evaluating containment of perched groundwater as a remedial alternative.

4.2.1.3.1 *Description*

The containment option considered for the perched groundwater addressed in this CMS/FS is a hydraulic barrier. A hydraulic barrier is created by using extraction wells to form a lined cone of depression, or injection wells to reverse groundwater flow.

4.2.1.3.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of hydraulic barriers for consideration in this CMS/FS.

Site Characteristics: Site characteristics could limit the use of hydraulic barriers as a remedial technology. The relatively discontinuous transmissive zones and depth to perched groundwater would make designing and installing an effective hydraulic barrier difficult and costly. In addition, hydraulic barriers are difficult to maintain in areas with a saturated thickness of less than 15 ft.

Waste Characteristics: Groundwater containment technologies are applicable to a wide range of groundwater constituents. The use of hydraulic barriers alone would not meet cleanup levels.

Technology Characteristics: Using injection wells, hydraulic barriers can increase the saturated thickness for effective capture in a well field and is effective in combination with other technologies. This type of vertical barrier must be keyed into a lower confining layer. A relatively long and deep vertical barrier would be required to contain the larger area of the plume in the perched groundwater at the Pantex Plant boundary. Groundwater containment technologies generally are intended to minimize direct contact with impacted groundwater and/or reduce the mobility of COCs by imposing a physical barrier. These technologies cannot reduce the volume or toxicity of the COCs. Health and safety risks are minimized by elimination of the need to extract groundwater and/or excavate soil.

Hydraulic barriers are retained as a possible remedial technology, although they may be difficult to maintain.

4.2.1.4 Removal

This section describes the basis for evaluating removal of perched groundwater as a remedial technology.

4.2.1.4.1 *Description*

Groundwater removal involves the removal of groundwater COCs through extraction. Removal of groundwater would reduce offsite COC migration, and reduce or eliminate the risk of migration to the deeper Ogallala Aquifer. Vertical wells and horizontal wells are two methods for perched groundwater removal considered in this CMS/FS.

Vertical Wells

Vertical wells are oriented perpendicular to the land surface and are designed to remove groundwater from aquifers or perched water zones.

Horizontal Wells

Horizontal wells are constructed with the screened interval parallel to the land surface and are designed to remove groundwater from aquifers or perched water zones.

4.2.1.4.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of groundwater removal for consideration in this CMS/FS.

Vertical Wells

Site Characteristics: Site characteristics would not limit the use of vertical wells as a remedial alternative.

Waste Characteristics: Groundwater removal technologies are applicable to a wide range of groundwater COCs.

Technology Characteristics: This well-established technology is commercially available from many sources. The depth of the perched groundwater does not restrict the use of vertical wells; however, vertical wells have a limited capture area and may require a substantial well network which directly impacts capital cost. The size of the capture area will depend on the hydraulic properties of the aquifer, including the hydraulic conductivity and thickness of the aquifer, as well as the characteristics of the well, the pumping rate, and duration of pumping. In addition, low saturated thickness limits the available drawdown and yield of vertical wells. Groundwater extraction through vertical wells followed by *ex situ* treatment would help to reduce the toxicity, mobility, and volume of impacted groundwater.

Vertical wells are retained for further evaluation.

Horizontal Wells

Site Characteristics: Site characteristics could limit the use of horizontal wells as a remedial technology. Placement of the horizontal well would be difficult due to the depth to groundwater coupled with the thickness of the saturated layer along the leading edge of the perched ground water zone (approximately 5 to 15 ft).

Waste Characteristics: Groundwater removal technologies are applicable to a wide range of groundwater COCs.

Technology Characteristics: Horizontal wells using conventional directional drilling techniques have a maximum proven application depth of 235 ft bgs. A potential option for installing horizontal wells would be through the use of drilling techniques used in the oil/natural gas industry, which have been proven at much greater depths. Careful monitoring and guidance of drilling direction and progress is required with horizontal installations. Fewer horizontal wells may be required compared to vertical wells because horizontal well screens provide greater surface area in contact with the impacted groundwater. The well installation would require substantial drilling setback distances to achieve design depth and completion. Capital costs for the installation of horizontal wells are high and groundwater recovery rates are difficult to estimate. In addition, horizontal wells are often difficult to develop due to the difficulty associated with backfilling annular space. Groundwater extraction through horizontal wells followed by *ex situ* treatment would help to reduce the toxicity, mobility, and volume of impacted groundwater.

Horizontal wells are retained for further evaluation.

4.2.1.5 Biological Treatment (*In Situ*)

This section describes the basis for evaluating *in situ* biological treatment of perched groundwater as a remedial technology.

4.2.1.5.1 *Description*

In general, *in situ* biological treatments are methods of treating subsurface COCs in groundwater without being brought to the surface. *In situ* biological treatment options are directed toward the groundwater and soil microorganisms (e.g., bacteria or fungi) that grow and use COCs directly as a food and energy source, destroy COCs through co-metabolic reactions, or through the use of select plant species to sequester and destroy COCs. The rate at which microorganisms degrade COCs is influenced by:

- Specific COCs present
- Temperature
- Oxygen supply
- Nutrient supply
- pH
- Availability of the constituent to the microorganism
- Concentration of the COCs (high concentrations may be toxic to the microorganism)
- Presence of substances toxic to the microorganism (e.g., mercury)
- Inhibitors to the metabolism of the COCs (FRTR, 2005).

A variety of *in situ* biological processes are available to treat groundwater present in the saturated zone. These include enhanced biodegradation and MNA. Each of these technologies and their process options are described below.

Enhanced Biodegradation

Enhanced biodegradation is an innovative technology that stimulates indigenous or inoculated microorganisms within the groundwater to degrade organic compounds by enhancing the groundwater environment through one or a combination of the following:

- Bioaugmentation
- Nitrate enhancement
- Oxygen enhancement with air sparging
- Oxygen enhancement with hydrogen peroxide
- Co-metabolic treatment.

Aerobic bioremediation utilizes oxygen (i.e., electron acceptor) and nutrient amendments to enhance the aerobic microbial communities to convert organic COCs (i.e., electron donor and food/energy source) to carbon dioxide, water, and microbial cell mass. Oxygen is typically introduced by injection of clean water mixed with the select nutrients and dissolved oxygen. Hydrogen peroxide has also been used as an oxygen source.

Anaerobic bioremediation is typically conducted by injecting a carbon source such as acetate, lactate, or molasses. As these substrates break down, hydrogen is released and acts as an electron donor for microbial reductive biodegradation. In the absence of oxygen, the organic COCs act as the electron acceptor. Organic COCs are metabolized to methane, carbon dioxide, and hydrogen gas.

Bioaugmentation involves the use of specifically selected bacteria cultures, substrates, and/or nutrients designed to increase the degradability of target compounds such as chlorinated aliphatic hydrocarbons. Nitrate enhancement involves circulating solubilized nitrate throughout groundwater contamination zones to provide an alternative electron acceptor for biological activity and enhance the rate of degradation of organic COCs. Development of nitrate enhancement remains at the pilot scale. This technology enhances the anaerobic biodegradation through the addition of nitrate (FRTR, 2005).

Oxygen enhancement with air sparging, also called biosparging, involves the injection of air below the water table to increase the groundwater oxygen concentration and enhance the rate of biological degradation of organic COCs by naturally-occurring microbes. The ease and low cost of installing small-diameter air injection points allows considerable flexibility in the design and construction of a remediation system. Oxygen enhancement with air sparging is typically used in conjunction with SVE or bioventing to enhance removal of the volatile component under consideration (FRTR, 2005).

During oxygen enhancement with hydrogen peroxide, a dilute solution of hydrogen peroxide is circulated through the groundwater to increase the oxygen content of groundwater and enhance the rate of aerobic biodegradation of organic COCs by naturally-occurring microbes.

Co-metabolic degradation of organic COCs may occur under both aerobic and anaerobic conditions. Co-metabolic biodegradation reactions degrade organic COCs using enzymes or cofactors that are fortuitously produced during microbial metabolism of another compound (EPA, 1998a). The addition of methane or methanol supports methanotrophic activity, which has been demonstrated effective to degrade chlorinated solvents (e.g., vinyl chloride and TCE) by co-metabolism (FRTR, 2005).

Monitored Natural Attenuation

MNA is a remedial approach which includes natural physical, chemical, or biological processes to reduce the mass, toxicity, mobility, volume, or concentration of COCs in soil or groundwater. Prior to implementing MNA, modeling and evaluation of COCs degradation rates and pathways is required. The primary objective of site modeling is to demonstrate if natural processes of degradation will reduce COC concentrations below regulatory standards or risk-based levels before potential exposure pathways are completed. In addition, long-term monitoring must be conducted throughout the process to confirm that degradation is proceeding at rates consistent with meeting cleanup objectives.

4.2.1.5.2 Screening Factors

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of each *in situ* biological treatment technology for consideration in this CMS/FS.

Enhanced Bioremediation

Site Characteristics: Site characteristics would not limit the use of enhanced bioremediation as a remedial technology.

Waste Characteristics: Enhanced biodegradation techniques have been successfully used to remediate groundwater with nonhalogenated VOCs, nonhalogenated semi-volatile organic compounds (SVOCs), pesticides, and other organic chemicals. Nitrate enhancement has primarily been used to remediate groundwater containing benzene, toluene, ethylbenzene, and xylenes (BTEX). This technology has shown effectiveness in reducing hexavalent chromium to chromium (III), which is less mobile, less soluble, and less toxic. In addition, anaerobic microbial degradation has been shown to be effective for degrading nitroaromatics in groundwater; however, enhancement of conditions required to sustain anaerobic conditions at the depths and the area required at Pantex Plant have not been demonstrated. Successful demonstrations of TNT, RDX, and HMX degradation are reported in literature. Incomplete biotransformation of nitroaromatics could lead to the formation of toxic byproducts that are more mobile in the environment than their parent compounds; therefore, the process must be monitored.

Technology Characteristics: The use of enhanced bioremediation would help to reduce the toxicity and volume of COCs; however, risk of increasing COC mobility and leaching of constituents into groundwater is a concern. Costs associated with enhanced bioremediation systems are low to moderate. Variables affecting the cost are the nature and depth of the COCs, use of bioaugmentation and/or hydrogen peroxide or nitrate addition, and groundwater pumping rates. These technologies may be classified as long-term technologies, which may take several years for plume cleanup (FRTR, 2005).

Enhanced bioremediation is retained for further evaluation as a possible remedial technology based on successful demonstrations of effectiveness in treating HEs and other site COCs.

Monitored Natural Attenuation

Site Characteristics: Site characteristics would not limit the use of MNA as a remedial alternative.

Waste Characteristics: MNA is typically applied to VOCs, SVOCs, PAHs, and fuel hydrocarbons. Additional laboratory and field analysis would be required to verify that indigenous microbial communities are capable of degrading HEs.

Technology Characteristics: Long-term modeling and monitoring is required to track COC migration, degradation, and cleanup status. Institutional and/or engineered controls may be necessary to ensure short/long-term protectiveness. Longer time frames may be required to achieve remediation objectives compared to active remediation. The vertical extent and volume of COCs would not limit the use of this remedial technology.

MNA is retained for further evaluation as a possible remedial technology.

4.2.1.6 Physical/Chemical Treatment (*In Situ*)

This section describes the basis for evaluating *in situ* physical/chemical treatment of perched groundwater as a remedial technology.

4.2.1.6.1 Description

Physical/chemical treatment uses the physical properties of the COCs or the medium to chemically convert, separate, or contain the COCs. Physical/chemical treatment is typically cost-effective and can be completed in short time periods (in comparison to biological treatment). Equipment is readily available and is not engineering- or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits.

Available *in situ* physical/chemical treatment technologies include:

- Air sparging
- Bioslurping
- Chemical oxidation
- Dual Phase Extraction (DPE)
- In-well air stripping
- Passive/reactive treatment walls.

Air Sparging

In situ air sparging is a technology in which air is injected through an aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper removing COCs (e.g., VOCs) by volatilization. The injected air containing the volatile COCs is passed through a vapor extraction system to remove the generated vapor phase contamination. This *in situ* air sparging is designed to operate at high flow rates to maintain increased contact between groundwater and soil, and strip more groundwater by sparging. Oxygen added to perched groundwater and vadose zone soils can also enhance biodegradation of COCs below and above the water table (FRTR, 2005).

Bioslurping

Bioslurping is the adaptation and application of vacuum-enhanced dewatering technologies to remediate hydrocarbon-contaminated sites. Bioslurping involves the simultaneous application of vacuum enhanced extraction/recovery, vapor extraction, and bioventing to address light nonaqueous-phase liquid (LNAPL) contamination. Vacuum extraction/recovery is used to remove free product along with some groundwater; vapor extraction is used to remove high volatility vapors from the vadose zone; and bioventing is used to enhance aerobic biodegradation in the vadose zone and capillary fringe (Miller, 1996).

Chemical Oxidation

In situ groundwater treatment by chemical oxidation is the use of chemical additives to induce a change of valence or degradation of COCs by adjusting the electrical potential of the solution. Common oxidizing agents include ozone, hydrogen peroxide, sodium persulfate, and potassium permanganate. Oxidants are introduced to the area of groundwater through vertical or horizontal injection wells with forced advection to rapidly move the oxidant into the subsurface (FRTR, 2005).

An *in situ* chemical oxidation treatability study using potassium permanganate was conducted at Pantex Plant (Section 5.7). It was determined that it is feasible to treat HEs with potassium permanganate at Pantex Plant.

Dual Phase Extraction

DPE is a high vacuum system applied to simultaneously remove various combinations of contaminated groundwater and vapor from the subsurface. Product separation from the extracted water may be necessary prior to disposal or recycling of the product. As a result of the removal of substantial quantities of water during dual pumping operations, onsite water treatment will normally be required.

In-Well Air Stripping

Air is injected into a double-screened well, lifting the water in the well, and forcing it out the upper screen. Simultaneously, additional water is drawn in the lower screen. Once in the well, VOCs in the groundwater are transferred from the dissolved phase to the vapor phase by air bubbles. The air rises in the well to the water surface where vapors are drawn off and treated by a SVE system. The partially treated groundwater is forced into the vadose zone, and the process is repeated as water follows a hydraulic circulation pattern or cell that allows continuous cycling of groundwater. As groundwater circulates through the treatment system *in situ*, COC concentrations are gradually reduced.

Passive/Reactive Treatment Walls

Passive/reactive treatment walls, also known as permeable reactive barriers (PRBs), allow the passage of water while causing the degradation or removal of COCs. PRBs are installed across the flow path of a plume, allowing the water portion of the plume to passively move through the wall. These barriers prohibit the movement of COCs by employing as zero-valent metals, chelators, sorbents, or microbes. The COCs are either degraded or retained in a concentrated form by the barrier material. The wall could provide permanent containment for relatively benign residues or provide a decreased volume of the more toxic COCs for subsequent treatment.

An *in situ* treatability study using sodium dithionite is being conducted at Pantex Plant (Section 5.14). Results of an initial bench scale study indicated that the use of a chemical reductant to reduce naturally-occurring iron oxide phases in sediments shows great promise as a treatment for the perched groundwater. The sediment can be reduced to achieve considerable reduction/oxidation capacity, and RDX is quickly degraded in these reduced sediments (PNNL, 2001).

4.2.1.6.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of each *in situ* physical/chemical treatment technology for consideration in this CMS/FS.

Air Sparging

Site Characteristics: Site characteristics would not limit the use of air sparging as a remedial technology.

Waste Characteristics: Air sparging is effective for removing aerobically degradable or volatile constituents, specifically VOCs and petroleum hydrocarbons. The low volatility of nitroaromatics limits the effectiveness of air sparging, and it is ineffective in the treatment of metals.

Technology Characteristics: This technology is most effective for VOCs, while the primary COCs at Pantex Plant are heavy metals and HEs. Airflow through the saturated zone may not be uniform, requiring extensive airflow modeling before implementation. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells (FRTR, 2005).

Air sparging is eliminated from further evaluation as a remedial technology based on the inability to treat HEs and dissolved inorganics.

Bioslurping

Site Characteristics: Site characteristics would not limit the use of bioslurping as a remedial technology.

Waste Characteristics: Bioslurping can be successfully used to remediate groundwater with petroleum hydrocarbon constituents. However, for HEs and dissolved metals, it is a relatively ineffective technology.

Technology Characteristics: Operation and maintenance (O&M) during bioslurping ranges from several months to several years depending on site-specific conditions. Low temperatures have been reported to slow the rate of remediation. Bioslurping can be a cost-effective *in situ* remedial technology, which simultaneously accomplishes LNAPL removal and groundwater/soil remediation in the vadose zone.

Bioslurping is eliminated from further evaluation as a remedial technology based on the inability to treat HEs and dissolved inorganics.

Chemical Oxidation

Site Characteristics: Site characteristics would not limit the use of chemical oxidation as a remedial technology.

Waste Characteristics: Chemical oxidation may be used for the removal of nitroaromatic compounds in liquid streams. An onsite treatability study utilizing potassium permanganate showed successful treatment of HEs at Pantex Plant. Chemical oxidation is ineffective for treating and/or removing metals.

Technology Characteristics: *In situ* chemical oxidation is a well-established remediation technology viable for mass reduction in source areas, as well as for plume treatment. Limiting factors of chemical oxidation include handling large quantities of hazardous oxidizing chemicals due to the oxidant demand of the target organic chemicals and the unproductive oxidant consumption of the formation. Some COCs may be resistant to oxidation (FRTR, 2005).

Chemical oxidation is retained for further evaluation as a possible remedial technology.

Dual Phase Extraction

Site Characteristics: Site characteristics would not limit the use of DPE as a remedial technology.

Waste Characteristics: DPE is typically used to remove VOCs, SVOCs, and fuels from groundwater and soil. Waste characteristics would not limit the use of DPE as a remedial technology.

Technology Characteristics: DPE for fluid/vapor treatment is generally combined with bioremediation, air sparging, or bioventing when the target constituents include long-chained hydrocarbons. Use of DPE with these technologies may shorten the cleanup time at a site. DPE may also be used with pump and treat technologies to recover groundwater in higher-yielding aquifers. DPE requires both water treatment and vapor treatment, resulting in added equipment capital and operation costs (FRTR, 2005).

DPE is retained for further evaluation as a possible remedial technology.

In-Well Air Stripping

Site Characteristics: Site characteristics would not limit the use of in-well air stripping as a remedial technology.

Waste Characteristics: The target constituent groups for air stripping are halogenated VOCs, SVOCs, and fuels.

Technology Characteristics: In-well air stripping is a conventional remedial technology. The duration of in-well air stripping is short- to long-term, depending on constituent concentrations, Henry's Law constants of the constituents, the radius of influence, and site hydrogeology. In general, in-well air strippers are more effective at sites containing high concentrations of dissolved constituents with high Henry's Law constants. Fouling of the system may occur by infiltrating precipitation containing oxidized constituents. In-well air stripping may not be efficient in sites with strong natural flow patterns. For effective in-well treatment, the constituents must be adequately soluble and mobile, allowing transport by the circulating groundwater.

In-well air stripping is eliminated from further evaluation based on the inability to treat HEs and dissolved inorganics.

Passive/Reactive Treatment Walls

Site Characteristics: Site characteristics would not limit the use of passive/reactive treatment walls as a remedial technology. However, due to the depth to groundwater, hydraulic installation of the PRB would be required.

Waste Characteristics: Target constituent groups for passive treatment walls are VOCs, SVOCs, explosives, and inorganics. The technology may be less effective in treating some fuel hydrocarbons.

Technology Characteristics: Passive treatment walls are generally intended for long-term operation to control migration of COCs in groundwater. Passive treatment walls may lose their reactive capacity, requiring replacement of the reactive medium, or their permeability may decrease due to precipitation of metal salts. Biological activity may also limit the permeability of the passive treatment wall. Constructability presents a potential concern for installation of treatment walls at depths of 300 ft bgs (FRTR, 2005).

Passive/reactive treatment walls are retained for further evaluation.

4.2.1.7 Biological Treatment (*Ex Situ*)

This section describes the basis for evaluating *ex situ* biological treatment of perched groundwater as a remedial alternative.

4.2.1.7.1 Description

Ex situ biological techniques are destruction techniques applied to extracted/pumped groundwater, which are directed toward stimulating the groundwater/soil microbial populations to grow and use the COCs as a food and energy source by creating a favorable environment for the microorganisms. Generally, this means providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Sometimes, microorganisms adapted for degradation of the specific constituents are applied to enhance the process.

There are two types of *ex situ* biological treatment technologies that will be focused on for consideration: bioreactors and constructed wetlands.

Bioreactors

A bioreactor is a technology that involves the extraction of groundwater, which is subsequently put into contact with microorganisms (in attached or suspended growth) to act as biological reactors to degrade COCs. Nutrients are often added to the bioreactors to support the growth of microorganisms. The microbial population may be derived either from the COC source or from an inoculum of organisms specific to a COC.

In suspended systems, such as activated sludge, fluidized beds, or sequencing batch reactors, groundwater is circulated in an aeration basin where a microbial population aerobically degrades organic matter and produces CO_2, H_2O, and new cells. The cells form a sludge, which is settled out in a clarifier, and is either recycled to the aeration basin or disposed. In attached growth systems (i.e., upflow fixed film bioreactors, rotating biological contactors, and trickling filters), microorganisms are established on an inert support matrix to aerobically degrade water COCs. The trickling filter consists of a bed of highly permeable media, a water distributor, and an underdrain system. Wastewater is distributed over the top of the filter bed through which wastewater is trickled. The organic COCs in wastewater are degraded by the microorganisms attached to the filter medium.

Constructed Wetlands

Constructed wetlands use natural geochemical and biological processes inherent in an artificial wetland ecosystem in order to accumulate and remove metals, explosives, and other COCs from influent waters. The process can use a filtration or degradation process. Although the technology incorporates principal components of wetland ecosystems, including organic soils, microbial fauna, algae, and vascular plants, microbial activity is responsible for most of the remediation. Influent water with explosive residues or other COCs flows through and beneath the gravel surface of a gravel-based wetland. The wetland, using emergent plants, is a coupled anaerobic-aerobic system. The anaerobic cell uses plants in concert with natural microbes to degrade the COCs. The aerobic cell, also known as the reciprocating cell, further improves water quality through continued exposure to the plants and the movement of water between cell compartments (FRTR, 2005).

4.2.1.7.2 Screening Factors

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of each *ex situ* biological treatment technology for consideration in this CMS/FS.

Bioreactors

Site Characteristics: The site conditions would not inhibit the use of bioreactors, except low ambient temperatures significantly decrease biodegradation rates, resulting in longer cleanup times or increased costs for heating.

Waste Characteristics: Bioreactors are used primarily to treat SVOCs, fuel hydrocarbons, explosives, and any biodegradable organic material. The process may be less effective for some pesticides. Successful pilot-scale field studies have been conducted on some halogenated compounds, such as pentachlorophenol (PCP), chlorobenzene, and dichloro-benzene isomers. Bioreactors with cometabolites are used to treat polychlorinated biphenyls (PCBs), halogenated VOCs, and SVOCs in extracted groundwater. Very high COC concentrations may be toxic to microorganisms and require special design approaches.

Technology Characteristics: Bioreactors are a well-developed, long-term technology that has been used for many decades in the treatment of municipal and industrial wastewater. However, only in the past decade have studies have been performed to evaluate the effectiveness of bioreactors in treating groundwater and leachate from hazardous waste sites. The process may take up to several years. Bioreactor equipment and materials are readily available. As with other pump and treat technologies, time needed to clean up is dependent upon subsurface conditions and the rate of desorption of COCs from subsurface materials. Startup time can be slow if organisms need to be acclimated to the wastes; however, the existence of cultures that have been previously adapted to specific hazardous wastes can decrease startup and detention times. Costs are highly dependent on the COCs and their concentrations in the influent stream. Biological treatment has often been found to be more economical than carbon adsorption.

Bioreactors are retained as a possible remedial technology.

Constructed Wetlands

Site Characteristics: Colder conditions slow the rate at which the wetland/microbial population is able to break down COCs. In addition, temperature and flow fluctuations affect wetland function and can cause a wetland to display inconsistent COC removal rates.

Waste Characteristics: This technology has the ability to accumulate and remove metals, explosives, and other COCs from influent waters. For example, the United States Army Corps of Engineers (USACE) is demonstrating a gravel-based wetland system at Milan Army Ammunition Plant through the Environmental Security Technology Certification Program. The gravel-based system has been effective at degrading TNT and RDX, with a total nitrobody concentration of 10,000 parts per billion (ppb). Analyses indicate degradation due to the rise and fall of daughter products. TNT is reduced to less than 2 ppb. The demonstration had been operational since June 1996 (ESTCP, 1999).

Technology Characteristics: Wetland treatment is a long-term technology intended to operate continuously for years, but its long-term effectiveness is not well known. Wetland aging may be a problem, which may contribute to a decrease in COC removal rates over time. The cost of building an artificial wetland varies considerably from project to project, and may not be financially viable for many sites. A heavy flow of incoming water can overload the removal mechanisms in a wetland, while a dry spell can damage plants and severely limit wetland function. Study results indicate heavy metal removal efficiency can approach the removal efficiency of chemical precipitation treatment plants. Because wetland removal processes are primarily microbial, the technology can be developed with traditional

process engineering approaches. Laboratory studies can indicate whether remediation is possible, while bench-scale experiments can determine the proper loading and reactor design.

If planned and maintained properly, treatment wetlands can provide groundwater wastewater treatment for the impacted water, and also promote water reuse, wildlife habitat, and public use benefits. Potentially harmful environmental impacts (such as the alteration of natural hydrology, introduction of invasive species, and the disruption of natural plant and animal communities) can be avoided by following proper planning, design, construction, and operating techniques.

Constructed wetlands are retained as a possible remedial technology.

4.2.1.8 Physical/Chemical Treatment (*Ex Situ*)

This section describes the basis for evaluating *ex situ* physical and chemical treatment of groundwater as a remedial technology.

4.2.1.8.1 Description

Ex situ physical/chemical technologies treat perched groundwater that has been pumped above ground surface, using the physical or chemical properties of the COCs or medium to destroy (i.e., chemically convert), separate, or contain the COCs. Physical/chemical treatment is typically cost-effective and can be completed in short time periods (in comparison with biological treatment). Equipment is readily available and is not engineering- or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs, and may require permits.

Available *ex situ* physical/chemical treatment separation technologies include:

- Adsorption/absorption
- Advanced oxidation processes
- Air stripping
- GAC/liquid-phase carbon adsorption
- Ion exchange
- Precipitation/coagulation/flocculation
- Separation
- Sprinkler irrigation
- Ultraviolet (UV) oxidation (a destruction technology).

Adsorption/Absorption

Adsorption mechanisms are generally categorized as physical adsorption, chemisorption, or electrostatic adsorption. Weak molecular forces, such as Van der Waals forces, provide the driving force for physical adsorption, while a chemical reaction forms a chemical bond between the compound and the surface of the solid in chemisorption. Electrostatic adsorption involves the adsorption of ions through Coulombic forces, and is normally referred to as ion exchange, which is addressed separately in the ion exchange modules. In liquids, interactions between the solute and the solvent also play an important role in establishing the degree of adsorption (FRTR, 2005).

The most common adsorbent is GAC. Other natural and synthetic adsorbents include: activated alumina, forage sponge, lignin adsorption, sorption clays, and synthetic resins.

Activated alumina is a filter medium made by treating aluminum ore so it becomes porous and highly adsorptive. Activated alumina will remove a variety of COCs, including excessive fluoride, arsenic, and selenium. The medium requires periodic cleaning with an appropriate regenerant such as alum or acid in order to remain effective (FRTR, 2005).

Forage sponge is an open-celled cellulose sponge incorporating an amine-containing chelating polymer that selectively absorbs dissolved heavy metals. The polymer is intimately bonded to the cellulose to minimize physical separation from the supporting matrix. The functional groups in the polymer (i.e., amine and carboxyl groups) provide selective affinity for heavy metals in both cationic and anionic states, preferentially forming complexes with transition-group heavy metals (FRTR, 2005).

Lignin adsorption/sorptive clays are used to treat aqueous waste streams with organic, inorganic, and heavy metals. The waste stream is treated due to the molecular adhesion of the COCs to an adsorptive surface (FRTR, 2005).

Synthetic resins are more expensive than GAC, but can be designed to achieve higher degrees of selectivity and adsorption capacity for certain compounds than activated carbon. Resins are typically regenerated using acids, bases, or organic solvents instead of thermal methods, so they are better suited for thermally unstable compounds such as explosives, and are resistant to deactivation due to the adsorption of dissolved solids. Additionally, resins tend to be more resistant to abrasion than GAC, increasing their service life (FRTR, 2005).

Advanced Oxidation Processes

Advanced oxidation processes, including UV radiation, ozone, and/or hydrogen peroxide are used to destroy organic COCs as water flows into a treatment tank. If ozone is used as the oxidizer, an ozone destruction unit is used to treat collected off gases from the treatment tank and downstream units where ozone gas may collect or escape.

UV oxidation is a destruction process that oxidizes organic and explosive constituents in wastewater by the addition of strong oxidizers and irradiation with UV light. Oxidation of target COCs is caused by direct reaction with the oxidizers, UV photolysis, and through the synergistic action of UV light in combination with ozone and/or hydrogen peroxide. If complete mineralization is achieved, the final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that it is a destruction process, as opposed to air stripping or carbon adsorption, for which COCs are extracted and concentrated in a separate phase. UV oxidation processes can be configured in batch or continuous flow modes, depending on the flow rate under consideration (FRTR, 2005).

UV photolysis is the process by which chemical bonds of the COCs are broken under the influence of UV light. Products of photo-degradation vary according to the matrix in which the process occurs, but the complete conversion of an organic COC to carbon dioxide, water, etc., is not probable (FRTR, 2005).

Air Stripping

Air stripping is a full-scale technology in which VOCs are partitioned from extracted groundwater by greatly increasing the surface area of the water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Air stripping involves the mass transfer of volatile constituents from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank.

The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect remediated water. Auxiliary equipment that can be added to the basic air stripper includes an air heater to improve removal efficiencies; automated control systems with sump level switches and safety features, such as differential pressure monitors, high sump level switches, and explosion-proof components; and air emission control and treatment systems, such as activated carbon units, catalytic oxidizers, or thermal oxidizers. Packed tower air strippers are installed either as permanent installations on concrete pads, or on a skid or a trailer. Aeration tanks strip volatile compounds by bubbling air into a tank through which water flows. A forced air blower and a distribution manifold are designed to ensure air-water contact without the need for any packing materials. The baffles and multiple units ensure adequate residence time for stripping to occur. Aeration tanks are typically sold as continuously operated skid-mounted units. The advantages offered by aeration tanks are considerably lower profiles (less than 6 ft [2 m] high) than packed towers (15 to 40 ft [5 to 12 m] high) where height may be a problem, and the ability to modify performance or adapt to changing feed composition by adding or removing trays or chambers. The discharge air from aeration tanks can be treated using the same technology as packed tower air discharge treatment.

GAC/Liquid-Phase Carbon Absorption

GAC or liquid-phase carbon adsorption is a full-scale technology in which groundwater is pumped through one or more vessels containing activated carbon to which dissolved organic constituents adsorb. When the concentration of COCs in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place, removed and regenerated at an offsite facility, or removed and disposed. GAC is a granular media, approximately the size of medium-fine sand. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes.

The two most common reactor configurations for carbon adsorption systems are the fixed bed and the pulsed or moving bed. The fixed bed configuration is the most widely used for adsorption from liquids. Pretreatment for removal of suspended solids from streams to be treated is an important design consideration. If not removed, suspended solids in a liquid stream may accumulate in the column, causing an increase in pressure drop. When the pressure drop becomes too high, the accumulated solids must be removed (e.g., by backwashing). The solids removal process necessitates adsorber downtime and may result in carbon loss and disruption of the mass transfer zone (FRTR, 2005). However, shutdowns can be mitigated by the installation of a back-up system.

Ion Exchange

Ion exchange is a full-scale technology in which ions are removed from the aqueous phase by the exchange of cations or anions between the COCs and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. Liquids are passed over a resin bed where ions (i.e., cations and anions) in the resins and in contaminated materials are exchanged. After the resin capacity has been exhausted, resins can be regenerated for re-use (FRTR, 2005).

Precipitation/Coagulation/Flocculation

Precipitation of metals has long been the primary method of treating metal-laden industrial wastewaters. As a result of the success of metals precipitation in such applications, the technology is being considered and selected for use in remediating groundwater containing heavy metals, including their radioactive isotopes. In groundwater treatment applications, the metal precipitation process is often used as a

pretreatment for other treatment technologies (e.g., chemical oxidation or air stripping) where the presence of metals would interfere with the other treatment processes (FRTR, 2005).

Metals precipitation from water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification (settling) and/or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation. Typically, metals precipitate from the solution as hydroxides, sulfides, or carbonates (FRTR, 2005).

Separation

Separation processes seek to detach COCs from their medium (e.g., groundwater). *Ex situ* separation of a waste stream can be performed by many processes, including filtration/ultrafiltration/microfiltration, freeze crystallization, membrane pervaporation, and reverse osmosis.

Filtration is the physical process of mechanical separation based on particle size whereby particles suspended in a fluid are separated by forcing the fluid through a porous medium. As fluid passes through the medium, the suspended particles are trapped on the surface of the medium and/or within the body of the medium. Ultrafiltration/microfiltration occurs when particles are separated by forcing fluid through a semipermeable membrane. Only the particles whose size is smaller than the openings of the membrane are allowed to flow through (FRTR, 2005).

Freeze crystallization processes remove purified solvent from solution as frozen crystals. When a solution containing dissolved COCs is slowly frozen, water ice crystals form on the surface and the COCs are concentrated in the remaining solution. The ice crystals can be separated, washed, and melted to yield a nearly pure water stream (FRTR, 2005).

Membrane pervaporation is a process that uses permeable membranes that preferentially adsorb VOCs from water. Water first passes through a heat exchanger, raising the water temperature. The heated water then enters the pervaporation module, containing membranes composed of a nonporous organophilic polymer (similar to silicone rubber) formed into capillary fibers. VOCs diffuse by vacuum from the membrane-water interface through the membrane wall. Treated water exits the pervaporation module, while the organic vapors travel from the module to a condenser where they return to the liquid phase (FRTR, 2005).

Reverse osmosis is an *ex situ* treatment technology for contaminated water that involves using a semi-permeable membrane to produce a clean water stream and a smaller volume of a concentrated solution of contaminants.

Sprinkler Irrigation

Sprinkler irrigation is a relatively simple treatment technology used to volatilize VOCs from wastewater. The process involves the pressurized distribution of VOC-laden water through a standard sprinkler irrigation system. Sprinkler irrigation transfers VOCs from the dissolved aqueous phase to the vapor phase, whereby the VOCs are released directly to the atmosphere (FRTR, 2005).

4.2.1.8.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of *ex situ* physical/chemical treatment technology for consideration in this CMS/FS.

Adsorption/Absorption

Site Characteristics: The site conditions would not limit this technology.

Waste Characteristics: The target constituent groups for adsorption/absorption processes are most organic constituents and selected inorganic constituents from liquid and gas streams. Activated alumina can remove fluoride and heavy metals. The forager sponge is specifically used to remove heavy metals. Lignin adsorption/sorptive clays treat organic, inorganic, and heavy metals within aqueous waste streams. Synthetic resins are useful for thermally unstable compounds such as explosives due to the non-thermal regeneration requirements of the resins. Water-soluble compounds and small molecules are not adsorbed well (FRTR, 2005).

Technology Characteristics: Adsorption/absorption processes have a long history of use as treatment for municipal, industrial, and hazardous waste streams. The concepts, theory, and engineering aspects of the technologies are well developed. They are proven technologies with documented performance data. Contaminated media often require treatment/disposal as hazardous wastes if they cannot be regenerated. Costs are high if used as the primary treatment on waste streams with high COC concentrations. Adsorption processes are not practical where the content of the absorbable hazardous substance is so high that very frequent replacement of the absorbent unit is necessary (FRTR, 2005).

Adsorption/absorption processes are retained to supplement a selected *ex situ* corrective action alternative.

Advanced Oxidation Processes

Site Characteristics: There are no limitations for using this technology due to the site conditions.

Waste Characteristics: A majority of these applications are for groundwater with petroleum products or with a variety of industrial solvent-related organics such as TCE, dichloroethene (DCE), trichloroethane, and vinyl chloride. When UV/ozone is used on VOCs such as trichloroethane, the constituents may be volatilized (e.g., "stripped") rather than destroyed. They would then have to be removed from the off-gas by activated carbon adsorption or catalytic oxidation. This technology is also effective in degradation of explosives, such as mono-, di-, and trinitrotoluene; however, it is less effective for RDX and HMX. UV oxidation is ineffective in metals removal.

Technology Characteristics: UV oxidation is an innovative groundwater treatment technology that has been used in full-scale groundwater treatment application for more than 10 years. Currently, UV oxidation processes are in operation in more than 15 full-scale remedial applications. Wide ranges of sizes of UV oxidation systems are commercially available. The aqueous stream being treated must provide for good transmission of UV light (high turbidity causes interference). This factor can be more critical for UV/hydrogen peroxide than UV/ozone. Turbidity does not affect direct chemical oxidation of the COCs by hydrogen peroxide or ozone.

The duration of O&M for UV oxidation depends on influent water turbidity, COC and metal concentrations, existence of free radical scavengers, and the required maintenance intervals on UV reactors and quartz sleeves. The aqueous stream to be treated by UV oxidation should be relatively free of heavy metal ions (less than 10 mg/L) and insoluble oil or grease to minimize the potential for fouling of the quartz sleeves. Costs may be higher than competing technologies due to the purchase of UV oxidation reactors and their energy requirements. Additional costs associated with UV oxidation include handling and storage of oxidizers, which require special safety precautions (FRTR, 2005).

Advanced oxidation processes are retained to supplement a selected *ex situ* corrective action alternative.

Air Stripping

Site Characteristics: The site conditions would not limit the use of the air stripping technology.

Waste Characteristics: Air stripping is used to separate VOCs from water. It is ineffective for inorganic COCs. Generally, organic compounds with Henry's Law constants greater than 0.01 atmospheres - m^3/mol are considered amenable to stripping. Some compounds that have been successfully separated from water using air stripping include BTEX, chloroethane, TCE, DCE, and PCE.

Technology Characteristics: Air strippers can be operated continuously or in a batch mode where the air stripper is intermittently fed from a collection tank. The batch mode ensures consistent air stripper performance and greater energy efficiency than continuously operated units because mixing in the storage tanks eliminates any inconsistencies in feed water composition. Modifying packing configurations greatly increases removal efficiency. Air stripping equipment may be installed permanently, or as a packaged, transportable system. Consideration should be given to the type and amount of packing used in a tower. Process energy costs are high, and increase if COCs have low volatility at ambient temperature, resulting in the need for preheating of the groundwater. Off-gases may require treatment based on mass emission rate.

A recent innovation is the low-profile air stripper that is offered by several commercial vendors. This unit packs a number of trays in a very small chamber to maximize air-water contact while minimizing space. Because of the significant vertical and horizontal space savings, these units are increasingly being used for groundwater treatment. The potential exists for inorganic (e.g., iron greater than 5 parts per million [ppm], hardness greater than 800 ppm) or biological fouling of the equipment, requiring pretreatment or periodic column cleaning (FRTR, 2005).

Air stripping is retained to supplement a selected *ex situ* corrective action alternative.

Granulated Activated Carbon/Liquid-Phase Carbon Absorption

Site Characteristics: Site conditions would not limit the use of this technology.

Waste Characteristics: The target constituent groups for carbon adsorption are hydrocarbons, SVOCs, and explosives. Limited effectiveness may be achieved on halogenated VOCs and pesticides. GAC is a non-destructive technology that displaces constituents from one media to another. Spent GAC from the treatment of groundwater containing explosives is recycled by an offsite firm, in accordance with Federal and state regulations. Liquid-phase carbon adsorption is effective for removing COCs at low concentrations (less than 10 mg/L) from water at nearly any flow rate, and for removing higher concentrations of COCs from water at low flow rates (typically 0.5 to 1 gpm [2 to 4 Lpm]).

Technology Characteristics: Adsorption by activated carbon has a long history of use as a treatment for municipal, industrial, and hazardous waste streams. The concepts, theory, and engineering aspects of the technology are well developed. It is a proven technology with documented performance data. Groundwater treatment with liquid-phase GAC would be relatively simple to implement at Pantex Plant. Packaged systems are readily available from reliable vendors in the marketplace. The presence of multiple COCs can impact process performance. Single component isotherms may not be applicable for mixtures. Bench tests may be conducted to estimate carbon usage for mixtures. Modification of GAC, such as silicone- impregnated carbon, could increase removal efficiency and extend the length of operation. It may also be safer to regenerate. Carbon adsorption is particularly effective for polishing

water discharges from other remedial technologies to attain regulatory compliance. Carbon adsorption systems can be deployed rapidly, and COC removal efficiencies are high. Logistic and economic disadvantages arise from the need to transport and decontaminate spent carbon. The duration of GAC is usually short-term; however, if concentrations are low enough, the duration may be long-term. The duration of O&M is dependent on constituent type, concentration, and volume; regulatory cleanup requirements; and metal concentrations (FRTR, 2005).

GAC is retained to supplement a selected *ex situ* corrective action alternative.

Ion Exchange

Site Characteristics: Site characteristics would not limit the use of ion exchange as a remedial technology.

Waste Characteristics: Ion exchange can remove dissolved metals and radionuclides from aqueous solutions. Other compounds that have been treated include nitrate, ammonia-nitrogen, and silicate.

Technology Characteristics: Factors affecting the design of an ion exchange system include the presence of oil and grease, COC concentration, exchange capacity of the resin, suspended solids, metals, oxidant content, inorganic ions in groundwater, and pH of the groundwater. Oxidants in groundwater may damage the ion exchange resin. Wastewater is generated during the regeneration step and will require additional treatment and disposal.

Ion exchange is retained to supplement a selected *ex situ* corrective action alternative.

Precipitation/Coagulation/Flocculation

Site Characteristics: Site characteristics would not limit the use of precipitation/coagulation/flocculation as a remedial technology.

Waste Characteristics: Precipitation is used mainly to convert dissolved ionic species into solid-phase particulates that can be removed from the aqueous phase by coagulation and filtration. Remedial application of this technology usually involves removal of dissolved toxic metals and radionuclides. Depending on the process design, sludges may be amenable to metal recovery.

Technology Characteristics: Precipitation of heavy metals as the metal hydroxides or sulfides has been practiced as the prime method of treatment for heavy metals in industrial wastewater for many years. Bench-scale treatability tests should be conducted to determine operating parameters and characteristics (i.e., reagent type and dosage, optimum pH, retention time, flow rate, temperature, mixing requirements, flocculent [polymer] selection, suspended solids, precipitate settling and filtration rates, and sludge volume and characteristics). The treated groundwater may require pH adjustment. The precipitation process may generate toxic sludge requiring proper disposal.

Precipitation/coagulation/flocculation is retained to supplement a selected *ex situ* corrective action alternative.

Separation

Site Characteristics: Site characteristics would not limit the use of separation techniques as remedial alternatives. However, adequate space is required for some separation techniques (i.e., distillation and freeze crystallization).

Waste Characteristics: The target constituent groups for *ex situ* separation processes are VOCs, SVOCs, pesticides, and suspended particles. Solvents may be recovered for reuse.

Technology Characteristics: Membrane pervaporation and freeze crystallization are limited to only aqueous waste streams. The presence of oil and grease constituents may interfere with these processes by decreasing flow rate. Space must be adequate for freeze crystallization treatment systems. In freeze crystallization, eutectic mixtures form as solutions become more concentrated; feed stream must be dilute enough to accomplish significant volume reduction before a eutectic mixture forms.

Separation techniques are eliminated from further evaluation due to waste characteristics.

Sprinkler Irrigation

Site Characteristics: Site characteristics would not limit the use of sprinkler irrigation as a remedial alternative.

Waste Characteristics: Sprinkler irrigation can be utilized for any COC that readily transfers from the dissolved phase to the vapor phase (e.g., VOCs). The target constituent groups for sprinkler irrigation are VOCs, SVOCs, fuels, explosives, and pesticides.

Technology Characteristics: Metals in wastewater cannot be treated. Regulatory approval may be difficult to obtain because of the potential of direct release for COCs to the atmosphere. Ponding of wastewater may result from heavy irrigation. The performance of sprinkler irrigation may be affected by temperature. As Clean Air Act requirements increase, this technology may become obsolete.

Sprinkler irrigation is retained to supplement a selected *ex situ* corrective action alternative.

4.2.1.9 Disposal and Handling

This section describes the basis for evaluating disposal and handling methods for perched groundwater as a remedial technology.

4.2.1.9.1 Description

Disposal and handling methods for groundwater provide technology needed to manage the perched groundwater after its extraction and its eventual disposal after treatment.

Available disposal and handling technologies include:

- Onsite disposal
- Offsite disposal
- Deep well injection
- Handling
- Beneficial reuse.

Onsite Disposal

Onsite disposal options include discharge to surface water and re-injection. Each option is an effective method for the discharge of treated water.

Offsite Disposal

Offsite disposal of groundwater includes two methods including either discharge to a Publicly Owned Treatment Works (POTW) or other disposal facility. Either method would consist of using tanker trucks to transport either treated or untreated water to the facility for disposal.

Deep Well Injection

Deep well injection is a liquid waste disposal technology where treated or untreated liquid waste is placed into geologic formations which have no potential to allow migration of COCs into potential potable water aquifers. A typical injection well consists of concentric pipes, which extend several thousand feet down from the surface level into highly saline, permeable injection zone(s) confined vertically by impermeable strata (FRTR, 2005).

Handling

Onsite and offsite disposal requires waste materials to be transported to the selected disposal facility. The transportation options for hauling untreated groundwater offsite involve the individual or combined use of tanker trucks and railcars from the site to the selected disposal facility, or construction and use of a pipeline from the point of extraction and collection to the disposal point. Onsite handling options include the use of tanker trucks, or construction and use of a pipeline from the point of extraction and collection to the disposal point.

Beneficial Reuse

Beneficial reuse options for treated groundwater include reclamation/recycle/reuse alternatives such as land spraying/irrigation. In 2005, one beneficial reuse option for treated groundwater was implemented through design and installation of a conveyance line to the subsurface irrigation system that also received treated wastewater from the Pantex Plant WWTF.

4.2.1.9.2 *Screening Factors*

This section describes the impact of site, waste, and technology characteristics on the effectiveness and implementation of disposal and handling techniques for extracted groundwater for consideration in this CMS/FS.

Onsite Disposal

Site Characteristics: The site conditions do not limit the use of onsite disposal methods.

Waste Characteristics: Pretreatment for COCs would be necessary before groundwater could be discharged to surface water or re-injected to the perched groundwater.

Technology Characteristics: Implementability for onsite disposal will depend upon the requirements for permits. A permit from the National Pollutant Discharge Elimination System (NPDES) is not required for discharge to surface waters; however, the substantive requirements of a permit must be met. Operational costs would be relatively low for either method of disposal.

Onsite disposal is retained.

Offsite Disposal

Site Characteristics: Site conditions do not limit the use of offsite disposal methods.

Waste Characteristics: Pretreatment for certain COCs may be required before untreated groundwater could be discharged to a POTW or other facility, if the POTW cannot handle specific untreated water. Otherwise, criteria for selecting an offsite facility would require the ability to handle the COCs in the groundwater.

Technology Characteristics: Offsite disposal of groundwater to a POTW or other wastewater disposal facility is an easily implemented option. However, the costs for offsite disposal can be moderate to high, if treatment is required, and can vary depending on the transport distance to the nearest facility.

Offsite disposal is retained.

Deep Well Injection

Site Characteristics: Site characteristics may limit the use of deep well injection as a remedial alternative. Site assessment and aquifer characterization are required to determine suitability of the site for wastewater injection.

Waste Characteristics: The target constituent groups for deep well injection are VOCs, SVOCs, fuels, explosives, and pesticides. However, existing permitted deep well injection facilities are limited to a narrow range of specific wastes.

Technology Characteristics: Groundwater containment technologies generally are intended to minimize direct contact with untreated groundwater and/or reduce the mobility of COCs by imposing a physical barrier. These technologies cannot, however, reduce the volume or toxicity of the COCs. Injected wastes must be compatible with the mechanical components of the injection well system and the natural formation water. A waste generator may be required to perform physical, chemical, biological, or thermal treatment for removal of various COCs or constituents from the waste to modify the physical and chemical character of the waste to assure compatibility. Waste streams containing organic COCs above their solubility limits may require pretreatment before injection into a well. Extensive assessments must be completed prior to receiving approval from regulatory authority (FRTR, 2005).

Deep well injection is eliminated as a potential remedial alternative because of the difficulty of implementation and limited availability of injection facilities.

Handling

Site Characteristics: Tanker trucks are effective due to their adaptability to site and route conditions. Pantex Plant does have two rail spurs, so rail cars are implementable. The need for the construction of a pipeline(s) for the transport of groundwater from a point of collection to the onsite or offsite disposal point would be limited by site conditions.

Waste Characteristics: Containers on trucks, rail cars, or piping need to be resistant to the COCs in the groundwater in order to transport safely. Waste would have to be manifested and a licensed transporter(s) secured.

Technology Characteristics: Trucks are limited by their holding capacity and shorter haul distances due to safety concerns. The use of rail cars is limited by proximity to rail service lines or spurs. Rail cars are

also more effective for longer haul distances. Transport by the way of truck from the site to the spur may be needed. The cost of transporting wastewater by truck would be moderate to high, depending on distance of haul. The cost of obtaining permits and transporters would be high. The initial cost of installing the pipelines would be moderate.

Trucks, rail cars, and pipelines are retained.

Beneficial Reuse

Site Characteristics: The site conditions do not limit the use of beneficial reuse options.

Waste Characteristics: Pretreatment for COCs would be necessary before groundwater could be reused onsite for industrial/agricultural purposes.

Technology Characteristics: Technology characteristics would not limit beneficial reuse options. A system is currently in place at Pantex Plant.

Beneficial reuse is retained as a technology to dispose of treated groundwater.

Table 4-1. Identification and Screening of Remedial Technologies and Process Options for Perched Groundwater

Response Actions	Technologies	Options
Land Use Controls	Institutional Controls	Government controls, enforcement tools, informational devices, proprietary controls
	Engineered Controls	Capping or closing abandoned wells
Monitoring	Monitoring	Groundwater monitoring
Containment	Physical Barriers	Vertical Engineered Barriers
		Deep Soil Mixing
		Geosynthetic Membrane
		Hydraulic Barriers
		Jet Grouting
		Sheet Pile
		Slurry Walls
		Soil Freezing
Removal	Groundwater Removal	Vertical wells
		Horizontal wells
		Collection Trenches
Treatment (*In Situ*)	Biological Treatment	Enhanced Biodegradation
		Aerobic
		Anaerobic
		Bioaugmentation
		Co-Metabolic Treatment
		Nitrate Enhancement
		Oxygen Enhancement with Air Sparging
		Oxygen Enhancement with Hydrogen Peroxide
		Monitored Natural Attenuation
		Phytoremediation
		Aeration
		Enhanced Rhizosphere Biodegradation
		Hydraulic Control
		Phyto-accumulation
		Phyto-degradation
		Phyto-stabilization
		Phyto-volatilization
	Physical/Chemical	Air Sparging
		Bioslurping
		Chemical Oxidation
		Dual Phase Extraction
		Thermal Treatment
		Electrical Heating
		Hot Water or Steam Flushing/Stripping
		Steam Injection
		Hydrofracturing Enhancements
		In-Well Air Stripping
		Circulating Wells

Table 4-1. Identification and Screening of Remedial Technologies and Process Options for Perched Groundwater (continued)

Response Actions	Technologies	Options
Treatment (*In Situ*) (continued)	Physical/Chemical (continued)	Passive/Reactive Treatment Walls
		Funnel and Gate
		Iron Treatment Wall
Treatment (*Ex Situ*)	Biological Treatment	Bioreactors
		Constructed Wetlands
	Physical/Chemical	Adsorption/Absorption
		Activated Alumina
		Forager Sponge
		Lignin Adsorption/Sorptive Clays
		Synthetic Resins
		Advanced Oxidation Processes
		UV Oxidation
		UV Photolysis
		Air Stripping
		GAC/Liquid-Phase Carbon Adsorption
		Ion Exchange
		Precipitation/Coagulation/Flocculation
		Coagulants and Flocculation
		Separation
		Distillation
		Filtration/Ultrafiltration/Microfiltration
		Freeze Crystallization
		Membrane Pervaporation
		Reverse Osmosis
		Sprinkler Irrigation
Disposal and Handling	Onsite Disposal/Discharge	Discharge to Surface Water Deep Well Injection
	Offsite Disposal/Discharge	Dispose/Discharge to Publicly Owned Treatment Works or Other Disposal Facility
	Deep Well Injection	Injection wells place treated or untreated liquid waste into geologic formations that have no potential to allow migration of COCs into potential potable water aquifers
	Handling	Trucks Railcars
	Beneficial Reuse	Land Spraying/Irrigation Reclamation/Recycle/Reuse

Shading denotes options that were screened out from further consideration.

5.0 TREATABILITY STUDIES

This section describes site-specific treatability studies at Pantex Plant regarding remediation of expected COCs. Information from these studies, including the results and conclusions, were considered in the identification and evaluation of remedial technologies and corrective measure alternatives for perched groundwater in this CMS/FS, and in the selection of voluntary ICMs conducted at Pantex Plant.

5.1 BIODEGRADATION OF HEs AND *IN SITU* COMETABOLISM OF CHLORINATED SOLVENTS (NITROGEN INJECTION)

Research efforts on the biodegradation of HEs, specifically to determine if HMX and RDX could be aerobically biodegraded, were initiated by BWXT Pantex in the spring of 1995. The research was conducted by a joint venture between the personnel from Texas A&M University and TTU, and was presented in *Biodegradation of High Explosives and In Situ Cometabolism of Chlorinated Solvents (Nitrogen Injection) October 1995 Annual Report* (Autenrieth, et al., 1995).

Soil samples obtained from borings in the vicinity of Zone 12 were used to develop an indigenous population of microorganisms with prior exposure to HMX and RDX. The results of the study showed no significant biodegradation of HMX and RDX. In addition, soil core samples did not yield aerobic microorganisms capable of degrading the nitroaromatic compounds. Furthermore, the research suggests microorganisms capable of biodegrading HMX and RDX must be isolated from sites with recent contamination. The study recommended additional research to be conducted to determine nutritional requirements for metabolizing HMX and RDX.

Additional research was conducted by the Texas A&M University and TTU research team to study *in situ* aerobic degradation by bacterial cometabolism of TCE in groundwater. The results of the laboratory study showed good biotransformation of TCE by phenol- and methane-degrading bacteria. However, *in situ* demonstrations of methanotrophic transformation of TCE showed only moderate TCE degradation efficiency. Phenol-degraders were shown to more effectively degrade TCE.

5.2 BIODEGRADATION OF RDX

A Report on Biodegradation of Hexahydro-1,3,5-trinitro-1,3,5-triazaine (RDX) (Hallgarth and Autenrieth, 1996) described the results of a laboratory study conducted to simulate and characterize RDX degradation that may occur within the aerobic layers of soil. The results of the study indicated RDX degradation in the presence of oxygen is possible, but at a high cost. The researchers found large quantities of carbon yield anoxic conditions favorable for increasing the RDX utilization rate. However, providing adequate amounts of a carbon source during field implementation would be cost prohibitive.

The authors noted a need to add an exterior nitrogen source based on low specific growth rates encountered during kinetic rate experiments. At high concentrations of RDX, both growth and RDX utilization were found to be inhibited. The study recommended the use of periodic nitrogen source addition for culture maintenance.

5.3 *IN SITU* BIOREMEDIATION OF TCE-CONTAMINATED GROUNDWATER

The overall goals of the laboratory studies described in *A Report on In-Situ Bioremediation of TCE-Contaminated Groundwater at Pantex: Laboratory Feasibility Studies* (Morley and Speitel, 1996) were to conduct an initial feasibility assessment for *in situ* bioremediation of TCE in perched groundwater at Pantex Plant and to evaluate and compare laboratory methods. Since TCE can be degraded aerobically by cometabolism, it was necessary to determine if suitable aerobic bacteria are present in perched groundwater, and if so, the extent to which the organisms can degrade TCE.

The initial bacterial densities were estimated by using plate counts in aquifer cuttings. Two different methods of biostimulation were used to increase the indigenous populations of two types of bacteria known to cometabolize TCE: methanotrophs and phenol degraders. Biostimulation is the addition of substrates, nutrients, and oxygen to saturated aquifer material to increase active populations. Aquifer sediments were sampled from well PTX06-1012, located south of Zone 11. Headspace bottles and test-tube microcosms were the two methods used for biostimulation because of the limited availability of sediment from the perched groundwater. The plate counts of the biostimulated bacteria populations for both methods were performed and compared to the initial estimates. The stimulated sediment from both methods was then used in two TCE biodegradation studies to determine the rate and extent of TCE conversion to carbon dioxide and other end products. The two studies consisted of a batch hypovial test and test-tube microcosms.

The results presented in the report are as follows:

- For both biostimulation methods, plate counts confirmed that these indigenous bacteria increased in population.
- The two degradation studies reported that TCE was degraded by both methods following zero-order kinetics.
- Biodegradation of TCE occurred only under certain conditions. The addition of supplemental nutrients (nitrogen and/or phosphorus) was necessary for biostimulation of bacteria in perched groundwater sediments.
- The greatest TCE losses occurred in sediments that had been stimulated with phenol degraders and supplemental nutrients. Both degradation studies showed that indigenous phenol degraders could cometabolize TCE at appreciable rates; however, methanotrophs cannot cometabolize TCE.

Bioremediation of TCE in groundwater may be a feasible option as indicated by the results.

The report provided the following recommendations for continued research:

- Characterization of toxicity due to additional constituents at the site, including HEs and heavy metals.
- Determination of specific nutrient requirements (e.g., nitrogen and/or phosphorus) and the optimal form and concentration that should be added.
- Optimization of the oxygen source (e.g., dissolved air, dissolved oxygen, or peroxides) and delivery method.

- Optimization of substrate concentrations and application methods to stimulate indigenous phenol degraders, but to prevent biofouling of the injection points.

- Assessment of the potential for low rates of intrinsic bioremediation of TCE in perched groundwater, including the availability of aromatic compounds, naturally-occurring methane, or other primary substrates for cometabolism of TCE, and limitations posed by oxygen and nutrient availability.

- Field studies to determine the actual response of indigenous organisms, and the ability to inject and mix nutrients into perched groundwater.

5.4 INVESTIGATION OF GROUNDWATER RECIRCULATION FOR THE REMOVAL OF RDX FROM PANTEX PLANT PERCHED GROUNDWATER

This study, as presented in the *Investigation of Groundwater Recirculation for the Removal of RDX from the Pantex Plant Perched Aquifer* (Boles, et al., 1998), included a two-phased approach: a field tracer test and modeling of the resulting field data. Specific objectives included:

- Field Tracer Test
  - Design of the hydraulic and chemical aspects of the tracer test for implementation within the existing Zone 12 treatability system
  - Installation of the necessary plumbing and equipment for the tracer test at the Pantex Plant
  - Performance of the tracer test.
- Modeling Phase
  - Determine the flow characterization of the perched groundwater
  - Estimate the retardation of RDX
  - Evaluate the removal of RDX from perched groundwater with the dual-phase extraction system
  - Evaluate the use of groundwater recirculation to enhance the extraction of RDX from perched groundwater.

The report concluded the following:

- The design and installation of the injection system into the existing treatability system was successful.

- Because of the short test duration, the tracer test demonstrated breakthrough of bromide and HE-free effluent at only one of the three extraction wells.

- The field test kits for RDX analysis did not provide adequate results to be used to estimate RDX retardation using the groundwater models.

- Based on the evidence presented from the tracer test and modeling, at least two stratigraphic layers are present within regions of perched groundwater.

- Hydraulic conductivity is the parameter with the most substantial effect on the transport of constituents in perched groundwater.

- The linear sorption coefficient (K_d) for RDX in perched groundwater in the Zone 12 area was estimated at 0.050 L/kg using the groundwater flow and transport models. With this K_d value, the retardation coefficient for RDX was calculated as 1.4.

- This type of pump and treat system provides an effective means of removing significant amounts of RDX from perched groundwater at Pantex Plant.

The report recommended further removal of RDX from perched groundwater at Pantex Plant using this technology. It also recommended further investigation to verify that other compounds, such as HMX and VOCs, are removed by this technology.

5.5 BIOREMEDIATION OF RDX IN THE VADOSE ZONE BENEATH PANTEX PLANT

The report on *Bioremediation of RDX in the Vadose Zone Beneath the Pantex Plant* (Shull, et al., 1999) presented the findings of a study conducted to determine if microorganisms present in the soils at Pantex Plant could degrade RDX and, if so, how this process could be enhanced. The objectives of the study were as follows:

- Determine if indigenous soil organisms are capable of RDX biodegradation.

- Determine the impact of electron acceptor availability and nutrient addition on RDX biodegradation.

- Determine the extent of RDX mineralization (i.e., conversion to inorganic carbon) during biodegradation.

- Estimate the kinetics of RDX biodegradation to provide information for mathematical fate and transport modeling.

The study was conducted on unsaturated soils obtained from Zone 12. Batch techniques using ^{14}C-RDX chemicals were developed to investigate RDX degradation under aerobic, anoxic, and microaerobic conditions. The results of the study showed microorganisms indigenous to Pantex Plant soil in the vadose zone in Zone 12 degraded RDX to a significant extent under anoxic and microaerobic conditions. To create these conditions in the vadose zone, the injection of either an inert gas or highly degradable organic substance would be required. The addition of phosphorus had little effect on the removal rate of RDX, except in microaerobic and anoxic experiments with organic carbon.

The report provided the following recommendations for continued research:

- Modification of methods to eliminate RDX partitioning problems between ether and water.

- Because significant accumulation of water-soluble intermediates was observed, these intermediates should be identified to determine if they are an environmental concern.

- Characterization of toxicity effects of high concentrations of HEs.
- Determination of delivery method to create anoxic/microaerobic conditions in the vadose zone.
- Optimization of substrate concentrations and application methods to stimulate indigenous RDX degraders.
- Field studies to determine the actual response of indigenous bacteria and the ability to create optimal conditions.
- Studies to determine HMX degradation since HMX is frequently present with RDX.

5.6 IMPLEMENTATION OF REMEDIATION TECHNOLOGY SCREENING AND TREATABILITY TESTING OF POSSIBLE REMEDIATION TECHNOLOGIES FOR PANTEX PLANT PERCHED GROUNDWATER

This study was conducted to identify possible ways to treat groundwater at Pantex Plant. During the evaluation, data gaps were identified that limited a full evaluation of the candidate technologies. Treatability studies were performed to fill certain data gaps. The *Draft Final Implementation Report of Remediation Technology Screening and Treatability Testing of Possible Remediation Technologies for the Pantex Perched Aquifer (Potassium Permanganate)* (IT and Stoller, 2000) described the efforts, identified remaining needs, and provided recommendations to further advance and support the alternative evaluation and selection process for perched groundwater.

The technology screening identified the following potential technologies as viable options for treatment of perched groundwater:

- Hydraulic barriers
- Reactive barriers
- *In situ* plume treatment
- MNA.

To fill data gaps required in evaluating these technologies, the following treatability studies were completed:

- *In situ* chemical oxidation using potassium permanganate ($KMnO_4$)
- *In situ* enhanced bioremediation
- MNA.

Treatability study results show $KMnO_4$ effectively treated RDX, HMX, TNT, and DNT to levels below RRS 2 criteria. The enhanced bioremediation laboratory treatability testing indicated HE compounds could be effectively treated in groundwater to below RRS 2 criteria under either aerobic or anaerobic conditions. Anaerobic results indicated degradation of HEs under both non-methanogenic and methanogenic conditions with a supplemental carbon source.

Finally, the results from the MNA treatability study indicated conditions in perched groundwater might be amenable to natural biological degradation of RDX. Furthermore, RDX transformation products mononitrosoamine (MNX), dinitrosoamine (DNX), and trinitrosoamine (TNX) are present in the groundwater, indicating RDX degradation may be ongoing.

5.7 FEASIBILITY OF *IN SITU* REDOX MANIPULATION OF SUBSURFACE SEDIMENTS FOR RDX REMEDIATION AT PANTEX PLANT

This laboratory study was conducted to assess RDX abiotic degradation by chemically reduced sediments and other geochemical aspects of the application of this technology to perched groundwater at Pantex Plant. The results from the study, presented in *Feasibility of In Situ Redox Manipulation of Subsurface Sediments for RDX Remediation at Pantex* (PNNL, 2001) show the sediments can be reduced to achieve considerable reduction/oxidation capacity. In addition, the results indicated RDX was rapidly degraded (i.e., within minutes) to at least the fourth degradation product in batch studies using abiotic reduced sediments.

5.8 CONCEPTUAL DEPLOYMENT SCENARIOS FOR *IN SITU* REMEDIATION OF THE SOUTHEAST PERCHED GROUNDWATER PLUME AT PANTEX PLANT

Conceptual Deployment Scenarios for In Situ Remediation of the Southeast Perched Aquifer Plume at Pantex Plant (Aquifer Solutions, 2002) was prepared in conjunction with other ongoing efforts by the USDOE Technical Advisory Group managed by the ITRD workgroup. Development of the deployment scenarios for *in situ* remediation of the southeast perched groundwater plume was intended to provide a starting point for further discussion and testing related to how the technologies may be used, and the capabilities and cost of the technologies. During the evaluation, data gaps were identified which would limit a full evaluation of the candidate technologies.

The technology screening identified the following technologies as viable options for treatment of perched groundwater:

- *In situ* reduction/oxidation manipulation (ISRM)
- Anaerobic *in situ* bioremediation (ISB)
- Chemical oxidation using $KMnO_4$.

For the purpose of determining areas of the site that are generally applicable to each technology, three key COPCs were considered: hexavalent chromium, RDX, and TCE. Each of the technologies evaluated holds advantages for application in specific areas of the site, and all the technologies may be appropriate for at least limited application as part of an overall remediation approach for the Pantex Plant perched groundwater. ISRM using sodium dithionite can effectively treat hexavalent chromium, TCE, RDX, and others, but RDX requires further testing to determine the conditions to prevent partial transformation to RDX by-products. Areal treatment using anaerobic ISB is capable of treating hexavalent chromium, TCE, RDX, and other COPCs. Chemical oxidation using $KMnO_4$ is effective in the treatment of RDX and TCE, but it is not amenable to treatment of hexavalent chromium.

Remaining technology data gaps for these technologies include:

- Passive reactive barrier using ISRM
    - Optimal treatment zone residence time, sodium dithionite injection requirements, and optimal injection well spacing are undetermined.
    - Additional follow-on natural attenuation or enhanced biological treatment needs are undetermined.

- Areal treatment using anaerobic ISB
  - Site-specific microbial community and populations across the perched groundwater are undetermined.
  - Status of natural microbial processes across the perched groundwater is undetermined.
  - Subsurface microbial reaction kinetics, amendment injection requirements, and optimal well spacing are undetermined.
- Chemical oxidation using $KMnO_4$
  - Long-term persistence and reaction kinetics of $KMnO_4$ in the subsurface are undetermined.
  - $KMnO_4$ injection requirements, radius of influence, and optimal injection well spacing are uncertain.

The following pilot studies have been performed in the perched groundwater since this treatability study to gain a better understanding of factors such as well spacing, radius of influence, residence time of injected amendments, etc.:

- Pilot study conducted in February 2004 to investigate ISRM. A description and results of the study are included in Section 5.14.
- Pilot study to investigate anaerobic ISB began in August 2005. A description of the study is included in Section 5.13. The results were not available to include in this report.
- No pilot study is planned for chemical oxidation using $KMnO_4$.

5.9 EXPANSION OF THE *IN SITU* HE BIODEGRADATION SYSTEM IN SHALLOW SUBSURFACE SOIL AT SWMU 122B

The objective of this project was to plan, design, and implement an expansion of the existing *in situ* biodegradation technology developed by TTU in partnership with USDOE's ITRD Program. The objectives and results of this project were described in *Expansion of the In Situ HE Biodegradation System in Shallow Subsurface Soil at SWMU 122b at the Pantex Plant, Implementation Report* (Caldwell, 2002). The specific objectives of the project include:

- Expand the existing *in situ* biodegradation system.
- Reduce soil concentrations of HEs *in situ* at selected locations by injecting humidified nitrogen generated by a nitrogen generation system that utilized membrane filtration to generate oxygen gas and oxygen depleted (nitrogen rich) air into the target soil volume to create an anaerobic atmosphere and encourage indigenous facultative and anaerobic microbial populations to metabolize HEs.
- Improve cost data and operation techniques that could apply to the implementation of the technology elsewhere.

- Provide data on the effectiveness of HE biodegradation and resulting breakdown products.
- Integrate the existing system and the expansion seamlessly.

The results of the system expansion indicated no significant trends were observed to signify the system had been effective at achieving the goal of reducing the contaminant concentrations to below RRS 1 levels. The study did show the conditions created by the system to be conducive for biodegradation of HE compounds. In addition, the report indicated the study successfully created a low oxygen environment in the target soil area.

Soil analysis for HEs indicated no apparent trend in changes in concentration from pre-treatment to six months of operation. Results of nitrate/nitrite soil samples showed no apparent trends with regard to increases or decreases in concentration from pre-treatment to post-treatment. Microbial deoxyribonucleic acid results from bacteria in the soils collected during pre-treatment and post-treatment were also inconclusive with regard to indications of biodegradation of the HE compounds.

5.10 EVALUATION OF THE PGPTS AND ASSOCIATED WELL FIELD

The objective was to perform a critical study of existing data and thus evaluate the effectiveness of the PGPTS and associated well field located near Zone 12, as presented in *Evaluation of the Perched Groundwater Pump & Treat System and Associated Well Field* (Rainwater, et al., 2003). This study included review of design and implementation documents that described the planning and construction of the PGPTS, as well as O&M reports that record the operational history of the system. The primary purpose of the PGPTS is to serve as an ICM to determine the effectiveness and efficiency of the pump and treatment processes for perched groundwater.

The PGPTS became operational in September 1995 to demonstrate collection and treatment of groundwater containing HEs and VOCs (e^2M, 1995). The PGPTS was expanded as of October 2000 to 45 operational extraction wells, nine injection wells, GAC treatment, and chemical precipitation/microfiltration (CPM) pretreatment. At the time of the study, 36 extraction wells pumped directly to the GAC treatment, and nine wells pumped to the CPM system.

The results and conclusions of the report are as follows:

- The current treatment processes are effective in removing the target HEs and chromium from the influent waters; almost 250 million gallons of contaminated water were successfully collected and treated through April 2003.
- The heterogeneous and relatively thin layer of perched groundwater limits the effectiveness of the extraction and injection well field for hydraulic containment.
- Operational histories of the extraction wells show that most of the wells operate less than 75 percent of the time and at flow rates far below the capacities of the installed pumps.
- Most of the pumps in the extraction wells are over-sized when compared to the capacity of the aquifer to transmit water, and it is also possible that siltation has occurred in some wells.
- Some injection wells have experienced decreasing capacity and surface leakage.

- There has not yet been enough travel time to allow significant reductions in plume concentrations.
- Perched groundwater has been impacted offsite, and the current ICM is not extensive enough to pull back that contamination.

Based on this review, the following recommendations were made:

- All wells that are not on the Supervisory Control and Data Acquisition (SCADA) system should be incorporated so times of operation can be tracked.
- Extraction wells that are not operating at least 75 percent of the time should be checked for siltation within the well screens and resizing of pumps for more constant operation.
- Existing or temporary pressure transducers in extraction wells can be used to perform recovery tests to estimate local hydraulic conductivity values.
- Inconsistencies and questions in the well logs for all extraction and injection wells must be clarified where possible.
- Hydraulic analysis of the flow conditions between the extraction wells and treatment systems must be performed to estimate head required from the extraction well pumps.
- Injection wells should be tested and serviced to recover flow capacity.
- Ongoing numerical modeling efforts should refine predictions of system performance.

Consideration of expansion of the ICM to include other contaminated zones of perched groundwater both onsite and offsite can occur after the recommended maintenance activities for the existing wells.

5.11 Bench Testing for *In Situ* Ozone Oxidation of HEs

The *Bench Testing for In Situ Ozone Oxidation of High Explosives, Final Report* (Comfort, 2004) presented results of a study to determine the efficacy of ozone to degrade and mineralize RDX. In addition, the study evaluated aerobic biodegradation following partial ozonation of an RDX solution.

Solution trials showed 2 percent (w/w) ozone was effective in mineralizing 80 percent of RDX in solution, provided some Pantex Plant soil was present to buffer the solution. Results from the evaluation of partial ozonation indicate ozone-generated RDX products were much more biodegradable than untreated controls. The products of RDX ozonation appeared to stimulate biodegradation of native RDX. The report concluded the use of ozone as a remedial treatment of the contaminated vadose zone is feasible.

5.12 Bioremediation of HE Soils at the Burning Ground

This treatability study began in July 2005. QPL, Inc., was contracted to perform bioremediation within three areas at the Burning Ground identified as having elevated levels of HEs and barium (presumably

barium nitrate). The following paragraphs summarize the objectives and plan for the project as they existed before implementation.

The objectives of this project are to:

- Provide the information necessary to perform a voluntary corrective action by bioremediation of HE- and barium-contaminated soils within the three project areas.

- Remediate to a depth of 2 ft soils contaminated with HEs and barium to concentrations below the soil-to-air-ingestion (SAI)-MSC ALs for the respective analytes in the area of concern.

QPL, Inc. developed a strategy to bioremediate the constituents in the HE-contaminated soils to concentrations below the SAI-MSC ALs based on a review of analytical data and information provided by BWXT Pantex. QPL Inc.'s bioremediation treatment consisted of an aqueous solution of naturally-occurring soil microbes and nutrients applied directly to contaminated soils. The bioremediation microbes were grown onsite. Following a growth period of approximately two days, the bioremediation broth was stabilized to a pH of 9 to 10 to reduce barium leachability and applied topically to the project areas. Flame retardant tarps were placed over the treatment areas to prevent moisture loss and facilitate microaerophillic environments. Because of the high concentrations of HEs and barium in the areas, a total of ten or more treatments were planned for the affected sites to achieve the goal of reducing HE concentrations to levels below their respective SAI-MSCs. Historically, QPL, Inc., reports TNT and its metabolites degrade first, followed by RDX, and then HMX. Total nitrobodies usually average between a 1 to 2 percent reduction daily based on laboratory bench scale results.

5.13 *IN SITU* GROUNDWATER BIOREMEDIATION SYSTEM PILOT STUDY (JANUARY 2006 DRAFT REPORT)

The ITRD group evaluated a number of *in situ* remediation technologies that destroyed groundwater contaminants in place within perched groundwater and, as a result, wrote a report entitled, *Conceptual Deployment Scenarios for In Situ Remediation of the Southeast Perched Aquifer Plume* (Aquifer Solutions, 2002). This report (Section 5.10) identified three promising technologies, including ISB. BWXT Pantex (Aquifer Solutions, 2005) selected a group of three companies to: 1) design a pilot-scale anaerobic ISB system at Pantex Plant to treat HE contamination in the southeast perched groundwater plume; 2) build the ISB system; and 3) operate and maintain the ISB system. The project will expand the bench scale to a pilot scale field demonstration of ISB. The objective of this project is to gain a better understanding of how to manage the southeast plume of impacted perched groundwater through bioremediation by reducing contaminant toxicity, improving implementability, reducing operational costs; and increasing the short- and long-term effectiveness of the treatment.

This project began in August 2005. The subcontractors provided a detailed description of the:

- Remediation technique and method of implementation at the site
- Determination of the size and depth of the areas to be remediated
- Treatment durations and frequencies
- Approximate break-down times for the COPCs at each location
- Recommended confirmation-sampling frequencies.

The primary COCs for the ISB are HEs (primarily RDX and HMX), halogenated organics (TCE and 1,2-DCA), and hexavalent chromium. The ISB pilot scale system will be designed for areas within the

perched groundwater that have 15 ft of saturated thickness or less. ISB involves the use of indigenous microorganisms to degrade contaminants in the subsurface. The process generally involves enhancement of the subsurface microbial processes by injection of nutrients (nitrogen and phosphorus) and by maintaining appropriate reduction/oxidation and dissolved oxygen conditions. One advantage of this technology is that the amendments injected during the process are fairly benign. ISB technology can potentially involve either anaerobic or aerobic microbial processes. While TCE and hexavalent chromium are only treated using anaerobic ISB, testing has shown that RDX and other HE compounds can potentially be degraded anaerobically or aerobically. Anaerobic ISB is considered the preferred treatment because it will treat HEs, hexavalent chromium, and TCE, and because it does not require the constant addition of dissolved oxygen. However, microbially mediated reductive ISB treatment of COPCs follows different mechanisms for different COPCs.

To date, the key data gaps existing for ISB at Pantex Plant include:

- Assessing geochemical conditions and microbial populations to achieve optimal groundwater treatment
- Determining the type and quantity of amendments required to achieve groundwater treatment
- Characterizing the biodegradation kinetics sufficiently so that the process can be managed *in situ* to ensure complete biological treatment
- Documenting that the biodegradation does not result in any harmful, persistent transformation products and that mineralization of HEs occurs.

The ISB pilot project construction activities included well installation, injection of the amendment, and real time monitoring of the ISB field pilot area during injection. A total of 13 monitoring and injection wells were installed. Baseline groundwater sampling was completed on October 11-14, 2005. The ISB treatment system pilot study was established by injecting an amendment consisting of concentrated Newman Zone® amendment and water obtained from a nearby Pantex Plant fire hydrant into six wells during December 1-14, 2005. The Newman Zone® amendment was a buffered nonionic formulation that contained 50 percent salad grade soybean oil by volume, 4 percent sodium lactate, 1 percent sodium bicarbonate, and the remainder consisting of water and a proprietary, unspecified amount of nonionic surfactants. Overall, a total volume of 163,500 gallons of solution, comprised of 7,800 gallons of Newman Zone® amendment mixed with water, was injected into the six treatment wells.

The results and conclusions of the report are as follows:

- Six wells were injected with the ISB amendment instead of nine wells, resulting in the total target injection volume for each well remaining the same, but the Newman Zone® amendment in water became more concentrated.
- The increased concentration allowed for greater availability of carbon donor per kg of soil and therefore a greater chance for success to create and maintain strongly reducing conditions to support anaerobic biodegradation.
- The injection flow rates were observed to be variable and lower than anticipated due to lower than expected aquifer hydraulic conductivity. The observed injection rates for five of the six wells were 10 to 90 percent less than expected and generally decreased with time.

- Results from aquifer hydraulic testing performed during the injection process reflect the high degree of geologic heterogeneity in the ISB test area.

- Direct amendment distribution was confirmed by the presence of the amendment observed in select monitoring wells.

- The amendment may migrate in groundwater over the months following injection. As the amendment ferments, releasing volatile fatty acids and other fermentation products, these readily bio-available electron donors will also be transported some distance away from the initial zone of amendment emplacement.

Based on this review, the recommendation was made that the ongoing project O&M activities and results will determine the overall effectiveness of the ISB technology for COPC treatment, and the potential need for periodic reinjection of amendment.

5.14 *IN SITU* PRB FOR PERCHED GROUNDWATER PILOT

The *Design and Build the In-Situ Source Control Interim Corrective Measures for the Pantex Perched Aquifer* project began in February 2004 (BWXT Pantex, 2005d). The primary project tasks included design of a pilot scale *in situ* ozone oxidation system to treat residual HEs in the vadose zone beneath SWMU 122b and design of a pilot scale *in situ* PRB using sodium dithionite to provide source control for the southeast plume of perched groundwater adjacent to Zone 12. The overall objective of the *in situ* permeable reactive barrier was to create an immobile chemically-reducing zone in the perched groundwater that would serve as a potentially long-lasting reactive barrier zone for the treatment of COPCs.

The ICM reactive barrier was constructed as a pilot-scale system with an overall length (perpendicular to groundwater flow) of approximately 60 ft and a width (in the direction of flow) of approximately 40 ft. Field construction of the reactive barrier involved injection of 165,000 gallons of dithionite solution (with a potassium carbonate buffer) into two wells, and the subsequent withdrawal of 175,000 gallons of reacted fluids. Injection into the treatment wells occurred over a period of seven days in February 2005.

Results of this treatability study are as follows:

- The dithionite injection flow rates, pressures, and observed radius of influence met the project goals.

- Chemically reducing conditions were established within an approximate 27-ft radius around each injection well, and substantial treatment overlap was obtained between the injection wells. The results indicate that an injection well spacing larger than 30 ft could possibly be considered for future work, although potentially at the risk of reduced intensity and uniformity of the chemical reduction treatment.

- Laboratory analyses of groundwater samples indicated all three primary COPCs were reduced by dithionite.

    - Initial RDX concentrations ranged from 210 to 440 µg/L. RDX was not detected after treatment.

- TCE concentrations ranged from 0.76 to 4.3 µg/L initially, but TCE was present in only one sample after treatment at 0.57 µg/L.
- Initial chromium concentrations ranged from 26 to 94 µg/L, but chromium was present in only one sample after treatment at 2.1 µg/L.

- The initial post-treatment groundwater samples likely represent a mixture of the injected fluids with ambient groundwater. It is expected to take three to six months for a pore volume of groundwater not affected by the injection process to migrate through the reactive barrier.

The post-treatment groundwater analytical results showed an increased concentration of some metals including arsenic, antimony, cadmium, cobalt, manganese, potassium, magnesium, sodium, iron, and zinc. Post-treatment concentrations of arsenic and antimony exceeded RRS 2 criteria. Post-treatment concentrations of arsenic ranged from 30.7 to 43.2 µg/L (exceeding the RRS 2 standard of 12 µg/L), and the post-treatment antimony concentrations ranged from 4.9 µg/L to 20.8 µg/L (exceeding the RRS 2 standard of 15 µg/L). Furthermore, post-treatment groundwater analytical results for pH, sulfate, iron, sodium, and manganese exceeded EPA's secondary maximum contaminant levels (SMCLs). Because these immediate post-treatment samples were strongly influenced by the injection process and the immediate chemical reduction reactions, additional monitoring will be needed to assess the long-term effects of the reactive barrier on metals concentrations.

Because the reactive barrier treatment relies on passive groundwater movement, at least several months of monitoring will be required to assess the overall barrier performance in reducing COPC concentrations. Results of the pilot scale study will be evaluated to determine the effectiveness of ISRM for treatment of the southeast perched groundwater contaminant plume and will form the basis for the full-scale design requirements, if proven feasible for treatment of impacted perched groundwater at Pantex Plant.

6.0 EVALUATION CRITERIA AND RANKING SYSTEM

This section presents the criteria for evaluation of the corrective measure alternatives, describes each, and presents the system for ranking the effectiveness of each alternative in meeting the criteria. Section 6.1 presents the nine criteria identified in the *RCRA Corrective Action Plan* (EPA, 1994) for assessing alternatives to address perched groundwater. Section 6.2 presents the ranking system implemented for each alternative that allows comparison to the others.

The assessment of corrective measure alternatives, conducted using the evaluation criteria and ranking system described below, is presented in Section 7. Of the nine criteria, the first four are considered essential; the remaining five criteria are factors to be considered when weighing alternatives.

6.1 EVALUATION CRITERIA

Each remedial alternative must be evaluated against requirements in the *RCRA Corrective Action Plan* (EPA, 1994) and 30 TAC §335.562, *Remedy Evaluation Factors for RRS 3* to ensure this CMS/FS provides information of sufficient quality and quantity to justify the selection of a remedy.

In addition, CERCLA contains nine evaluation criteria [40 CFR 300.430(e)(9)(iii)] that must be used to judge each alternative. These nine criteria are grouped as two "threshold criteria," five "primary balancing criteria," and two "modifying criteria." The threshold criteria consist of (1) protection of human health and the environment, and (2) compliance with ARARs. Compliance with ARARs is covered in Criteria 2 through 4, listed below. The five primary balancing criteria are listed below as Criteria 5 through 9. The two modifying criteria, State Acceptance and Community Acceptance, are completed through issuance of the proposed plan for public review and comment.

The nine criteria used to evaluate the alternatives in this CMS/FS are:

1. Protection of human health and the environment
2. Attainment of media-specific cleanup standards
3. Control of source releases
4. Compliance with applicable standards for waste management
5. Long-term reliability and effectiveness
6. Reduction in toxicity, mobility, or volume of waste
7. Short-term effectiveness and safety
8. Implementability
9. Cost.

6.1.1 Protection of Human Health and the Environment

Protection of human health and the environment is a critical factor in determining suitability of the corrective measures. Each alternative is discussed in terms of its ability to achieve and maintain short- and long-term protection.

6.1.2 Attainment of Media-Specific Cleanup Standards

Each proposed remedy must meet the applicable cleanup standards presented in Section 3. Media-specific cleanup standards were considered in the development of the extent and technical approach for each alternative. An estimate of the time required to meet the standards by each alternative is discussed under this criterion.

6.1.3 Control of Source Releases

Source releases are to be controlled as much as reasonably possible; therefore, a key objective of an appropriate remedy is to prohibit additional adverse effects on the environment by eliminating further releases. To achieve this objective, some alternatives combine source controls with other measures. Alternatives were developed to cover a range of source control options.

6.1.4 Compliance with Applicable Standards for Waste Management

Under this criterion, each alternative is evaluated in terms of its ability to comply with all applicable state and federal regulations for management of wastes.

6.1.5 Long-Term Reliability and Effectiveness

The expected long-term reliability and effectiveness of each alternative is evaluated giving consideration to the risks and effects of failure, whether the technology (or combination of technologies) has been used effectively under similar circumstances, and whether the alternative is sufficiently flexible to deal with uncontrollable changes (e.g., weather). This criterion addresses the useful life of alternative components and associated O&M issues.

6.1.6 Reduction in Toxicity, Mobility, or Volume of Waste

This criterion addresses the ability of an alternative to eliminate or substantially reduce the toxicity, mobility, or volume of contamination. The type and quantity of residual contamination is also assessed under this criterion.

6.1.7 Short-Term Effectiveness and Safety

Short-term effectiveness addresses the protection of workers and the community during implementation of a remedial action. Potential safety factors considered under this criterion include fire, explosion, exposure to hazardous substances, and potential threats associated with treatment, excavation, transport, and disposal or containment of waste material.

6.1.8 Implementability

This criterion includes the degree of difficulty associated with implementing a remedy. Information considered when evaluating implementability includes administrative activities, constructability, operational reliability, availability of equipment and specialists needed to construct the remedy, and time necessary for implementation.

6.1.9 Cost

The relative cost of each alternative is presented and includes engineering, site preparation, construction, materials, labor, disposal, annual O&M costs, and multiple other factors, as appropriate. Cost estimates are based on reference manuals, historical costs, vendor quotes, and engineering estimates.

6.2 EXPLANATION OF RANKING SYSTEM

The following section explains the ranking system used for comparison of the alternatives. This comparison uses the nine evaluation criteria as the basis for the assessment.

1. **Protection of Human Health and the Environment:** This criterion is ranked using a "yes" or "no." "Yes" indicates both short-term and long-term protection is achieved using the technology or option. "No" indicates either short-term or long-term protection (or both) is not achieved and the technology or option does not meet the criterion.

2. **Attainment of Media-Specific Cleanup Standards:** This criterion is defined as the overall remedial action objective of reducing risk to a receptor. It can be achieved by meeting the MSC limits or by removing the pathway for exposure through use of long-term site controls (i.e., institutional or engineering controls). This criterion is ranked using a "yes" or "no." "Yes" indicates the technology or option can attain acceptable cleanup standards identified for each unit. "No" indicates the goals will not be attained.

3. **Control of Source Releases:** This criterion is ranked using a "yes" or "no." "Yes" indicates the technology or option results in containment of the contaminants. In circumstances where there is little or no potential for contaminants to migrate because of existing barriers or constraints or natural attenuation, containment is not required and consequently the criterion is given a "yes" with a footnote indicating the rationale. "No" indicates the technology or option does not result in containment of contaminants that have the potential to migrate from the release site.

4. **Compliance with Applicable Standards for Waste Management:** This criterion is ranked using a "yes" or "no." "Yes" indicates the technology or option results in attainment of all applicable standards in addition to the cleanup goals. "No" indicates the standards cannot be met using the specified technology or option.

5. **Long-Term Reliability and Effectiveness:** This criterion is ranked using a scale of 1 through 5.

   - "1" indicates the technology or alternative offers no long-term reliability or effectiveness for the specific unit and COCs.

   - "2" indicates the technology or alternative offers some long-term reliability or effectiveness, but requires continuous maintenance to sustain the protection or may potentially degrade over time.

   - "3" indicates the technology or alternative offers a moderate level of long-term reliability or effectiveness, but requires periodic maintenance to sustain the protection or may potentially degrade over time. Some uncertainty is associated with the ability of the technology or alternative to sustain long-term integrity or protection.

   - "4" indicates the technology or alternative offers an acceptable level of long-term reliability or effectiveness, but requires some periodic maintenance to sustain protection or may potentially degrade over time.

   - "5" indicates the technology or alternative offers a high level of long-term reliability or effectiveness, requires little to no maintenance to sustain the protection, and exhibits a low

potential for degradation of the protection over time. High confidence is associated with the ability of the technology or alternative to sustain long-term integrity or protection.

6. **Reduction in Toxicity, Mobility, or Volume of Waste:** This criterion is ranked using a scale of 1 through 5.

   - "1" indicates the technology offers no reduction in toxicity, mobility, or volume of the COCs.
   - "2" indicates the technology or alternative offers reduction in only one of the three objectives, and a high degree of uncertainty is associated with the implementability and potential success of the technology or alternative.
   - "3" indicates the technology or alternative offers reduction in at least two of the objectives, and a moderate level of uncertainty is associated with the implementability and potential success of the technology or alternative.
   - "4" indicates the technology or alternative offers reductions in all three objectives, but some uncertainty is associated with the ability of the technology or alternative to sustain long-term integrity or protection.
   - "5" indicates the technology or alternative offers reductions in all three objectives, with a high level of certainty based on proven implementation of the technology or alternative.

7. **Short-Term Effectiveness and Safety:** This criterion is ranked using a scale of 1 through 5.

   - "1" indicates the technology implementation presents an unacceptably high level of risk during implementation that cannot be mitigated using reasonable safety and protection measures, or short-term risk is high because no action will be taken.
   - "2" indicates the technology implementation presents unacceptably high risks that can be mitigated only by implementing safety and protective measures.
   - "3" indicates the technology implementation presents moderate but unacceptable risks that can be mitigated by implementing industry standard safety and protective measures.
   - "4" indicates the technology implementation presents little risk and, as such, requires minimal additional safety and protective practice beyond that normally required for a similar activity in an uncontaminated site.
   - "5" indicates the technology implementation presents very little risk and, as such, requires no additional safety and protective practice beyond that normally required for a similar activity in an uncontaminated site.

8. **Implementability:** This criterion is ranked using a scale of 1 through 5.

   - "1" indicates the technology implementation is unproven and extremely difficult under site conditions, or equipment required for implementation is not available.

- "2" indicates the technology implementation is proven only in pilot-scale tests and may be difficult under site conditions, or equipment required for implementation is only in development or difficult to obtain or maintain.
- "3" indicates the technology implementation is proven for at the field scale level and presents some difficulty under site conditions, or equipment required for implementation is under development or may be difficult to obtain.
- "4" indicates the technology has been employed at similar sites with little difficulty and with good results.
- "5" indicates the technology has been employed under similar conditions with little difficulty and proven success.

9. Cost: Rather than provide a relative ranking for cost, the present value for each alternative is listed in the ranking matrix to allow direct comparison of the cost for each alternative.

7.0 ASSESSMENT OF GROUNDWATER CORRECTIVE MEASURE ALTERNATIVES

This section identifies several corrective measure alternatives that were evaluated to determine the recommended alternative. All the alternatives were evaluated to determine if the alternative could achieve remedial action objectives and meet the nine evaluation criteria discussed in Section 6. The approach for conducting the evaluation is defined and the results are summarized in this section.

Five alternatives were evaluated against the nine criteria to determine the recommended alternative:

(1) No Action
(2) Monitored Natural Attenuation (MNA)
(3) Existing Pump and Treat with MNA,
(4) Enhanced Pump and Treat with MNA, and
(5) Targeted Treatment with MNA.

The evaluation of each of the alternatives against the nine criteria is summarized in section 7.3

The No Action alternative, natural attenuation, was determined to be inadequate for further consideration since it will not achieve protection of human health and the environment (one of the threshold criteria) or meet the remedial action objectives. Therefore, Alternative 2 – MNA was selected to serve as the baseline for comparison with the other alternatives. The selected corrective measure(s) must achieve the following remedial action objectives (1) prevent potential for exposure to impacted perched groundwater and (2) minimize potential for migration of COCs from perched groundwater to the underlying Ogallala Aquifer. Modeling simulations were used to aid in the evaluation of each of the alternative's ability to meet the remedial action objectives; detailed descriptions of the simulations are presented in Appendix A.

Following evaluation of the five alternatives to determine if the remedial action objectives could be achieved, additional simulations were conducted to combine the strengths of each alternative and arrive at a recommendation. The recommended alternative (see Section 7.5) consists of monitored natural attenuation with enhanced pump and treat, and continued pursuit and periodic reevaluation of targeted *in situ* treatment in the Fine-Grained Zone Transition Area, as discussed in Section 3.3.1.3. Details of the assessment are presented in the remainder of this section and provide the technical and practical considerations that are the basis of the recommendation.

7.1 ALTERNATIVE DEVELOPMENT

Remedial technologies were identified and described in Section 4. The following process options from Section 4 have been retained for use individually, or in combination, in the development of alternatives for perched groundwater:

- Land use controls
  - Engineering controls (fences)
  - Institutional controls (land use and deed restrictions)
- Containment (hydraulic barriers)
- Removal (vertical extraction wells, horizontal extraction wells)

- *In situ* biological treatment (enhanced bioremediation, natural attenuation)
- *In situ* chemical treatment (advanced oxidation, reductive degradation and dechlorination)
- *Ex situ* physical/chemical treatment (adsorption/absorption processes, ion exchange, GAC, pumping).

After analysis of these technologies, alternatives were developed based on experience gained at Pantex Plant through treatability studies, ICMs, ongoing analysis of the existing PGPTS, groundwater modeling (Appendix A), site knowledge, and professional engineering judgment.

The following alternatives are evaluated for the impacted portions of the perched groundwater:

- Alternative 1: No Action
- Alternative 2: MNA
- Alternative 3: Existing Pump and Treat with MNA
- Alternative 4a: Enhanced Pump and Treat using Horizontal Extraction Wells with MNA
- Alternative 4b: Enhanced Pump and Treat using Vertical Extraction with MNA
- Alternative 5: Targeted Treatment with MNA.

All of the alternatives include long-term groundwater monitoring, except Alternative 1.

7.2 MODELING OF ALTERNATIVES

Modeling simulations were conducted to evaluate the primary remedial action objectives of reducing or eliminating the flux of water from the perched groundwater in the southeast area to reduce the potential for COCs to be transported to the Ogallala Aquifer. Alternatives were evaluated using a two dimensional, single layer model (SLM) that simulates flow and transport within the saturated portion of the perched groundwater flow system only. As such, the SLM represents a screening level tool, which provides a consistent framework for comparison of the different alternatives under consideration for remediation of perched groundwater. However, the model does not calculate leakage of perched groundwater through the lower model boundary; therefore, the model cannot simulate the spatial, vertical flux of perched groundwater through the FGZ to the underlying Ogallala Aquifer.

Baseline simulations of COPC migration through the FGZ for the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) were conducted using a Focused Transport Model (FTM) refined to better represent transport processes in the area of interest. The FTM was a three-dimensional variably saturated flow and transport model based on the BIOF&T3D simulator and was used to simulate transient migration of COPCs assuming steady-state flow of groundwater. Modeling simulations for this CMS/FS must account for transient changes to groundwater flow caused by the effects of the remediation systems under evaluation; therefore, the FTM is not suitable. BIOF&T3D variably saturated models constructed to address coupled simulation of transient flow and transport processes, such as dewatering alternatives for perched groundwater, were not available at the time the CMS/FS was conducted because of the complexity associated with refining the sitewide model domain and balancing computational speed with the ability to accurately represent fate and transport of the COCs. The fully three-dimensional transient coupled flow and transport BioF&T3D model, which simulates flow from the land surface to the bottom of the Ogallala Aquifer over an approximately 17-square mile area (slightly greater in areal extent than the main perched groundwater) is in progress and expected to be functional in the summer of 2006. The model will account for changes in both the perched groundwater and Ogallala Aquifer over time.

The SLM used to evaluate the alternatives is documented in Appendix A. The model calculates the lateral flux of perched groundwater through general head boundaries simulated near the observed extent of perched groundwater. This flux is analogous to the theoretical vertical flux of perched groundwater through the FGZ to the underlying Ogallala Aquifer. By assuming that lateral flux through the model boundaries is equal to perched groundwater flux to the Ogallala Aquifer, alternatives can be evaluated and compared based on the change in water or mass flux leaving the lateral model boundaries. The SLM is not intended for calculation of spatial vertical flux through the FGZ underlying perched groundwater. Further, the SLM was calibrated so the calculated water flux out of the model boundaries matches the vertical flux through the FGZ calculated by the three-dimensional variably saturated flow and transport model. Therefore, the lateral flux of water and mass out of the general head boundaries in the SLM provides a relative (surrogate) measure of the volumetric water and RDX mass flux to the underlying Ogallala Aquifer, and is the primary metric for evaluation of different potential alternatives.

The general head boundaries that ring the simulated perched groundwater flow system (Figure 7-1) have been divided into segments (referred to as reaches) for further refinement of the assessment of the alternatives, as described below:

- Reach 0: This reach represents the entire simulated perimeter of the perched groundwater flow system with the exception of Reaches 1 through 4. Flux through this reach corresponds to the total predicted water and mass flux out of the perched groundwater flow system along the southern boundary west of Reach 1, along the western model boundary, and along the northern and eastern model boundaries north of Reach 4.

- Reach 1: This reach represents the southern boundary (lateral extent) of the perched groundwater flow system corresponding to the location where risk assessment modeling efforts predicted the initial and most significant migration of impacted perched groundwater through the FGZ. Reach 1 is the most critical reach for comparison of RDX mass flux and volumetric water flux out of perched groundwater among the various scenarios.

- Reach 2: This reach, located east and adjacent to Reach 1, represents the southeast-most extent of the perched groundwater flow system.

- Reach 3: This reach, located north and adjacent to Reach 2, represents the eastern boundary (lateral extent) of perched groundwater east of Zone 12.

- Reach 4: This reach, located north and adjacent to Reach 3, represents the eastern boundary (lateral extent) of perched groundwater northeast of Zone 12 and southeast of Playa 1.

Five suites of modeling scenarios, totaling 38 separate simulations, were completed to evaluate the remedial potential of No Action, MNA, MNA with the existing PGPTS, MNA with enhanced groundwater extraction using horizontal or vertical wells, and MNA with biodegradation enhancements. Results from the simulations were analyzed and the scenarios that provided the greatest reduction of mass leaving the model boundaries and greatest extraction of contaminant mass from perched groundwater were developed into alternatives. Table 7-1 lists 11 key simulations identified in Appendix A as being illustrative of the various remedial action strategies. In this section, modeling results documented in Appendix A are examined to support evaluation of corrective measure alternatives 1, 2, 3, 4a, 4b, and 5. Table 7-1 documents the model runs corresponding to these alternatives:

- Alternative 1: No Action corresponds to Model Run 2

- Alternative 2: MNA corresponds to Model Run 2

- Alternative 3: Existing Pump and Treat with MNA corresponds to Model Run 8
- Alternative 4a: Enhanced Pump and Treat Using Horizontal Extraction Wells with MNA corresponds to Model Run 22
- Alternative 4b: Enhanced Pump and Treat Using Vertical Extraction Wells with MNA corresponds to Model Run 35
- Alternative 5: Targeted Treatment with MNA corresponds to Model Run 38.

Table 7-1 also provides a summary of the RDX mass exiting the perched groundwater or degrading for each of the key simulations. The RDX distribution in the perched groundwater flow system was imported directly from the FTM model representation of the RDX distribution as presented in the Baseline HHRA (BWXT Pantex/SAIC, 2006). RDX concentrations were determined from trend analysis of groundwater data collected from perched groundwater investigation wells from 1999 through 2003. If a statistically significant trend existed at a given well, then the last reported value for the well was used, otherwise, a 95% UCL was calculated from data for each individual well (the lesser of the 95% UCL or maximum reported value were used in this case). The resultant RDX concentration data was used to depict the distribution of RDX in perched groundwater. The RDX mass was estimated using this distribution, observed perched groundwater levels from June 2003 (with porosity of 25%), and representative parameters (described in Appendix A). The initial RDX mass estimated for modeling is 4,780 kg in the perched groundwater and 5,350 kg in soil for a total initial mass in the system of 10,130 kg.

In addition to the aforementioned modeling simulations, alternatives for further reducing future stormwater recharge in the onsite ditches and playas were evaluated (see Appendix A) and determined to be of potential use for improving the effectiveness of reducing the volume of perched groundwater over a long period of time, i.e., decades. While some benefit could be derived from such alternatives, priority was given to assessing the alternatives that actively addressed the perched groundwater, and therefore, the alternatives for reducing future stormwater recharge were not considered further in this analysis.

Table 7-1. Summary of Selected Modeling Results

Alternative Number	Run	Description	Estimated Mass Exiting Perched Groundwater (kg) All Reaches 30 years	All Reaches 150 years	Reach 1 30 years	Reach 1 150 years	Total Decay Through Half-Life[a] (kg) 30 years	150 years	Estimated Mass Extracted by Active Remediation (kg) 30 years[b,c]
None	1	Baseline non-reactive transport simulation for comparison to risk assessment modeling results	2,340	3,350	1,050	1,311	0	0	--
1 & 2	2	Natural Attenuation	2,010	2,770	1,450	1,740	4,880	6,290	--
	3	Natural Attenuation, reduced recharge	1,870	2,450	1,373	1,621	4,690	5,820	--
3	5	Pump and treat, existing system with injection, Natural Attenuation	1,420	2,010	1,107	1,301	3,910	4,940	2,560
	8	Pump and treat, existing system, no injection, Natural Attenuation	710	990	580	670	3,130	4,120	2,800
4a	22	Pump and treat, existing system, no injection, plus six horizontal wells, Natural Attenuation	360	510	270	330	2,470	3,330	3,130
	23	Pump and treat, existing system, no injection, plus 8 horizontal extraction wells, Natural Attenuation	360	480	265	315	2,380	3,160	3,160
	24	Pump and treat, existing system, no injection, plus 8 horizontal extraction wells and reduced recharge, Natural Attenuation	380	510	282	350	2,430	2,960	3,340
	25	Pump and treat, existing system, no injection, plus 10 horizontal extraction wells, Natural Attenuation	380	490	276	325	2,370	3,150	3,160
4b	35	Pump and treat, existing system, no injection, plus 8 lines of vertical extraction wells, Natural Attenuation	100	160	80	100	1,660	2,180	4,310
5	38	MNA with Targeted Treatment	370	720	110	190	6,940	8,140	--

[a] Total decay through half-life is the sum of decay in water and decay in soil.

[b] Total RDX mass in water is estimated based on the initial RDX concentration in water at each model grid cell multiplied by the volume of water in each model grid cell as determined by the June 2003 measured water levels and porosity of 25%. The initial RDX concentration distribution is the same as that used in the Baseline HHRA. The corresponding mass in soil is calculated using the K_d, ultimately yielding [(Mass_soil) = 1.12 * (Mass_water)]. Initial RDX mass in the system is 4,780 kg in water for all simulations, and 5,350 kg in soil for reactive simulations (10,130 kg total initial mass for reactive simulations).

[c] All SLM modeling scenarios included an initial 3-year transient calibration period in which 916 kg of RDX were removed via the existing pump and treat system, and this mass is included in the total mass extracted numbers reported here for Runs 5, 8, 22, 23, 24, 25 and 35.

The original design of the existing PGPTS included re-injection of treated groundwater to promote flow of impacted perched groundwater to the extraction wells for removal (Figure 7-2), i.e., the focus of the design was to maximize the contaminant mass removal rate. The system continues to operate with some injection of treated effluent according to this design, although many of the original injection wells have been replaced because of decreasing capacity and surface leakage as described in *Evaluation of the Perched Groundwater Pump & Treat System and Associated Well Field* (Rainwater, 2003). Decreasing capacity of injection wells continues to affect operation of the existing PGPTS, leading to questions about the long-term reliability of injection. Additionally, lower head in the perched groundwater resulting from the elimination of injection will reduce the driving vertical flow gradient across the FGZ. Therefore, the selected alternatives do not include re-injection of treated water into perched groundwater.

To illustrate the effects of eliminating injection, Model Runs 5 and 8 (described in Table 7-1) simulated operation of the existing PGPTS with and without injection of treated effluent. Run 5 includes re-injection of treated groundwater, however, Run 8 does not. The simulated mass exiting the model boundaries is significantly less in Run 8 than in Run 5. Therefore, the potential for downward migration of impacted perched groundwater is also much less, greatly reducing the potential for impacts to the Ogallala Aquifer. Because the reduction in potential impacts to the Ogallala Aquifer (i.e., less RDX mass exiting the perched groundwater flow system through the model boundaries) is the primary metric for alternative evaluation, re-injection of treated groundwater was not included in any alternatives evaluated in this section.

The model results shown in Table 7-1 represent an evaluation of alternative comparison using a consistent framework. The model results and field results will differ, primarily due to the simplifications used to create the screening model. The model assumptions and limitations are discussed in Appendix A. The main assumptions for interpreting the model results for CMS remedial alternative evaluation are:

- The SLM only simulates the saturated portion of the perched groundwater, where the saturated thickness is currently greater than 0.5 ft. This is the most mobile portion of the RDX impact and shows the greatest reduction in the amount of mass flux, when controlled. However, this will underestimate the total mass of RDX present, and any effects that the vadose zone or FGZ have on extending the time to reaching target levels from continued leaching and dual porosity effects. Results presented refer only to the modeled portion of the system. The results presented below are best case, as the screening model cannot account for the effects of residual RDX leaching into the flowing portion of the perched groundwater system, or the rebound effects from the dual porosity nature of the FGZ. Times to reach the target levels are therefore deemed as no-sooner than times. Actual times to reach target levels will be longer.

- SLM uses a grid spacing of 100-ft, and smaller models and analytical solutions are used to develop the zones of influence of pumping wells in the thinner portions of the perched groundwater. These rates are then upscaled into the SLM. When the aquifer thickness decreases to the same relative value as the local undulations in the surface of the FGZ, the flow directions are controlled more directly by perched groundwater levels and the FGZ topography. Exploratory boreholes are planned to aid in identifying the top of the FGZ, and injection wells will be installed on the high points and extraction wells in the lower areas. While the SLM will show excellent capture, in the field there can easily be zones where the water flows past the recovery systems. Also, the effect of changes in conductivity above the FGZ, or leakage through the FGZ, can have basically the same result on the water table surface. This will complicate the results of operation of extraction and injection systems through water table measurements alone.

- SLM uses the widely applied first-order biodecay rates (half-lives) approach to simulate the natural or enhanced destruction of the RDX. These processes are known, among other aspects, to

be a simplification of the actual microbial processes and are redox zone dependent. The effective half-life in the field may change with time and location, as a result of other actions taken to remediate the groundwater.

7.3 ALTERNATIVE EVALUATION

The alternatives are evaluated on their ability to meet the remedial action objectives and achieve the nine criteria defined in Section 6. All alternatives are then compared using the scoring system outlined in Section 6.

The overall remedial action objectives for perched groundwater are:

- Remove or prevent exposure to perched groundwater containing COCs that pose a risk to human health in excess of ILCR of 1.0E-05 and/or an HQ > 0.1.
- Eliminate or minimize migration of perched groundwater containing COCs at concentrations exceeding acceptable risk values offsite and to the Ogallala Aquifer.

The remedial action objectives can be met either by eliminating the exposure pathway through the use of long-term site controls or by treating impacted groundwater to the concentration limits established for each COC in Section 3. Table 7-2 presents the COCs and MSCs that apply to both the Plant boundary and offsite locations.

Table 7-2. Perched Groundwater Constituents of Concern and Media-Specific Concentration Limits

COC	MSC[1] (µg/L)	Basis for MSC
1,2-Dichloroethane	5.0	MCL
1,3,5-Trinitrobenzene	91.7	NC
1,3-Dinitrobenzene	0.302	NC
2,4-Dinitrotoluene	0.0637	C
2,6-Dinitrotoluene	0.0637	C
2-Amino-4,6-dinitrotoluene	0.423	NC
4-Amino-2,6-dinitrotoluene	0.442	NC
Boron	273.0	NC
Chromium (hexavalent)	100.0	MCL
Chromium (total)	100.0	MCL
HMX	90.0	NC
RDX	4.15	C
TCE	5.0	MCL
TNT	1.49	NC

COC - constituent of concern
MSC - media-specific concentration limits
C - MSC based on cancer endpoint
NC - MSC based on noncancer endpoint
MCL - MSC is the maximum contaminant level
[1]MSC based on chemical-specific HQ of 0.1 and chemical-specific ILCR of 1.0E-05 for carcinogens (See Table H-11 in Appendix H of BWXT Pantex, 2006)

RDX has been selected as an indicator constituent for the nature and extent of all other constituents in perched groundwater at Pantex Plant for this report. RDX is the primary COC identified in the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006). Generally, RDX has the greatest extent and highest concentrations in perched groundwater of any of the COCs. Therefore, the SLM results and mass removal rates are discussed only for RDX, because similar performance is expected for other COCs.

7.3.1 Alternative 1: No Action

Under this alternative, no active measures would be implemented to reduce or contain contamination in perched groundwater (i.e., current pump and treat activities would be discontinued and no additional measures would be taken to mitigate continued migration of COCs). Naturally-occurring processes (sorption, degradation, and dispersion [mixing]) are included (but not monitored) in the modeling completed for this scenario. The current monitoring program would also be discontinued under this alternative. Pantex Plant would continue to restrict use of perched groundwater onsite; however, there would be no restrictions on offsite use.

Protection of Human Health and the Environment. Because Pantex Plant would continue to restrict onsite use of perched groundwater, the No Action alternative would provide for onsite protection of human health. However, migration of impacted perched groundwater and potential risks to offsite receptors would continue.

Attainment of Media-Specific Cleanup Standards. Attainment of media-specific cleanup standards at property boundaries would not occur within 30 years under the No Action alternative. In addition, no action would be taken to eliminate exposure pathways.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]), indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. The No Action alternative would not result in the generation of waste to be managed.

Long-Term Reliability and Effectiveness. Restricting onsite use of perched groundwater is expected to be reliable in the future, provided Pantex Plant continues site control. The model shows an estimated mass of 2,770 kg of RDX exiting the perched groundwater zone after 150 years under this alternative.

Reduction in Toxicity, Mobility, or Volume of Waste. No active measures are taken to reduce contaminant toxicity, mobility, or volume under this alternative. Naturally-occurring processes including sorption, degradation, and dispersion (mixing) act to reduce mobility and toxicity.

Short-Term Effectiveness and Safety. No additional health risks to workers or the community would occur because no remedial actions would be implemented. The model shows an estimated mass of 2,010 kg of RDX exiting the perched groundwater zone after 30 years.

Implementability. Implementation of the No Action alternative would require termination of the existing PGPTS and cancellation of the monitoring program and any additional planned remedial activities for perched groundwater.

Cost. No cost is associated with this alternative.

7.3.2 Alternative 2: MNA

Alternative 2, MNA, is similar to the No Action alternative; however, under this alternative long-term monitoring will be completed. Under this alternative, no active measures would be implemented to reduce or contain contamination in perched groundwater (i.e., current pump and treat activities would be discontinued and no additional measures would be taken to mitigate continued migration of COCs). This alternative relies on natural attenuation to reduce COC concentrations. Sampling completed as part of an MNA assessment (completed by IT and Stoller [2000]) identified RDX degradation products in perched groundwater. Results from this study (Appendix A) indicated that natural attenuation was occurring, but rates were not determined. Natural attenuation processes included in this alternative include sorption, degradation, and dispersion (mixing). The current monitoring program would remain in place to monitor natural attenuation. Pantex Plant would continue to restrict use of perched groundwater onsite. This alternative was developed to provide a baseline for comparison /evaluation of other alternatives.

Ten additional monitoring wells (two in the perched groundwater and eight in the Ogallala Aquifer) would be added to the current network to better characterize the concentration and migration of contaminants in the perched groundwater and to monitor the Ogallala Aquifer. Long-term monitoring of perched groundwater and the Ogallala Aquifer would include groundwater elevation measurements and periodic sampling and analysis to determine COC concentrations.

The ten additional monitoring wells are shown in Figure 7-3 and their locations are described below.

- Three of the Ogallala Aquifer and one of the perched groundwater wells would be located east of the Plant on private agricultural land
- One Ogallala Aquifer well would be located on TTU property
- One perched groundwater well is located in the southwest corner of the site
- Four Ogallala Aquifer wells would be located farther north on Pantex Plant.

Protection of Human Health and the Environment. Because Pantex Plant would continue to restrict onsite use of perched groundwater, the MNA alternative would provide for onsite protection of human health. However, migration of impacted perched groundwater and potential risks to offsite receptors would continue.

Attainment of Media-Specific Cleanup Standards. Attainment of media-specific cleanup standards at property boundaries would not occur within 30 years under the MNA alternative. In addition, no action would be taken to eliminate exposure pathways.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and has completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]) indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. Any investigative derived waste (IDW) generated during installation of the new monitoring wells would be handled in accordance with established BWXT Pantex operating procedures for waste management.

Long-Term Reliability and Effectiveness. Restricting onsite use of perched groundwater is expected to be reliable in the future as Pantex Plant continues to maintain site control. Long-term effectiveness of natural attenuation is uncertain; degradation rates used were estimated from available site data, but have not been quantified at the site (although RDX degradation products have been detected in MNA sampling [IT and Stoller, 2000]). The degradation rate used in the modeling was estimated from site-specific information (see Appendix A). The estimated rate is at the low end (slow rate) of published literature values for observed RDX degradation. At 150 years, a total of 2,770 kg of RDX is estimated to have left the perched groundwater, with 1,740 kg of that mass leaving through Model Reach 1.

Reduction in Toxicity, Mobility, or Volume of Waste. No active measures are taken to reduce contaminant toxicity, mobility, or volume under this alternative. Natural attenuation processes result in an estimated reduction in RDX mass at 30 years of 4,880 kg, with 6,290 kg at 150 years. This equates to approximately 48% of the initial mass in the modeled portion of the system being degraded in 30 years, and 62% of the initial mass in the modeled portion of the system being degraded in 150 years under MNA.

Short-Term Effectiveness and Safety. As shown in Table 7-1, at 30 years, an estimated mass of 2,010 kg of RDX has left the perched groundwater, with 1,450 kg of that mass leaving through Model Reach 1. No additional health risks to workers or the community would occur because no remedial actions would be implemented.

Implementability. Implementation of the MNA alternative would require termination of the existing PGPTS and cancellation of additional planned remedial activities for perched groundwater. Implementation of this alternative, including installation of the ten new monitoring wells, could be completed in less than one year.

Cost. The estimated direct cost to implement Alternative 2 for the perched groundwater zone at Pantex Plant is $2,289,000. Thirty year O&M costs are estimated to be $12,212,000 for groundwater monitoring. These costs are detailed in Appendix B.

7.3.3 Alternative 3: Existing Pump and Treat with MNA

This alternative uses institutional controls to limit exposure to perched groundwater COCs. The current PGPTS would remain in use for 30 years (Figure 7-2); however, no additional remedial actions would be undertaken to treat, contain, or remove perched groundwater containing COCs. Model runs 5 (with reinjection) and 8 (no reinjection) (Table 7-1) demonstrate that cumulative RDX mass exiting the perched groundwater zone can be reduced by over 50 percent if extracted groundwater is not re-injected after treatment. For this reason, this alternative does not include re-injection of extracted groundwater. Instead, the treated groundwater would be beneficially reused for irrigation in onsite and offsite locations that would not contribute to recharge of the perched groundwater. All land proposed for this irrigation is agricultural land currently under or available for cultivation. Natural attenuation processes are considered in the evaluation of this alternative.

Components of this alternative include:

- Continued use of the current PGPTS for 30 years with no re-injection

- Natural attenuation processes
- Current groundwater monitoring wells augmented by the installation of two perched groundwater monitoring wells and eight Ogallala Aquifer monitoring wells (Figure 7-3)
- Institutional controls to restrict use of perched groundwater onsite and offsite to the south and east of Pantex Plant.

Additional controls would be added to current Pantex Plant operational restrictions (e.g., natural resource use restrictions, well restriction areas, deed restrictions, deed notices, and restrictive covenants). These controls would likely be in place for the foreseeable future or until groundwater COCs have been reduced below MSCs. Implementation of such institutional controls would involve the EPA and the TCEQ.

Use of the existing 52 vertical extraction wells would continue. Extracted groundwater would be processed in the existing aboveground treatment plant and sent to the new irrigation system. The irrigation system would consist of an onsite retention basin and an aboveground spray irrigation system located either onsite or offsite. The five injection wells would be plugged and abandoned or converted for use as monitoring wells.

The existing aboveground treatment plant includes GAC vessels providing 500-gpm capacity to remove HE compounds and a 150-gpm capacity ion exchange module for the removal of chromium. Treated effluent is currently sent to the injection wells or to the Pantex Plant WWTF for subsurface irrigation. Effluent discharged to the WWTF for irrigation must also be treated to remove boron and chromium to MSC levels. The current system includes a 150-gpm ion exchange module for the removal of boron. The treatment plant typically processes between 150 and 250 gpm from the current extraction wells but not all of this flow goes through all three treatment vessels. The average flow rate for a given month has ranged from no flow to approximately 300,000 gpd with an average flow rate of approximately 160,000 gpd (BWXT Pantex/SAIC, 2004). Modeled pumping rates (average rate over last 5 years) from the system begin at 196 gpm (282,200 gpd [average rate over first 5 years of pumping]), but drop to 85 gpm (122,400 gpd) by the end of the simulated 30-year pumping period. The drop in flow rates reflects the reduction in perched groundwater flow to extraction wells as the saturated thickness decreases over time. Flow rates resulting from the elimination of re-injection are uncertain and may call for an upgrade to the ion exchange modules for the removal of chromium and boron.

Protection of Human Health and the Environment. This alternative would minimize human exposure to COCs in perched groundwater both onsite and offsite. Overall, protection of human health would be adequate as long as the administrative controls are effectively implemented through public notification, maintained, and enforced. However, the Ogallala Aquifer would remain at risk for the future because of potential vertical migration of COCs.

Attainment of Media-Specific Cleanup Standards. Alternative 3 does not reduce COC concentrations in perched groundwater to media-specific cleanup standards within the 30-year RCRA evaluation period. However, applying institutional controls to restrict use of perched groundwater will protect potential receptors from exposure to COCs in perched groundwater. Therefore, the overall remedial objective would be met.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and has completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA*

Report [BWXT Pantex/SAIC, 2006]) indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. The PGPTS would continue to operate under the standards and requirements set forth in the *Compliance Plan* (TCEQ, 2003d). The treated groundwater would continue to be tested to monitor for attainment of applicable standards for irrigation. GAC and ion exchange resins would be returned to the suppliers for regeneration, as needed. Any investigative derived waste (IDW) generated during installation of the new monitoring and extraction wells would be handled in accordance with established BWXT Pantex operating procedures for waste management.

Long-Term Reliability and Effectiveness. Operational records for the existing PGPTS show the system has successfully removed contaminants from perched groundwater within the Plant boundaries, although the system has not been in operation long enough to allow significant reductions in plume concentrations. As of March 2006, the PGPTS has treated 459 million gallons of perched groundwater with a current monthly treatment average of 9 to 11 million gallons. Continued maintenance of the current PGPTS, such as carbon filter replacement and pump change out, should keep the system operating effectively. Replacement parts are readily available and relatively easy to install.

As shown in Table 7-1, significant long-term reduction in RDX mass exiting the perched groundwater flow system is predicted due to the lowered perched water levels and hydraulic gradients, removal of RDX by the extraction wells, and natural attenuation. At 150 years, a total of 990 kg of RDX is estimated to leave the perched groundwater, with 670 kg of that mass leaving through Model Reach 1. This is approximately 64% more effective than MNA alone. However, operation of the current PGPTS does not eliminate continued offsite migration of COCs. Therefore, this alternative relies on institutional controls to prevent exposure to offsite perched groundwater.

Reduction in Toxicity, Mobility, or Volume of Waste. This alternative uses the existing PGPTS and natural attenuation to reduce the toxicity, mobility, and volume of COCs in perched groundwater. Data from historical operation of the existing PGPTS and transport simulations were used to estimate mass removal rates for this alternative. The PGPTS with no re-injection removes an estimated 2,800 kg of RDX over the 30-year period of operation, significantly reducing the potential for future RDX impacts to the Ogallala Aquifer. This equates to approximately 31% of the initial mass in the modeled portion of the system being degraded in 30 years, and 41% of the initial mass in the modeled portion of the system being degraded in 150 years.

This alternative reduces the volume of water leaving the perched groundwater flow system by 25% (806 million gallons) in 30 years. The model-predicted volume of groundwater extracted over 30 years of pumping is 1.83 billion gallons. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 1.5 billion gallons (an average reduction of 9.4 gpm) over the 300-year period of simulation.

Natural attenuation processes result in an estimated reduction in RDX mass at 30 years of 3,130 kg with 4,120 kg at 150 years. The RDX mass reduction results from lowered perched water levels and hydraulic gradients, removal of RDX by the extraction wells, and from natural attenuation. The reduction in water levels and hydraulic gradients also increases travel time, thus providing more time for natural attenuation processes to occur.

Short-Term Effectiveness and Safety. Only limited new construction is associated with this alternative; therefore, short-term implementation risks are low. The use of PPE and safe operating procedures would prevent adverse effects to personnel during installation of the ten monitoring wells and subsequent

sampling activities. The existing PGPTS would continue operation under this alternative following the established operating procedures at Pantex Plant. Plant personnel are familiar with well drilling activities and operation of the treatment system equipment and processes. Work plans and safety plans would be prepared prior to installing the new monitoring wells and would be followed during construction to minimize safety risks.

At 30 years, a total of 710 kg of RDX is estimated to leave the perched groundwater, with 580 kg of that mass leaving through Model Reach 1. This is approximately 65% more effective than MNA alone.

Implementability. Under 30 TAC §335.167(d), owners/operators of permitted facilities must implement corrective actions beyond the facility boundary, unless the owner/operator can demonstrate that gaining the necessary permission to undertake corrective action was not possible because the landowner denied site access. In such instances, TCEQ can pursue additional actions to gain access to property that is key to protecting human health and the environment. Therefore, placing administrative controls on the offsite properties and installing additional monitoring wells offsite is expected to be implementable. In addition, no technical difficulties are anticipated in establishing or maintaining the monitoring program and access controls.

Implementation of institutional controls and installation of the new monitoring wells is expected to take one year to complete. Operation of the PGPTS will continue for 30 years.

Cost. The estimated direct cost to implement Alternative 3 for the perched groundwater zone at Pantex Plant is $3,193,000. Thirty year O&M costs are estimated to be $39,517,000 for operation of the existing PGPTS and groundwater monitoring. The cost estimate assumes that the existing treatment system is adequate to handle the flow from the extraction wells after re-injection has been terminated. Because the extraction rates are uncertain, it may be necessary to upgrade the current system to handle the additional water requiring treatment for irrigation. Costs for upgrades to the current treatment system are included in the cost estimates for Alternatives 4a and 4b in Appendix B.

7.3.4 Alternative 4a: Enhanced Pump and Treat using Horizontal Extraction Wells with MNA

Under this alternative, six horizontal wells would be installed to reduce the amount of water in the existing perched groundwater. This action would decrease both the horizontal gradients driving water flow along the FGZ and reduce the vertical gradients that result from the mounding of the perched water on the FGZ, as well as the corresponding fluxes of water and COCs. The reduction in water levels and gradients reduces groundwater flow rates and increases travel times, providing more time for natural attenuation processes to occur. Reducing the perched water that exists on the FGZ will reduce the total volume of water available for transport to the lower Ogallala Aquifer Formation. This alternative reduces the volume of water but does not significantly reduce the residually held COCs contained in the soil moisture after the water drains from the vadose zone or the FGZ. The presence of the residual COCs in the vadose zone and in the FGZ (including the diffused portion) could result in a long tail and rebound effect of COCs even after a significant amount of the perched water is removed. Horizontal wells would be placed in areas of greater saturated thickness and/or high concentration of RDX (Figure 7-4), and conditions conducive to the installation exist. The existing groundwater extraction wells would continue to be used, but treated groundwater would not be re-injected. Instead, the treated groundwater would be reused for irrigation in onsite and offsite locations that would not contribute to recharge of the perched groundwater. All land proposed for this irrigation is agricultural land currently under or available for cultivation. All wells would operate for 30 years. Natural attenuation processes are included in this alternative.

Components of this alternative include:

- Installation of six horizontal extraction wells (Figure 7-4)
- Continued use of the current groundwater extraction wells for 30 years with no re-injection
- Expansion of the existing treatment system
- Current groundwater monitoring wells augmented by the installation of two perched groundwater monitoring wells and eight Ogallala Aquifer monitoring wells (Figure 7-3)
- Institutional controls to restrict the use of perched groundwater onsite and offsite to the south and east of Pantex Plant
- Natural attenuation processes.

Design production rates for the horizontal wells are 100 gpm each, dropping off sharply after 5 years (as discussed in Appendix A). The average flow rate for the 6 horizontal wells predicted during the first 5 years is 265 gpm and drops to 84 gpm during the last 5 years of the 30-year period of pumping simulated. The average flow rate for the 52 existing extraction wells predicted during the first 5 years is 96 gpm and drops to 54 gpm during the last 5 years of the 30-year period of pumping simulated. Modeling results for the horizontal well near Playa 1 (reach #10 of Figure 7-4) indicates this well removes by far the greatest volume of water with an average pumping rate of 103 gpm for the period of simulation. Horizontal wells at reach 11 and reach 12 (Figure 7-4) have modeled rates of 13 gpm and 24 gpm, respectively, over the 30-year period of simulation. The average model-predicted flow rates for the entire extraction system is 265 gpm over the 30-year period of operation.

As illustrated in Figure 7-4, three horizontal wells (at reach 13, reach 14, and reach 15) are in areas of thin saturation offsite to the south and east of the Plant. Modeled flow rates from these wells are much less and average 1.6 gpm, 0.1 gpm, and 0.8 gpm, respectively. By volume, the flow rates from these three wells were less than 2% of the total volume of groundwater extracted by the 6 horizontal wells over the 30-year period of simulation. Exploratory borings to identify optimal locations (greatest saturated thickness and most conductive perched groundwater matrix) could enhance production rates from areas of thin saturation.

The treatment plant can easily be modified by adding additional ion exchange and carbon canisters in the early years of remediation and decreasing the number as remediation continues. The cost estimates were based on an average extraction rate of 50 gpm per well for 30 years, for an additional 300 gpm (432,000 gpd). The average daily flow rate for a given month from the existing extraction system has ranged from no flow to approximately 300,000 gpd, with an average daily flow rate of approximately 160,000 gpd (BWXT Pantex/SAIC, 2004). The current flow from the existing extraction system is roughly 300,000 gpd with a monthly treated volume at 9 to 11 million gallons. The current PGPTS consists of GAC vessels providing a 500-gpm capacity to remove the HE compounds. The system also includes 150-gpm ion exchange modules for the removal of chromium and boron. The cost estimates were based on treating an average of 450 gpm for chromium and boron. The capacity of the existing GAC system appears adequate to handle the additional 300 gpm from the new horizontal wells.

No re-injection of treated groundwater would occur; consequently, an estimated average of 590,000 gpd (160,000 gpd from the existing 52 extraction wells and 430,000 gpd from the horizontal wells) of treated groundwater would be disposed through the use of a new irrigation system. The irrigation system would

consist of two onsite retention basins and an aboveground spray irrigation system located either onsite or offsite.

Protection of Human Health and the Environment. This alternative would minimize human exposure to COCs in perched groundwater both onsite and offsite. Overall, protection of human health would be adequate as long as the administrative controls are effectively implemented through public notification (posting of signs), maintained, and enforced. This alternative enhances treatment of the onsite perched groundwater, but would not capture COCs that have migrated offsite, nor would it fully capture COCs currently onsite due to the inability to create a 100% effective hydraulic containment in this complex hydrogeologic setting. Thus, the Ogallala Aquifer would remain at risk for the future because of potential continued horizontal and eventual vertical migration of offsite COCs.

Attainment of Media-Specific Cleanup Standards. Alternative 4a is not expected to reduce COC concentrations in perched groundwater to media-specific cleanup standards within the 30-year RCRA evaluation period, nor will it attain 100% effective capture of COCs that are migrating from the site and/or have already migrated offsite. However, applying institutional controls to restrict use of perched groundwater will protect potential receptors from exposure to COCs in perched groundwater. Therefore, the overall remedial objective would be met for the perched groundwater, however the flux of COCs to the Ogallala Aquifer would continue at a reduced rate, and subsequent migration could still occur.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and has completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]) indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. The PGPTS would operate under the standards and requirements in the *Compliance Plan* (TCEQ, 2003d). The treated groundwater would continue to be tested to monitor attainment of applicable standards for irrigation. GAC and ion exchange resins would be returned to the suppliers for regeneration, as needed. Any IDW generated during installation of the new monitoring and extraction wells would be handled in accordance with established Pantex Plant operating procedures for waste management.

Long-Term Reliability and Effectiveness. Operational records for the existing PGPTS show that the system has successfully removed contaminants from perched groundwater within the Plant boundaries although the system has not been in operation long enough to allow significant reductions in plume concentrations. As of March 2006, the PGPTS has treated 459 million gallons of perched groundwater with a currently monthly treatment average of 9 to 11 million gallons. Continued maintenance of the current PGPTS, such as carbon filter replacement and pump change out, should keep the system operating effectively. Replacement parts are readily available and relatively easy to install.

Because perched groundwater is basically a slowly recharged mound of water located on top of a low permeability FGZ, plume concentrations in this setting will only reduce if cleaner water is introduced into the system or if the COCs decay. Hence, this is a bulk water removal approach, as opposed to what is typically envisioned when placing recovery wells for remediating groundwater plumes in regional aquifers. The addition of horizontal wells to the areas of greatest perched saturated thickness will enhance overall treatment effectiveness through more rapid removal of the perched groundwater. The addition of six horizontal wells reduces water levels, hydraulic gradients (both laterally within perched groundwater and vertically through the underlying FGZ), and groundwater volumes within the perched

groundwater. As shown in Table 7-1, significant long-term reduction in RDX mass exiting the perched groundwater flow system results from lowered perched water levels and hydraulic gradients, removal of RDX by the extraction wells, and from natural attenuation. The reduction in water levels and hydraulic gradients also increases travel time, thus providing more time for natural attenuation processes to occur. At 150 years, a total of 510 kg of RDX is estimated to leave the perched groundwater, with 330 kg of that mass leaving through Model Reach 1. This is approximately 82% more effective than MNA alone.

Potential offsite migration and downward movement of COCs will be mitigated, but not entirely eliminated. Therefore, this alternative relies on institutional controls to prevent exposure to offsite perched groundwater.

Reduction in Toxicity, Mobility, or Volume of Waste. This alternative relies on the enhanced pump and treat system with horizontal wells and natural attenuation to reduce the toxicity, mobility, and volume of COCs in perched groundwater. Future impacts to the Ogallala Aquifer are minimized by focusing extraction in the areas of greatest saturated thickness and highest RDX concentrations in perched groundwater. Horizontal wells at Reach 14 and Reach 15 (shown on Figure 7-4) are key to early dewatering and would be operated at maximum capacity for as long as the formation yields the increased extraction rates. Operation of the groundwater pump and treat system with no re-injection plus six horizontal wells removes an estimated 3,130 kg of RDX over a 30-year period of operation.

This alternative reduces the volume of water leaving the perched groundwater flow system by 44% (1.4 billion gallons) in 30 years (detailed in Appendix A). The model-predicted volume of groundwater extracted over 30 years of pumping is 4.2 billion gallons. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 2.3 billion gallons (an average reduction of 14.6 gpm) over the 300-year period of simulation. The extraction of groundwater near Playa 1 reduces the perched groundwater mound, and thereby reduces the upgradient hydraulic head (water that would migrate from the mound and continue to transport RDX within the perched groundwater and potentially vertically across the FGZ) decreasing vertical and lateral gradients within the perched groundwater flow system beneath and downgradient of Playa 1 (includes the RDX plume south and east of Playa 1).

Natural attenuation processes result in an estimated reduction in RDX mass at 30 years of 2,470 kg, with 3,330 kg at 150 years. This equates to approximately 24% of the initial mass in the modeled portion of the system being degraded in 30 years, and 33% of the initial mass in the modeled portion of the system being degraded in 150 years. This mass removed is a result of the overall decline in perched groundwater levels and hydraulic gradients, resulting in longer travel times for RDX migration to extraction well locations, providing less mass flux and more time for natural attenuation.

Short-Term Effectiveness and Safety. The use of PPE and safe operating procedures would prevent adverse effects to personnel during installation of the six horizontal wells and ten monitoring wells and subsequent sampling activities. The existing PGPTS would continue operation under this alternative following the established operating procedures at Pantex Plant after the installation of the new wells. Plant personnel are familiar with well drilling activities and operation of the treatment system equipment and processes. Work plans and safety plans would be prepared prior to installing the new system of wells and would be followed during construction to minimize safety risks.

As discussed in Appendix A, this alternative effectively removes an estimated 3,130 kg of RDX from the flow system, significantly reducing the potential for future RDX impacts. At 30 years, a total of 360 kg of RDX is estimated to leave the perched groundwater, with 270 kg of that mass leaving through Model Reach 1. This is approximately 82% more effective than MNA alone.

Implementability. The horizontal wells must be completed in the saturated interval just above the FGZ. As shown in Table 2-1, the depth to the FGZ ranges from 224 to 322 ft with an average depth of 276 ft bgs. To reach this depth, the horizontal well must be completed through the fine-grained silts and clays of the Blackwater Draw Formation (on average 76 ft thick), the caprock caliche (on average 7 ft thick) and the fine-grained eolian sands and silts that comprise most of the upper Ogallala Aquifer Formation sediments (on average 193 ft thick). The sediments immediately above the FGZ are a combination of sand with gravel lenses. Some areas (e.g., near Playa 1) will have significant thickness of perched groundwater above the target location, so the location of the screen elevation to the FGZ is not as critical as in the thinner areas of the perched groundwater. Other locations may have as little as a few feet of saturated thickness. In these areas the uncertainty in the location of the FGZ and the ability to install the well accurately (or even install a well) at these depths is uncertain, as no documented example of this being performed at these depths to the required level of accuracy in similar materials has been found. Some of the known and potential issues with implementation include:

- Maintaining drilling fluid in the sand and gravel lenses during drilling will be difficult. A dual constant head boundary of fluid (fluid reservoir at each end of the bore hole) could be used. It is uncertain whether drilling fluid circulation could be maintained and an excessive amount of drilling fluid may be needed, creating a mobilization of RDX away from the intended location of the screen or possibly across more permeable areas of the FGZ.

- In the areas of greater saturated thicknesses, such as near Playa 1, a bentonite/composite drilling fluid can be used, and horizontal well development can be expected to be relatively easy using conventional methods. In the fringe areas of the perched groundwater, well development will be more difficult and may require use of a biodegradable fluid. Unless the horizontal borehole is properly developed, the drilling fluid will act as a seal surrounding the well screen. However, biodegradable/biopolymer drilling fluids are less effective at maintaining an open hole and reducing horizontal friction, so the drill casings may become stuck and require abandonment in place. This has been documented to have occurred at sites in sand at lesser depths and screen lengths envisioned for this application. Well development techniques that are common in the water supply or oil engineering fields will be difficult to apply in the thin water areas of the perched groundwater.

- The angularity of the soils is unknown; thus, the sleeve friction for computing the size of the equipment and the required strength of the well construction materials is not well known at this time. The complex, detailed drilling design will require assumptions to specify equipment and material load factors, in addition to the type of drilling fluid that can be used to penetrate the observed heterogeneity in the subsurface geologic materials.

- The target depth of the well is on the order of 230 ft near Playa 1 to 290 ft near the extent of perched groundwater south of Zone 12. The radius of curvature of the well construction material must not be exceeded at either the entry point or the exit point to avoid pipe crimping. The angle of entry also must not be exceeded for certain types of installation equipment. This can greatly extend the total length of the well. At an entry angle of 10 degrees, a well length of 3,324 ft is required to reach a depth of 290 ft. Including an additional 500 ft of screen and 3,324 ft for re-surfacing of the horizontal well, and the total length of well bore for a single horizontal well is 7,148 ft. Following this same method, the total length of well bore would be 5,772 ft for a well depth of 230 ft. One benefit of horizontal wells over vertical wells is the length of well screen relative to the total boring length. A 290 ft vertical well can have a boring to screen ratio of 2% or less in areas where the perched groundwater is 6 ft or less. Horizontal wells can have screen to boring ratios on the order of 7 to 9% (assuming a 500 ft long screen).

- The topographic surface of the FGZ is not precisely known and varies from location to location. As a result, a horizontal well could potentially be installed above the primary water-bearing zone in areas where the saturated thickness of the perched groundwater is thin. Furthermore, the FGZ is a series of upward fining sequences, not a single homogeneous unit, and groundwater may be flowing in several layers above and somewhat within the FGZ materials. This appears to be particularly true in the area southeast of Zone 12. Therefore, it will be necessary to install a series of boreholes along the proposed path of the horizontal well to more accurately identify the surface of the FGZ locally.

- Various methods of monitoring the location of the drill head are available, and gyroscopic methods can be used after installation to accurately determine the location of the borehole. Accurately steering the head of the drill bit during installation likely will be a challenge. In the thin portions of the perched groundwater, the horizontal well should be sloped to some extent to promote water movement within it to the extraction pumps. If the FGZ undulates, then installing a workable screen may be impossible. The combination of the variability/uncertainty of installing the well screen accurately with the uncertainty in the FGZ surface and system hydraulics could result in an installation that is unusable for its intended purpose in the thinner portions of the perched groundwater. Installing a horizontal well deeper in the FGZ to act as a localized drain may inadvertently perforate the FGZ and create a preferential pathway/conduit to the deeper Ogallala Aquifer sediments. The inability to precisely log such a borehole during drilling, or not install it in the correct location (or human/mechanical error) during installation would make a condition difficult to detect (or repair), and the lack of monitoring wells in the Ogallala Aquifer in the direction of subsequent potential flow paths would complicate the deployment of an early warning monitoring system should this condition of a FGZ breach be suspected.

- Although horizontal wells are easy to operate, siltation may occur. Several techniques are available for removing the silt from horizontal wells. One such technique is facilitated if the equipment that is in the well is designed to remove easily. This application consists of a pipe-in-pipe design. The inner pipe being a flow control tube that could be removed as needed for maintenance purposes. It should also be noted that any flushing of the well screen would introduce water to the perched groundwater matrix.

- The installation of horizontal extraction wells in areas of thin saturation and low predicted yield would require well installation as essentially a sump. Modeling results indicate that three of the six wells simulated would exhibit low production rates dropping below 1 gpm and less than 0.1 gpm on average for much of the 30-year period of simulation and remove <2% of the total volume of perched groundwater predicted to be extracted. Exploratory borings would aid in identifying the areas of higher yield and the FGZ surface, and may be necessary to adequately locate the horizontal extraction wells to minimize the number of low yielding wells installed.

The necessary equipment and specialists are available to install and operate a horizontal well extraction system. Larger rigs used in the oil industries would likely be most appropriate for this application. Construction of all components of this alternative would occur on Pantex Plant. The exception to this would be if spray irrigation were made available to adjacent landowners, in which case appropriate access agreements would be required.

Under 30 TAC §335.167(d), owners/operators of permitted facilities must implement corrective actions beyond the facility boundary, unless the owner/operator can demonstrate that gaining the necessary permission to undertake corrective action was not possible because the landowner denied site access. In

such instances, TCEQ can pursue additional actions to gain access to property that is key to protecting human health and the environment. Therefore, placing administrative controls on the offsite properties and installing monitoring wells offsite is expected to be implementable.

Implementation of deed restrictions and government controls to restrict use of the perched groundwater, installation of the ten new monitoring wells, and installation of the retention basins, extraction wells, and treatment system upgrades is expected to take one year to complete. However, this time could be extended by up to one year to gather pre-design information such as locating the FGZ with accuracy and to complete the detailed horizontal well design. It is assumed that the system will operate for 30 years.

Cost. The estimated direct cost to implement Alternative 4a for the perched groundwater at Pantex Plant is $15,629,000. This cost assumes no new buildings are necessary and no additional labor is required to operate the treatment system. Thirty year O&M costs are estimated to be $89,693,000 for operation of the enhanced PGPTS and environmental monitoring. The costs are higher for this alternative than for Alternative 4b due to the increased volume of water that will be extracted and treated. The cost estimate, Appendix B, includes the cost of treatment system upgrades to handle the additional flow from the horizontal extraction wells. Because the extraction rates are uncertain, it may be necessary to further upgrade the system beyond that which has already been included. It is reasonable to assume that the system could be further expanded and that the treatment system upgrade costs provided could be increased to cover the additional water requiring treatment for irrigation.

7.3.5 Alternative 4b: Enhanced Pump and Treat using Vertical Wells with MNA

Under this alternative, the existing PGPTS would continue to operate, but would be expanded by the addition of eight lines of extraction wells, totaling 87 additional wells to enhance or maximize RDX mass removal (Figure 7-5). The lines of extraction wells, covering distances between 1,880 and 2,980 ft in length, would be located to promote distal plume dewatering with vertical wells near areas of potential outflow of RDX to the Ogallala Aquifer (see Figure 7-5). Well spacing would be set to ensure cone of influence overlap with adjacent extraction wells, as practicable. The vertical wells would significantly reduce the amount of water in the existing perched groundwater. This action would decrease both the horizontal gradients driving water flow along the FGZ and reduce the vertical gradients that result from the mounding of the perched water on the FGZ, as well as the corresponding fluxes of water and COCs. Reducing the perched water that exists on the FGZ will reduce the total mass of water available for transport to the Ogallala Aquifer formation. This alternative reduces the volume of water but does not significantly reduce the residually held COCs contained in the soil moisture, after the water drains from the vadose zone, or in the FGZ. The presence of the residual COCs in the vadose zone and in the FGZ (including the diffused portion) could result in a long tail and rebound effect of COCs even after a significant amount of the perched water is removed. Natural attenuation processes are included in this alternative.

Treatment for the extracted perched groundwater would be expanded to handle approximately 200,000 gpd of additional groundwater (based on an average extraction rate of 1.5 gpm for 87 wells for a total of 130 gpm). The average flow rate for all 87 wells predicted during the first 5 years is 1.2 gpm and drops to 0.5 gpm during the last 5 years of the 30 year period of pumping simulated. The average flow rate for the 52 existing extraction wells predicted during the first 5 years is 97 gpm and drops to 53 gpm during the last 5 years of the 30-year period of pumping simulated. As illustrated in Figure 7-5, a number of vertical wells are shown in areas of thin saturation offsite to the south and east of the Plant. Flow rates from 35 of these wells are less than 0.1 gpm on average for each 5-year interval simulated in the model. For comparison, 0.1 gpm is 144 gallons per day or 1,577,880 gallons over a 30-year period, and seven of the existing extraction wells had predicted flow rates that were also less than 0.1 gpm. By volume, the flow

rates from the 35 wells were less than 5% of the total volume of groundwater extracted by the 87 new wells over the 30-year period of simulation.

For the purposes of cost estimating, it was assumed that the extracted groundwater would contain chromium, HE, and organic compounds that would require both the ion exchange module and GAC treatment. The average daily flow rate for a given month from the existing extraction system has ranged from no flow to approximately 300,000 gpd, with an average daily flow rate of approximately 160,000 gpd (BWXT Pantex/SAIC, 2004). The current flow from the existing extraction system is roughly 300,000 gpd with a monthly treated volume at 9 to 11 million gallons. The current PGPTS consists of GAC vessels providing a 500-gpm capacity to remove the HE compounds. The system also includes 150-gpm ion exchange modules for the removal of chromium and boron. Under this alternative the capacity of the chromium and boron treatment processes would be doubled to handle an additional 150 gpm. The capacity of the existing GAC system, 500 gpm, appears to be adequate to handle the additional 150 gpm from the new vertical wells.

No re-injection of treated groundwater would occur; consequently, an estimated average of 360,000 gpd (160,000 from the existing extraction wells and 200,000 from the new wells) of treated groundwater would be disposed through the use of a new irrigation system. The irrigation system would consist of two retention basins constructed near the east edge of Pantex Plant property and an aboveground spray irrigation network. The treated groundwater would be beneficially reused for irrigation in onsite and offsite locations that would not contribute to recharge of the perched groundwater. All land proposed for this irrigation is agricultural land currently under or available for cultivation.

Components of this alternative include:

- Installation of 8 lines of vertical extraction wells, totaling 87 additional wells (Figure 7-5)
- Continued use of current extraction wells with no re-injection for 30 years
- Expansion of existing treatment system
- Current groundwater monitoring wells augmented with the installation of two additional monitoring wells in the perched groundwater and eight additional monitoring wells in the Ogallala Aquifer (Figure 7-3)
- Deed restrictions and other institutional controls to restrict the use of onsite perched groundwater and the offsite perched groundwater to the south and east of Pantex Plant
- Natural attenuation processes.

Protection of Human Health and the Environment. This alternative would minimize human exposure to COCs in the perched groundwater both onsite and offsite. Overall, protection of human health and the environment would be adequate as long as the administrative controls are effectively implemented through public notification and are maintained. This alternative enhances treatment of the onsite perched groundwater, but would not capture COCs that have migrated offsite, nor would it fully capture COCs onsite due to the inability to create a 100% effective hydraulic containment in this complex hydrogeologic setting. Thus, the Ogallala Aquifer would remain at risk for the future because of potential continued horizontal and eventual vertical migration of offsite COCs.

Attainment of Media-Specific Cleanup Standards. Alternative 4b is not expected to achieve media-specific cleanup standards within the 30-year RCRA evaluation period. Applying institutional controls to restrict use of the perched groundwater will protect potential receptors from exposure to COCs in the groundwater. Thus, the overall remedial objective would be met.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and has completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]) indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. The PGPTS would operate under the standards and requirements set forth in the *Compliance Plan* (TCEQ, 2003d). The treated groundwater would be tested to monitor for attainment of applicable standards for irrigation. Any IDW generated during installation of the new monitoring and extraction wells would be handled in accordance with BWXT Pantex operating procedures for waste management. In addition, GAC and ion exchange resins would be returned to the suppliers for regeneration, as needed.

Long-Term Reliability and Effectiveness. Operational records for the existing PGPTS show the system has successfully removed contaminants from perched groundwater within the Plant boundaries, although the system has not been in operation long enough to allow significant reductions in plume concentrations. As of March 2006, the PGPTS has treated 459 million gallons of perched groundwater with a currently monthly treatment average of 9 to 11 million gallons. Continued maintenance of the current PGPTS, such as carbon filter replacement and pump change out, should keep the system operating effectively. Replacement parts are readily available and relatively easy to install.

Plume concentrations in this setting will only be reduced if cleaner water is introduced into the perched system or if the COCs decay, since the perched groundwater is basically a slowly recharged mound of water located on top of a low permeability FGZ. As discussed in Appendix A, there is a significant long-term reduction in mass exiting the perched groundwater flow system resulting from mass removal through pump and treat and natural attenuation. The addition of 87 vertical wells reduces water levels, gradients (both laterally within the perched and vertically across the underlying FGZ), and flow volumes within the perched groundwater flow system. The reduction in water levels and hydraulic gradients increases travel time, thus providing more time for natural attenuation processes to occur. As shown in Table 7-1, at 150 years of simulation, a total of 160 kg of RDX is estimated to leave the perched groundwater, with 100 kg of that mass leaving through Model Reach 1. This is approximately 94% more effective than MNA alone.

Reduction in Toxicity, Mobility, or Volume of Waste. This alternative relies on the enhanced pump and treat system with more vertical wells and natural attenuation to reduce the toxicity, mobility, and volume of COCs in perched groundwater. The enhanced groundwater pump and treat system with no re-injection plus 87 vertical wells in 8 lines would remove an estimated 4,310 kg RDX over the 30 year period of operation. This increase in mass removed is a result of the addition of more extraction wells in areas of RDX-impacted perched groundwater.

This alternative reduces the volume of water leaving the perched groundwater flow system by 37% (1.18 billion gallons) in 30 years (detailed in Appendix A). The model-predicted volume of groundwater extracted over 30 years of pumping is 2.6 billion gallons. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is

reduced by 2.1 billion gallons (an average reduction of 13.1 gpm) over the 300-year period of simulation. The extraction of groundwater within the footprint of the RDX plume reduces the hydraulic head, decreasing vertical and lateral gradients within the perched groundwater flow system within and downgradient of the extraction wells.

Natural attenuation processes result in an estimated reduction in RDX mass at 30 years of 1,660 kg and 2,180 at 150 years. This equates to approximately 16% of the initial mass in the modeled portion of the system being degraded in 30 years, and 22% of the initial mass in the modeled portion of the system being degraded in 150 years.

Short-Term Effectiveness and Safety. Operation of the enhanced PGPTS rapidly reduces the mass leaving the system compared to other alternatives. Based on the model, this alternative removes an estimated 4,310 kg of RDX from flow system in 30 years, significantly reducing the potential for future RDX impacts. At 30 years, a total of 100 kg of RDX is estimated to leave the perched groundwater, with 80 kg of that mass leaving through Model Reach 1. This is approximately 95% more effective than MNA alone.

This alternative is expected to pose low-to-moderately low risks to construction workers. The use of PPE and safe operating procedures would prevent adverse effects to personnel during installation of the 87 extraction wells and the ten new monitoring wells. The existing PGPTS would continue under this alternative following the established operating procedures at Pantex Plant. Plant personnel are familiar with well drilling activities and have conducted several treatability studies that used similar equipment and processes. Work plans and safety plans would be prepared prior to installing the new system of wells and would be followed during construction to minimize safety risks.

Implementability. Construction of components of this alternative would occur both on and off BWXT Pantex property. Construction of onsite components would be readily implementable. Construction of offsite components would require appropriate access agreements. Local workers with appropriate skill levels to construct the basin, install wells, and upgrade the treatment system are available. The necessary equipment and materials are also readily available.

Under 30 TAC 335.167(d), owners/operators of permitted facilities must implement corrective actions beyond the facility boundary, unless the owner/operator can demonstrate that gaining the necessary permission to undertake corrective action was not possible because site access was denied by the land owner. In such instances, TCEQ can pursue additional actions to gain access to property that is key to protecting human health and the environment. Therefore, placing administrative controls on the offsite properties and installing additional extraction and monitoring wells offsite is expected to be implementable. In addition, no technical difficulties are anticipated in establishing or maintaining the monitoring program and access controls.

The installation of vertical extraction wells in areas of thin saturation and low predicted yield (less than 0.1 gpm on average) would require well installation as essentially a sump. Several of the current PGPTS currently operate at less than 0.1 gpm, with the well cycling on and off depending upon the available water within the well. Modeling results indicate that 35 of the 87 wells simulated would exhibit production rates less than 0.1 gpm on average and remove <5% of the total volume of perched groundwater to be extracted. Exploratory borings would aid in identifying the areas of higher yield and the FGZ surface, and may be necessary to adequately locate the additional wells to minimize the number of low yielding wells installed.

Implementation of deed restrictions and other institutional controls to restrict use of the perched groundwater, installation of the ten new monitoring wells, and installation of the retention basins,

extraction wells, and treatment system upgrades is expected to take two years to complete. It is assumed that the system will operate for 30 years.

Cost. The estimated direct cost to implement Alternative 4b for the perched groundwater zone at Pantex Plant is $11,286,000. Thirty year O&M costs are estimated to be $63,326,000 for operation of the enhanced PGPTS and environmental monitoring. This cost assumes no new buildings are necessary and no additional labor is required to operate the treatment system. The cost estimate, Appendix B, includes the cost of treatment system upgrades to handle the additional flow from the vertical extraction wells. Because the extraction rates are uncertain, it may be necessary to further upgrade the system beyond that which has already been included. It is reasonable to assume the system could be further expanded and that the treatment system upgrade costs provided could be increased to cover the additional water requiring treatment for irrigation.

7.3.6 Alternative 5: Targeted Treatment with MNA

This alternative provides targeted *in situ* treatment along the south and east fringes of the perched groundwater at Pantex Plant. Several *in situ* remediation technologies, in various stages of study, are currently being investigated at Pantex Plant. These technologies include enhanced anaerobic bioremediation, PRBs using either sodium dithionite ($Na_2S_2O_4$) or calcium polysulfide (CaS_5), and chemical oxidation using potassium permanganate ($KMnO_4$). As noted in Appendix A, extensive research has been conducted both at Pantex Plant and other United States sites that demonstrates the effectiveness of the technologies proposed in this alternative.

Figure 7-6 illustrates the location for the *in situ* treatment. This location was selected to treat an area upgradient of Reach 1 (lines 1 through 4 on Figure 7-6) and to treat perched groundwater migrating offsite to the southeast (lines 5 and 6 on Figure 7-6) towards Reaches 2 and 3. Reach 1 represents the area where the greatest impacts to the Ogallala Aquifer could occur, as predicted in the risk assessment. The area treatment upgradient of Reach 1 reflects uncertainty in the location of the more permeable portion of the FGZ (refer to Figure 3-6 for the approximate location where the upper surface of the FGZ becomes more permeable) and the desire to mitigate any potential COC migration to the underlying Ogallala Aquifer. The line of treatment for the southeasterly migrating perched groundwater targeted the second-most critical area of predicted future impacts to the Ogallala Aquifer.

The main treatment technology evaluated in this alternative is anaerobic ISB. Anaerobic ISB will be evaluated in each criterion subsection and evaluated in the comparative analysis section. Additional information is still being gathered at the site for the application of sodium dithionite and calcium polysulfide; thus, the information required to conduct complete 30-year cost analyses for these treatment technologies is not available. The locations and distribution of the treatment zones reflect an uncertainty in where the FGZ becomes more permeable relative to the RDX plume location. As noted previously, it is difficult from water table measurements alone to determine whether a change in hydraulic conductivity or increased leakage is present. The conceptual design errs on the side of conservatism by treating an RDX area, as opposed to along only a single line. Following discussion and evaluation of the anaerobic ISB alternative, specific information on PRB technologies and chemical oxidation is presented for comparison to the anaerobic ISB technology.

Anaerobic In situ Bioremediation

In this alternative, six lines of regularly-spaced vertical injection wells located at or near local highs in the FGZ would be installed as shown in Figure 7-6. A Newman Zone® amendment consisting of food-grade soybean oil, sodium lactate, sodium bicarbonate, and proprietary non-ionic surfactants would be injected into the subsurface and would ferment to provide an anaerobic environment for reductive biodegradation

of COCs. The amendments would be injected every six months (based upon field treatability testing and flow model results) into all six lines of injection wells for a duration until the RDX in this zone is remediated, which is estimated for costing purposes to be the first ten years, based on travel time estimates in these areas. Based on particle tracking, it is anticipated that after ten years of injection the groundwater south of lines 1 and 5 would be effectively treated; therefore, for years 11 through 30, only the northern-most lines (lines 1 and 5, totaling 69 wells) would receive injections every six months. The injections would occur over a short period of 2-3 days, and would rely on temporary increases in head and radial flow away from the wells to distribute the amendment around and between the injection wells.

The ISB system would also include five lines of vertical extraction wells to maintain a balanced flux across the treatment zone. The extraction of groundwater would help to minimize the potential for increased flux across the FGZ associated with amendment injection and enhance groundwater circulation. The alternative proposes to remove the same amount of fluid as injected. Because of mixing with the current water fluxes, the water extracted will consist of part of the injected fluids and part existing perched groundwater.

Prior to the installation of injection and extractions wells, exploratory borings would be advanced to accurately determine the depth of the FGZ. The exploratory borings would be placed approximately 50 ft apart and information obtained from the borings would be used to install the injection and extraction well screens at the correct depths. The goal is to inject into the higher elevations of the FGZ and extract from the lower areas. Since the bioremediation flooding is intended to distribute remediating fluids throughout the zone, and enhance degradation of RDX within the zone, 100% capture is not needed in these areas. This is an advantage over a water extraction only system as the complexities and heterogeneities would make 100% water flux capture practically impossible to reliably achieve.

The injection and extraction wells would be spaced on average100 ft apart and installed to an approximate depth of 280 ft using 4-inch diameter polyvinyl chloride (PVC) for injection wells and 6-inch diameter PVC for extraction wells. Well screens would be 4-inch or 6-inch stainless steel for injection and extraction wells, respectively. The injection wells would be injected with amendments up to a volume of 30,000 gallons per well; however, due to subsurface heterogeneity, injection and extraction rates would be variable and tuned per well during start-up testing. Injection rates would proceed at the highest rate accepted at each injection well-head for a sufficient duration per injection cycle to emplace the specified volume of amendment.

A new building would be constructed to house mixing equipment for preparation of the amendments. A permanent infrastructure (i.e., piping manifolds) would be built to allow periodic injection of amendments. For cost estimating purposes, it was assumed that re-injection of amendments would occur every six months for 30 years. The proposed re-injection schedule is based on results of current ISB studies at Pantex Plant that indicate effectiveness of amendments decline after 3-4 months following injection (Aquifer Solutions, Inc., April 2006).

The extraction rates are expected to proceed at a sufficient rate and duration to maintain the pre-existing hydraulic gradient at the well-head until an equal amount of water equal to the volume injected each cycle is removed. An estimated 12 million gallons of amendments would be injected and extracted per year for the first 10 years. For years 11 through 30, the estimated volume to be injected and extracted is 2.1 million gallons per year. Approximately 33,000 gpd of extracted groundwater would be treated using carbon and ion exchange for the first ten years and 5,700 gpd for years 11 through 30. Approximately 33,000 gpd of extracted groundwater would be treated using carbon and ion exchange. The treated groundwater would not be re-injected. Instead, the treated groundwater would be beneficially reused for irrigation in onsite and offsite locations that would not contribute to recharge of the perched groundwater. The new irrigation system would consist of a retention basin constructed near the east edge of Pantex

Plant property and an aboveground spray irrigation network. All land proposed for this irrigation is agricultural land currently under or available for cultivation.

Performance monitoring would be conducted to assess amendment movement through groundwater, subsurface conditions, and COC destruction. Performance monitoring could be performed monthly for the first two years of system operation. Thereafter, monitoring could be performed every six months for the remainder of the 30-year operation period. Performance monitoring would be completed using the extraction wells or existing monitoring wells.

The PGPTS would be turned off for this alternative. Natural attenuation processes are included in this alternative; therefore, the current groundwater monitoring system for COCs is assumed to be in place.

Components of this alternative include:

- Installation of approximately 406 exploratory borings used to locate the FGZ to ensure accurate placement of the injection wells.
- Installation of six lines of vertical injection wells, totaling 203 wells, to deliver amendments that will enhance indigenous microbial degradation of contaminants at the fringes of the perched groundwater plume (Figure 7-6).
- Installation of approximately 360 exploratory borings used to locate the FGZ to ensure accurate placement of the extraction wells.
- Installation of five lines of vertical extraction wells, totaling 178 wells, to maintain the hydraulic gradient in the injection area.
- Treatment of the extracted groundwater using the existing treatment system consisting of carbon filtration and ion exchange units.
- Current groundwater monitoring wells augmented with the installation of two additional monitoring wells in the perched groundwater and eight additional monitoring wells in the Ogallala Aquifer (Figure 7-3).
- Deed restrictions and other institutional controls to restrict the use of onsite perched groundwater and the offsite perched groundwater to the south and east of Pantex Plant.
- Natural attenuation processes.

Protection of Human Health and the Environment. While ISB and natural attenuation results in significant contaminant reduction, continued migration is expected. Therefore, this alternative relies on deed restrictions to restrict use of both onsite and offsite perched groundwater. Overall protection of human health and the environment would be adequate as long as the administrative controls are effectively implemented through public notification (posting signs) and are maintained.

Attainment of Media-Specific Cleanup Standards. Alternative 5 is expected to treat the southern and southeastern portions of the plume and minimize further offsite migration; however, it does not achieve media-specific cleanup standards within the 30-year RCRA evaluation period. Applying institutional controls to prohibit use of the perched groundwater will protect potential receptors from exposure to contaminants in the groundwater. Thus, the overall remedial objective would be met.

Control of Source Releases. Sources of perched groundwater impacts at Pantex Plant consisted of historic discharges to the ditches, playas, and soils at SWMUs, as documented in the corresponding RFIRs. Pantex Plant discontinued industrial wastewater discharges to ditches and playas and has completed ICMs for contaminated soils at the Plant. Trend analysis in perched monitoring wells near and beneath source areas has shown static or decreasing concentrations (as documented in the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]) indicating controls implemented at release areas have been effective at reducing impacts to perched groundwater.

Compliance with Applicable Standards for Waste Management. The PGPTS would continue to operate under the standards and requirements set forth in the *Compliance Plan* (TCEQ, 2003d). The treated groundwater would continue to be tested to monitor for attainment of applicable standards for irrigation. GAC and ion exchange resins would be returned to the suppliers for regeneration, as needed. Any IDW generated during installation of the new monitoring and extraction wells would be handled in accordance with established Pantex Plant operating procedures for waste management.

The injection wells, which are considered to be Class V wells by the TCEQ, will require permitting for underground injection control. Per TCEQ 331.11 (O), Class V wells include "*aquifer remediation wells, temporary injection points, and subsurface fluid distribution systems used to inject nonhazardous fluids into the subsurface to aid in the remediation of soil and groundwater.*" Additionally, TCEQ 331.3(a) states that "*the construction of an injection well, the conversion of a well into an injection well, and the use or operation of an injection well is prohibited unless authorized by an injection well permit, order, or rule of commission.*" TCEQ 331.7(a) further requires that all injection wells and activities be authorized by permit.

Issuance of a permit for underground injection requires that an injection well inventory be submitted to the TCEQ prior to construction of the wells. The mechanical integrity of the wells and the ability to prevent pollution are also required.

Long-Term Reliability and Effectiveness. Research suggests, and pilot studies performed at Pantex Plant support, that ISB would be effective in reducing contaminant concentrations in the perched groundwater. As discussed in Appendix A, approximately 80% of the initial mass in the system is estimated to be removed in this alternative. At 150 years of simulation, a total of 720 kg of RDX is estimated to exit the perched groundwater, with 190 kg of that mass leaving through Model Reach 1 and 330 kg leaving through Reach 4. This is approximately 77% more effective than MNA alone.

The long-term reliability of anaerobic ISB is uncertain due to subsurface heterogeneity and the ability to distribute the amendment evenly in the target area. Also, the affects of the geochemical environment on amendment effectiveness are uncertain.

Reduction in Toxicity, Mobility, or Volume of Waste. Targeted treatment results in an estimated reduction in RDX mass of 6,940 kg and 8,140 kg at 30 years and 150 years, respectively. This equates to degradation of approximately 69% of the initial mass in the modeled portion of the system in 30 years and 80% degradation in 150 years. The volume of water leaving the perched groundwater flow system is not significantly affected relative to the MNA alternative. Treatability studies demonstrate that each of the treatment technologies considered for the targeted zones has the potential to mobilize metals. *In situ* treatment using oxidation has the potential to mobilize hexavalent chromium and result in elevated manganese. *In situ* treatment using reduction has the potential to mobilize arsenic and strontium. In each case, the mobilization of metals has been transient, with elevated concentrations occurring post amendment injection, then declining to near pre-amendment injection levels through time.

Short-Term Effectiveness and Safety. Degradation rates used for targeted treatment are estimated from available site data, but have not been measured directly at the site under site-specific conditions; thus, there is some uncertainty in the estimated mass removed. Degradation rates used in the modeling are at the low end (slow rate) for areas not targeted for treatment relative to published literature values. The half-life of RDX represented for the targeted treatment zones in the model (10 days) is within the range determined from treatability testing, but is still subjective and carries a great degree of uncertainty. As discussed in Appendix A, at 30 years, a total of 370 kg of RDX is estimated to exit the perched groundwater, with 110 kg and 190 kg of mass leaving through Model Reaches 1 and 4, respectively. The mass moving through Reach 1 in the first 30 years is lowest for this MNA plus targeted treatment relative to the alternatives evaluated. This is approximately 82% greater removal than with MNA alone.

In situ biotreatment will require the construction of a nutrient makeup facility that may pose low-to-moderate risks to construction workers. The use of PPE and safe operating procedures would prevent adverse effects to personnel during installation of injection, extraction, and monitoring wells. The anaerobic ISB amendment solution is non-hazardous and should not pose risks to workers. The extracted groundwater would be treated using carbon and ion exchange units following the established operating procedures at Pantex Plant for the existing treatment system. Plant personnel are familiar with well drilling activities and have conducted several treatability studies that used similar equipment and processes. Work plans and safety plans would be prepared prior to installing the new system of wells and would be followed during construction to minimize safety risks.

Implementability. The nutrient makeup facility, injection well network, and injection and extraction wells would be readily implementable. The necessary equipment and materials are readily available. Each location of the bioremediation system will be started up and tuned separately; using techniques similar to those described in the pilot study reports (Llano Permian et al., 2006). If this alternative is implemented, design optimization analysis will be conducted. Appendix A discusses some of the options, including screening runs that consist of higher flow rates with greater well spacing, resulting in fewer wells overall. The cost estimate is prepared using reliable information based on a proven field application. Design optimization can refine and improve the expected cost within the limits of the system constraints. Due to the heterogeneity in the perched groundwater flow conditions and uncertainty in the locations where the FGZ becomes more permeable, exploratory borings would be used to identify the optimal locations for injection and extraction wells, and to minimize the area to be treated.

Under 30 TAC §335.167(d), owners/operators of permitted facilities must implement corrective actions beyond the facility boundary, unless the owner/operator can demonstrate that gaining the necessary permission to undertake corrective action was not possible because the landowner denied site access. In such instances, TCEQ can pursue additional actions to gain access to property that is key to protecting human health and the environment. Therefore, placing administrative controls on the offsite properties and installing additional monitoring wells offsite is expected to be implementable. In addition, no technical difficulties are anticipated in establishing or maintaining the monitoring program and access controls.

Implementation of deed restrictions and government controls to restrict use of the perched groundwater, installation of the ten new monitoring wells, and installation of the retention basin, irrigation system, extraction wells, and injection wells and initial start-up is expected to take two years to complete, if the field work and design is performed concurrently and construction resources are available. It is assumed that the system will operate for 30 years. During this time, the research that is currently being conducted on the degradation of RDX will be regularly reviewed, and the system designed with intent to incorporate modular components and flexibility in operation and system modification. This approach would facilitate leveraging of scientific advances to minimize the need for reconstruction, to the extent practicable.

Cost. The estimated direct cost to implement Alternative 5 for the perched groundwater zone at Pantex Plant is $45,267,000. Thirty year O&M costs are estimated to be $616,504,000 for operation of the injection and extraction wells and environmental monitoring.

The cost estimate assumes that the existing treatment system is adequate to handle the flow from the ISB wells. Because the extraction rates are uncertain, it may be necessary to upgrade the current system to handle the additional flow. Costs for upgrades to the current treatment system are included in the cost estimates for Alternatives 4a and 4b in Appendix B.

Alternative Modifications. The following subsections discuss the differences in this alternative should PRBs using either sodium dithionite ($Na_2S_2O_4$) or calcium polysulfide (CaS_5) or chemical oxidation using potassium permanganate ($KMnO_4$) be implemented instead of anaerobic ISB. The system components for these alternate technologies are generally the same as described for the anaerobic ISB technology; however certain operating criteria may be different, such as the number of exploratory borings, the number and type of injection and extraction wells, the amount of amendment injected, etc. Specific operating criteria for each technology are presented in Table 7-3.

Due to several uncertainties associated with these treatment technologies, alternatives using these technologies were not quantitatively evaluated for the 30-year operations period. Costs for chemical oxidation were calculated for 30 years; whereas, only one unit period of injection was assumed for the reactive barrier modifications. Uncertainties and disadvantages of these technologies are briefly discussed at the end of each subsection.

Permeable Reactive Barrier with Sodium Dithionite

In this alternative, a high pH-buffered sodium dithionite solution would be injected into the subsurface and would create a PRB that would utilize existing iron in the aquifer to reduce the naturally-occurring iron in the subsurface to the Fe^{2+} valence state. The reduced Fe^{2+} then would act as a reductant to achieve *in situ* treatment of contaminants. The PRB would act in a passive mode. Emplacement of the PRB would involve injection of the sodium dithionite into a linear array of vertical wells.

The linear layout of injection and extraction well lines in this alternative would be the same as that described for the anaerobic ISB alternative as shown in Figure 7-6. Additionally, borings advanced for the injection and extraction wells would be used to accurately determine the depth of the FGZ, and information obtained from the borings would be used to install the injection well screens at the correct depths. Because of its short half-life, the use of sodium dithionite requires the setup of a dense linear well array, and it is anticipated that injection wells would be installed 30 ft apart. For cost estimating purposes, the injection wells are assumed to be installed to a depth of 280 ft using 4-inch diameter stainless steel.

The system would inject amendments up to a volume of 40,000 gallons per well. Injection would be variable per well as described for the anaerobic ISB technology. Uncertainty is high regarding the need for reinjection, so for cost estimating purposes, one injection was assumed. An estimated 27 million gallons of amendments would be injected in the first injection cycle. A total of 340 monitoring wells would be installed downgradient of the injection wells and staggered between them at 60 ft spacings to monitor the performance of the amendments. Further evaluation would be needed in the design phase to determine if extraction of groundwater is necessary for this technology.

Table 7-3. Basis of Estimate for Alternative 5 Costs: MNA with Targeted Treatment

Criteria	Technology			
	Anaerobic *In situ* Bioremediation	Permeable Reactive Barrier with Sodium Dithionite	Permeable Reactive Barrier with Calcium Polysulfide	Chemical Oxidation using Potassium Permanganate
Exploratory Borings to Identify FGZ (Injection Wells)	406 (approx. every 50 ft)	679 (Every 30 ft, tag the FGZ and directly install the injection wells)	340 (Every 60 ft, tag the FGZ and directly install the injection wells)	406 (approx. every 50 ft)
Injection Wells	203 (69)[a] (280 ft deep, 4-in diameter, PVC with SS screens)	679 (280 ft deep, 4-in diameter, SS)	340 (280 ft deep, 4-in diameter, PVC)	203 (69)[a] (280 ft deep, 4-in diameter, PVC with SS screens)
Well Spacing	100 ft	30 ft (injection wells)	60 ft (injection wells)	100 ft
Injection Rate and Volume[b]	30,000 gal/well	40,000 gal/well	25,000 gal/well	30,000 gal/well
Re-injection Frequency	every 6 months	NA	NA	every 6 months
Amendment Concentration	Approx. 5% by volume of Newman's Zone amendment	0.95% Na S_2O_4	29% CaS_5	0.5% $KMnO_4$
Exploratory Borings to Identify FGZ (Extraction Wells)	360 (approx. every 50 ft)	NA	NA	360 (approx. every 50 ft)
Extraction Wells	178 (69)[a] (280 ft deep, 6-in diameter, PVC with SS screens)	NA	NA	178(69)[a] (280 ft deep, 6-in diameter, PVC with SS screens)
Extraction Rate and Volume[b]	30,000 gal/well	NA	NA	30,000 gal/well
Performance Monitoring Network	Use extraction wells	340 monitoring wells would be installed downgradient of the injection wells and staggered between them at 60 ft spacings	170 monitoring wells would be installed downgradient of the injection wells and staggered between them at 120 ft spacings	Use extraction wells
Performance Monitoring Sampling Frequency[c]	Monthly for years 0-2, every 6 months for years 3-30	Monthly for years 0-2, every 6 months for years 3-30	Monthly for years 0-2, every 6 months for years 3-30	Monthly for years 0-2, every 6 months for years 3-30
Performance Monitoring Sampling Parameters	VOCs, explosives, metals, general chemistry	VOCs, explosives, metals, general chemistry	VOCs, explosives, metals, general chemistry	VOCs, explosives, metals, general chemistry

NA -The uncertainty is high regarding the need to re-inject in the future. The volume injected is not projected to increase the vertical migration rate significantly; therefore, no extraction wells are needed.
[a]After 10 years, only the northern-most line of injection and extraction wells would be used, i.e., for years 11 through 30, 69 injection and 69 extractions wells would be used.
[b]Injection and extraction rates would be variable per well. Injection rates would proceed at the highest rate accepted at each injection well-head for a sufficient duration per injection cycle to emplace the specified volume of amendment. Extraction rates are expected to proceed at a sufficient rate and duration so as to maintain the pre-existing hydraulic gradient at the well-head until an amount of water equal to the volume injected each cycle is removed.
[c]Sampling may occur for longer than 30 years; however, a 30-year sampling period was used for comparative cost analysis.

Due to its short half-life, the use of sodium dithionite is less likely to have as great a radius of influence as calcium polysulfide, discussed next. It is also uncertain if the natural subsurface iron used in a PRB system can be "recycled"; therefore, the use of a PRB with sodium dithionite to treat the southeast groundwater plume at Pantex Plant may be best applied in conjunction with another treatment technology (Aquifer Solutions, Inc., 2006). Additionally, the use of sodium dithionite, which is caustic and has a pH of 11, would require the use of a higher level of PPE than would be needed for the anaerobic ISB technology.

As shown in Appendix B, the estimated direct cost to implement a permeable reactive barrier using sodium dithionite in the perched groundwater zone at Pantex Plant is $108,070,000. Thirty year O&M costs are estimated to be $100,937,000.

Permeable Reactive Barrier with Calcium Polysulfide

The application of this technology is similar to the PRB option described above that utilized sodium dithionite. However, in this scenario, calcium polysulfide would be used in the reduction of the naturally-occurring iron in the subsurface. When mixed with water, polysulfide would dissociate to form bisulfide (HS^-) and aqueous hydrogen sulfide ($H_2S_{(aq)}$). The sulfide could react directly with the Cr^{6+} to form Cr^{3+}. Alternatively, the sulfide could reduce Fe^{3+} present in the aquifer to Fe^{2+}. Calcium polysulfide has a longer half-life (1-1.5 months) than sodium dithionite, thus, calcium polysulfide would likely be effective over a longer time frame and treat a larger area of groundwater than would sodium dithionite.
The linear layout of injection well lines in this alternative would be the same as that described for the anaerobic ISB alternative as shown in Figure 7-6. Borings advanced for injection wells would be used to accurately determine the depth of the FGZ, and information obtained from the borings would be used to install the injection well screens at the correct depths.

Because calcium polysulfide is more stable than sodium dithionite and has the potential to create a larger reactive zone downgradient of the injection wells, the injection well spacing would be increased to 60 ft for implementation of this technology (Aquifer Solutions, Inc., 2006). The exploratory borings for the injection wells would be placed approximately 60 ft apart, and it is anticipated that injection wells would be installed 60 ft apart directly at the location of the exploratory borings following identification of the FGZ. The injection wells would be installed to a depth of approximately 280 ft using 4-inch diameter PVC.

The system would inject amendments up to a volume of 25,000 gallons per well. Injection would be variable per well as described for the anaerobic ISB technology. Uncertainty is high regarding the need for re-injection, so for cost estimating purposes, one injection was assumed. An estimated 8.5 million gallons of amendments would be injected in the first injection cycle. A total of 170 monitoring wells would be installed downgradient of the injection wells and staggered between them at 120 ft spacings to monitor the performance of the amendments. Further evaluation would be needed in the design phase to determine if extraction of groundwater is necessary for this technology. For this evaluation, extraction of perched groundwater has not been included because the volume of water injected to create the barrier (0.5 gpm over the 30-year period of treatment) is significantly less than the volume of water exiting the perched groundwater flow system (estimated at 44 gpm in the southeast area).

As with the PRB option using sodium dithionite, it is uncertain if the natural subsurface iron used in a PRB system can be "recycled"; therefore, the use of a PRB with calcium polysulfide to treat the southeast groundwater plume at Pantex Plant may be best applied in conjunction with another treatment technology (Aquifer Solutions, Inc., 2006). Additionally, calcium polysulfide is corrosive in its concentrated form, but the application of a dilute solution is within a normal pH range. Workers are advised to use face shields and gloves when handling a concentrated solution of calcium polysulfide.

As shown in Appendix B, the estimated direct cost to implement a permeable reactive barrier using calcium polysulfide in the perched groundwater zone at Pantex Plant is $22,240,000. Thirty year O&M costs are estimated to be $52,321,000.

Chemical Oxidation using Potassium Permanganate

In this alternative, potassium permanganate solution would be injected into the subsurface and chemical oxidation reactions would degrade the target compounds. The active oxidant species used in this technology would be (MnO_4^-).

The linear layout of injection and extraction well lines in this alternative would be the same as that described for the anaerobic ISB alternative as shown in Figure 7-6. Exploratory borings would be advanced to accurately determine the depth of the FGZ and reduce the uncertainty associated with subsurface geologic heterogeneity. Information obtained from the borings would be used to install the injection and extraction well screens at the correct depths. The exploratory borings for both the injection and extraction wells would be placed approximately 50 ft apart.

As with the chemical oxidation technology, injection and extraction wells would be spaced 100 ft apart. Amendments would be injected up to a volume of 30,000 gallons per well. The amendments would be injected every six months into all six lines of injection wells until the RDX in this zone is remediated, which is estimated for costing purposes to be the first ten years, based on travel time estimates in these areas. Based on particle tracking, it is anticipated that after ten years of injection the groundwater south of lines 1 and 5 would be effectively treated; therefore, for years 11 through 30, only the northern-most lines (lines 1 and 5, totaling 69 wells) would receive injections every six months. The injections would occur over a short period of 2 to 3 days, and would rely on temporary increases in head and radial flow away from the wells to distribute the potassium permanganate fluid around and between the injection wells. An estimated 6 million gallons of amendments would be injected and extracted in the first injection cycle. The extraction of groundwater would help to minimize the potential for increased flux across the FGZ associated with amendment injection and enhance groundwater circulation. The alternative proposes to remove the same amount of fluid as injected. Because of mixing with the current water fluxes, the water extracted will consist of part injected fluid and part existing groundwater. Extracted groundwater would be treated using carbon and ion exchange. The treated groundwater would not be re-injected. Instead, the treated groundwater would be beneficially reused for irrigation in onsite and offsite locations that would not contribute to recharge of the perched groundwater, as described in the ISB alternative.

It is possible that following a period of potassium permanganate solution injection, a period of clean water injection would occur to push the oxidant out to a greater distance. The chemical oxidation system would also include five lines of vertical extraction wells to maintain a balanced flux across the treatment zone. The extraction of groundwater would help to minimize the potential for increased flux across the FGZ associated with amendment injection and enhance groundwater circulation. The alternative proposes to remove the same amount of fluid as injected. Because of mixing with the current water fluxes, the water extracted will consist of part of the injected fluids and part existing perched groundwater.

The use of potassium permanganate may result in the clogging of injection wells and piping systems by MnO_2 solids generated by the reaction of residual potassium permanganate in extracted groundwater. Potential oxidation of metals that are either naturally-occurring or are COC co-contaminants may also be possible. Oxidation of metals to a more soluble valence state has been documented as a transient effect in field treatability studies (i.e. Cr^{3+} oxidation to Cr^{6+} [IT and Stoller, 2000]). Such results would be detrimental to groundwater remediation efforts. Additionally, extraction of groundwater treated with

potassium permanganate may be hazardous because of the caustic nature of the treatment compound and because the extracted groundwater may contain Cr^{6+}.

As shown in Appendix B, the estimated direct cost to implement chemical oxidation using potassium permanganate in the perched groundwater zone at Pantex Plant is $45,267,000. Thirty year O&M costs are estimated to be $136,475,000.

7.4 ALTERNATIVE ANALYSIS

The alternatives in this CMS/FS were evaluated based upon their respective abilities to reduce the predicted migration of RDX-impacted perched groundwater to the underlying Ogallala Aquifer and to prevent exposure to untreated perched groundwater onsite and offsite, i.e., remedial action objectives. Each alternative includes controls/measures that break the pathway for potential exposure to impacted groundwater. Alternative 1 – No Action, requires deed recordation and institutional controls to break the pathway, but does nothing to mitigate perched groundwater, nor its predicted future migration. MNA also does nothing to actively mitigate impacted perched groundwater nor its predicted future migration, but does include monitoring to ensure the processes of natural attenuation, in conjunction with institutional controls, prevent exposure to impacted groundwater. The effects of natural attenuation are ongoing and are included in each alternative evaluated. Alternatives 3 and 4 (4a and 4b) rely upon pump and treat to remove perched groundwater and reduce to the extent possible the future migration of impacted perched groundwater to the Ogallala Aquifer through a combination of dewatering and enhanced RDX mass removal. The pump and treat alternatives largely target areas where saturated thickness is sufficient to support long-term (30 years) perched groundwater removal. Alternative 5, with targeted treatment, focuses the corrective measure in areas of thin saturation to the south and southeast, where the most significant potential impacts to the Ogallala Aquifer are predicted.

In addition to meeting remedial action objectives, the alternatives were evaluated to determine if they met the nine criteria identified in Section 6. In Table 7-4, the alternatives are scored on ability to meet the first four threshold criteria using a "yes" or "no". Alternatives are scored on ability to meet the remaining five general decision factors using a scale of 1 to 5. The rationale for the scoring of each alternative is described in detail in the remainder of this section.

Table 7-4. Alternative Analysis

Alternative	Criteria: Protect Human Health and the Environment	Attainment of MSCs	Control of Source Releases	Compliance with Applicable Standards	Long-term Reliability and Effectiveness	Toxicity, Mobility, Volume Reduction	Short-term Effectiveness	Implementability	Present Worth Total Cost[a]	Total Points
1. No Action	No	No	Yes	Yes	1	1	1	1	$0	4
2. MNA	No	No	Yes	Yes	1	1	1	1	$14,501,000	4
3. Existing Pump and Treat with MNA	Yes	Yes[b]	Yes	Yes	2	2	2	5	$42,710,000	11
4a. Enhanced Pump and Treat using Horizontal Wells, with MNA	Yes	Yes[b]	Yes	Yes	3	4	3	3	$105,322,000	13
4b. Enhanced Pump and Treat using Vertical Wells, with MNA	Yes	Yes[b]	Yes	Yes	5	4	5	4	$74,612,000	18
5. Targeted *In Situ* Treatment with MNA	Yes	Yes[b]	Yes	Yes	3	5	3	4	$661,771,000	15

[a]Costs are at a zero discounted rate and are rounded to the nearest thousand.
[b]Meets MSCs only through the use of institutional controls.

7.4.1 Alternative 1 – No Action

The No Action alternative, Alternative 1, does not meet all four of the essential criteria. The alternative does not include active measures to reduce or contain contaminants, nor does it include measures to prevent future exposures. The alternative does not prevent potential exposure to perched groundwater in the short term. Therefore, Alternative 1 could not meet the remedial action objectives. Modeling results, as documented in Appendix A, provide an estimate of the amount of mass of RDX and volume of water leaving each model boundary reach over the time of the simulation. Based on these modeling results, Alternative 1 shows a significantly higher mass exiting the perched groundwater compared to any other alternative. For these reasons, the alternative scored low on the long-term protectiveness, short-term effectiveness, and reduction of toxicity, mobility, and volume criteria. While the alternative would be easy to implement, it is not expected that this alternative would meet agency or public approval. There are no costs associated with this alternative.

7.4.2 Alternative 2 – Monitored Natural Attenuation (MNA)

The MNA alternative, Alternative 2, does not meet all four of the essential criteria. The MNA alternative contains monitoring of groundwater: otherwise, this alternative is the same as Alternative 1. The alternative does not include active measures to reduce or contain contaminants, nor does it include measures to prevent future exposures. The alternative does not prevent potential exposure to perched groundwater in the short term. Therefore, Alternative 2 could not meet the remedial action objectives. Modeling results, as documented in Appendix A, provide an estimate of the amount of mass of RDX and volume of water leaving each model boundary reach over the time of the simulation. The alternative scored low on the long-term protectiveness, short-term effectiveness, and reduction of toxicity, mobility, and volume criteria. While there is minimal construction and the alternative would be easy to implement, it is not expected that this alternative would meet agency or public approval. Costs associated with this

alternative are minimal compared to the other alternatives. Capital costs ($2,289,000) and long-term O&M costs ($12,212,000) are lowest with this alternative.

7.4.3 Alternative 3 – Existing Pump and Treat with MNA

Alternative 3, Existing Pump and Treat with MNA, does not reduce average concentrations in the perched groundwater to MSCs in the 30-year RCRA evaluation period, but achieves the overall remedial action objective by using access restrictions, land use controls and deed recordation to prevent potential exposure to perched groundwater. BWXT Pantex has implemented numerous process changes and ICMs, (i.e., discontinued discharge of process water to the ditches and soil ICMs) to control potential migration of contaminants present in the soils beneath Pantex Plant. Using the existing PGPTS with no re-injection will continue to control downward flux of water responsible for the movement of contaminants. Therefore, Alternative 3 could meet the remedial action objectives.

The PGPTS would continue to operate in compliance with all applicable waste management regulations. This alternative ranks lower than the enhanced pump and treat alternatives because over twice as much RDX is expected to exit the perched groundwater than by enhancing the current pump and treatment system with additional vertical or horizontal extraction wells. This alternative was given a 2 for reduction of toxicity, mobility, and volume because it is estimated to remove 2,800 kg of RDX during 30 years of operation, which is the less than the other active remediation alternatives. The short-term safety risks are low-to-moderate, because minimal construction would occur; however, this alternative scored a 2 for short-term effectiveness because almost twice as much mass would be exiting the perched groundwater in 30 years compared to alternatives 4a, 4b, and 5. The current PGPTS rapidly reduces the average concentration exiting the perched groundwater flow system in the first 30 to 35 years compared to Alternatives 1 and 2, but average concentrations still exceed MSCs and rebound slightly before declining. The alternative scored well for implementability because access restrictions could be imposed quickly and no additional construction is required. Capital costs ($3,193,000) and long-term O&M costs ($39,517,000) are lower than the other active remediation alternatives.

7.4.4 Alternative 4a – Enhanced Pump and Treat using Horizontal Wells, with MNA

Alternative 4a, Enhanced Pump and Treat using Horizontal Wells, with MNA relies on access restrictions, land use controls, and deed recordation to prevent potential exposure to perched groundwater thereby protecting human health and the environment and meeting MSCs. As with Alternative 3, this alternative builds upon source control measures that have been implemented at Pantex Plant. The extracted groundwater would not be re-injected which significantly reduces the potential for further downward migration of contaminants. Therefore, Alternative 4a could meet the remedial action objectives.

The enhanced PGPTS would continue to operate in compliance with all applicable waste management regulations. This alternative scored higher than Alternative 3 for long-term reliability and effectiveness because the mass exiting the perched groundwater in 150 years is reduced by over 40 percent with the addition of six horizontal wells. This alternative is estimated to remove 3,130 kg of RDX in 30 years of active extraction. This mass falls between the mass removed in Alternatives 3 and 4b, with 2,800 kg and 4,310 kg respectively, and was given a score of 4 for reducing the toxicity, mobility, and volume of contaminants because of its effectiveness in reducing the rate of potential migration of COCs to the Ogallala Aquifer. The extraction of groundwater near Playa 1 enhances the long term effectiveness of this alternative by reducing the upgradient hydraulic gradient and thereby reducing the potential future migration of impacted groundwater in areas downgradient of the playa. Alternative 4a reduces the average concentration exiting the perched groundwater flow system in the first 30 years more effectively than the previous alternatives; therefore, this alternative was given a 3 for short-term effectiveness. This

alternative scores low on the implementability criterion due to several potential installation difficulties. One of the primary concerns with installing horizontal extraction wells in areas of lower saturated thickness is that the location of the FGZ is not known with precision. Further investigation would be required to ascertain the location of the FGZ to minimize the risk of installing a horizontal well through the FGZ or above the primary flow zone within the perched groundwater. If installation is feasible, horizontal well technology is often preferred over vertical wells due to their expected life-cycle cost savings and ease of operation. The capital cost of this alternative is $15,629,000 and O&M costs are $89,693,000. Total costs ($105,322,000) are higher for Alternative 4a than 4b because the volume of extracted water requiring treatment is greatest under this alternative.

7.4.5 Alternative 4b – Enhanced Pump and Treat using Vertical Wells, with MNA

Alternative 4b, Enhanced Pump and Treat using Vertical Wells, with MNA also relies on access restrictions, land use controls, and deed recordation to protect human health and the environment and to meet the overall remedial action objectives. As with Alternatives 3 and 4a, this alternative builds upon source control measures that have been implemented at Pantex Plant. The extracted groundwater would not be re-injected which significantly reduces the potential for further downward migration of contaminants. Therefore, Alternative 4b could meet the remedial action objectives.

The enhanced PGPTS would continue to operate in compliance with all applicable waste management regulations. It is estimated that the mass of RDX that would exit the perched groundwater under this alternative is lower than any other alternative in the 30 and 150 year time periods; therefore, Alternative 4b was given a 5 for long-term reliability and effectiveness and short-term effectiveness. Based on modeling results, this alternative reduces contaminant mass by an estimated 4,310 kg allowing it to score high (4) among the alternatives for toxicity, mobility, and volume reduction, second only to Alternative 5 which removes 80% of the initial mass in the system in 150 years. This alternative scores well, 4 points, for the implementability criterion because BWXT Pantex has experience with installing and operating vertical extraction wells. The capital cost of installing 87 wells ($11,286,000) and the O&M costs for operating the enhanced pump and treat system for 30 years ($63,326,000) are both lower than the costs for the other enhanced pump and treat alternative, Alternative 4a.

7.4.6 Targeted *In Situ* Treatment with MNA

Alternative 5, Targeted *In Situ* Treatment with MNA, also relies on access restrictions, land use controls, and deed recordation to protect human health and the environment and to meet the overall remedial action objectives. This alternative receives a 3 for long-term reliability and effectiveness because both enhanced pump and treat alternatives reduce the mass exiting the perched groundwater by a greater percentage in the long-term. However, by accelerating decay, this alternative removes 69% of the initial mass in the system in 30 years and 80% in 150 years and is therefore given a 5 for toxicity, mobility, and volume reduction. This alternative scores a 3 for short-term effectiveness because it reduces the mass exiting the perched groundwater in the short-term by a mass approximately the same as Alternative 4a. The nutrient makeup facility, injection well network, and injection and extraction wells would be readily implementable at Pantex Plant so Alternative 5 is given a 4 for implementability. The capital cost is much higher than the other alternatives at $45,267,000 due to the large area of thinly saturated perched groundwater treated. O&M costs are also extremely high, at $616,504,000 because of the number of reinjections proposed.

7.5 RECOMMENDED ALTERNATIVE

As determined through evaluation of the alternatives presented in Sections 7.3 and 7.4, key features of the site geology and hydrogeology greatly affect the applicability of technologies and necessitate a combination of alternatives to best achieve the RCRA and CERCLA requirements for the remedies. Section 7.5.1 describes these key features and the basis for the recommended alternative. Section 7.5.2 describes the components of the recommended alternative and rationale for its selection.

7.5.1 Basis for Recommended Remedial Action/Corrective Measure Alternative

Key features of the site that govern perched groundwater flow (Section 3.4) must be recognized in the final alternative recommendation. The groundwater mound and greatest saturated thickness beneath and adjacent to Playa 1 represents an area where extraction of high volumes of perched groundwater may be achievable. Reduction of this mound will significantly reduce the upgradient hydraulic head driving the continued migration of impacted perched groundwater. Because of the slope on the FGZ surface and the extent of impacted perched groundwater (especially the large areas of thin saturation offsite to the south and east), the additional extraction near Playa 1 alone would not be sufficient. Similarly, the variability in the FGZ surface and heterogeneity of perched groundwater sediments necessitates exploratory boreholes during the design phase to identify the optimum locations for perched groundwater extraction.

Permeability variations in the saturated media indicate areas of higher hydraulic conductivity capable of supporting long-term extraction adjacent to lower yielding areas. Understanding this heterogeneity is key to appropriate selection of the remedy and effective system design.

With the above information in mind, the recommended alternative must include elimination of re-injection of treated perched groundwater in the current PGPTS and enhance the extraction capability of the current system with additional wells utilizing exploratory boreholes to guide placement. The recommended alternative will achieve the remedial action/corrective measure objectives by:

- Stabilizing, containing and/or reducing the migration of impacted perched groundwater southeast of the Plant, downgradient of the southeast corner of the Plant, because COCs (primarily RDX) in this area comprise the primary potential threat to the Ogallala Aquifer based on predictive modeling.

- Reducing the volume of water moving through the perched groundwater flow system. The perched groundwater represents the primary mechanism for mass transport of perched groundwater COCs. Alternatives that are effective in reducing the volume of water moving through perched groundwater, will also reduce the potential for migration of COCs from perched groundwater to the Ogallala Aquifer. Reduction of perched groundwater flow and RDX mass flux across Reach 1 is most critical based upon observed site conditions and predictive modeling.

- Reducing the upgradient driving head. Impacted perched groundwater currently occurs at the extent of saturation, beyond the influence of the existing PGPTS. Alternatives that reduce the upgradient driving head will reduce the rate of mass flux out of the perched groundwater flow system; potentially to the point where mass is bound or trapped within the underlying partially saturated media above the Ogallala Aquifer.

- Providing for continued evaluation and targeted implementation of innovative *in situ* treatment technologies to mitigate impacted perched groundwater with the greatest potential to migrate to underlying Ogallala Aquifer.

As discussed in Section 7.3, both Alternatives 4a and 4b are more effective than Alternative 3 at reducing the mass exiting the perched groundwater over the next 30 to 150 years. Based on the SLM, horizontal extraction wells (Alternative 4a) and vertical extraction wells (Alternative 4b) both dewater the perched groundwater flow system, but several implementability issues exist with installing horizontal wells. Of primary concern is the level of detailed information available for the location of the FGZ in the areas being considered and the risk of installing a horizontal well through the FGZ; thus, providing a preferential pathway to the Ogallala Aquifer.

Alternative 4a includes the installation of six new horizontal extraction wells. However, simulated pumping rates for 3 of those wells (modeled in areas of thin perched groundwater) represented less than 2% of the total flow extracted, suggesting that exploratory borings would be needed to provide specific information to determining how best to install the wells to enhance the flow rates in these areas, or if horizontal wells in thinly-saturated areas are even viable. In this case, the number of wells could be reduced to 3 or less depending upon the results of the exploratory borings. The single horizontal well near Playa 1 accounts for 72% of the volume of perched groundwater removed by the 6 horizontal extraction wells modeled.

Alternative 4b included the installation of 87 new vertical extraction wells. However, pumping rates for 35 of those wells were less than 0.1 gpm on average and less than 5% of the total flow extracted, suggesting that exploratory borings will provide the means for reducing the total number of additional vertical extraction wells. In this case, the 87 new wells could be reduced to 52 new wells or less depending upon the results of the exploratory borings. To further illustrate the point, only 15 of the vertical wells in alternative 4a had average pumping rates exceeding 1 gpm for the 30-year period of simulation, accounting for 72% of the volume of perched groundwater removed.

Several well placement designs for extraction wells should be developed and considered. Uncertainties and costs associated with installation of horizontal wells for the site specific conditions at Pantex can be offset with the installation of vertical wells. The most effective and efficient design will be selected and implemented, and could be supplemented with one or more *in situ* technologies.

7.5.2 Description of Recommended Alternative

The recommended alternative is based on extensive research, investigation, sampling, analyses, treatability studies, interim corrective measures such as the perched groundwater pump and treat system, engineering judgment and fate and transport modeling conducted by Pantex Plant over the past 20 years. In response to community and regulatory concerns expressed during past and recent public meetings on groundwater beneath and near Pantex, the recommendation focuses on protecting the Ogallala Aquifer from future impact and increasing the reliability of future detection monitoring in the Ogallala Aquifer, as the remedial action objectives.

The recommended alternative will eliminate re-injection of treated perched groundwater in the current PGPTS and enhance the extraction capability of the current system with additional wells utilizing exploratory boreholes to guide their placement. The recommended alternative targets enhanced RDX mass removal through installation of vertical extraction wells within the footprint of the RDX plume and reduction of upgradient perched groundwater driving head through groundwater extraction near Playa 1. Vertical wells will also be located at the leading edge of the RDX plume in the southeast area to contain further migration. Figure 7-7 depicts the components of the recommended alternative, which are presented as follows:

- Continued use of the current groundwater extraction wells for 30 years, with no re-injection

- Installation of 25 new vertical extraction wells to enhance extraction of perched groundwater
- Expansion of the current treatment system to handle 590,000 gpd
- Irrigation of crops with treated groundwater
- Current groundwater monitoring wells augmented with the installation of two additional monitoring wells in the perched groundwater and eight additional monitoring wells in the Ogallala Aquifer (Figure 7-3)
- Deed restrictions and other institutional controls to restrict the use of onsite perched groundwater and the offsite perched groundwater to the south and east of Pantex Plant
- Natural attenuation processes.

The vertical wells near Playa 1 may be installed as one or more horizontal wells. This determination will be made at the design stage. The proposed number and location of extraction wells were selected based upon the best performance (highest groundwater extraction rates) predicted for wells simulated in Alternatives 4a and 4b. The location of the 52 existing PGPTS extraction wells are also shown on Figure 7-7 as those wells would continue in operation for the 30 years of active remediation. Pumping rates in four of the existing wells were increased based upon predicted yield and ongoing efforts to enhance overall groundwater extraction through system upgrades.

The primary goal of the nine vertical extraction wells included southeast of the Plant (Figure 7-7) is to stabilize and contain the migration of impacted perched groundwater. This line of wells will cover a length of ~2,400 feet perpendicular to groundwater flow.

Average pumping rates for the 30-year period of operation are shown in Table 7-5. The predicted average pumping rate for the existing PGPTS ranges from 150 gpm in the first 5 years to 63 gpm in the last 5 years. The vertical wells near Playa 1, remove the greatest quantities of water over the 30-year period of simulation. Predicted pumping rates for the 25 new vertical extraction wells have been subdivided in Table 7-5 to distinguish between the 9 vertical wells installed to stabilize southeast perched groundwater migration and the 16 other vertical wells installed to enhance the extraction rates. The data in Table 7-5 indicate a decline in predicted yield over time from each group of extraction wells, as expected.

The cumulative pumping rate over the first 5-year period averages 553 gpm. This rate exceeds the current carbon treatment capacity of the PGPTS (500 gpm) and the capacity forming the basis of engineering considerations applied for alterative costing for Alternative 4a (590,000 gpd or ~410 gpm), which had the highest long-term average pumping rate for the alternatives considered. Uncertainty in actual well production rates justifies not planning expansion of the PGPTS beyond the upgrades proposed in Alternative 4a. However, if actual production significantly exceeds the 500-gpm capacity of the existing PGPTS, then expansion of the system or implementation of skid-mounted treatment units would be considered. The predicted average rate during the first 5 years of system operation assumes that all extraction wells begin operation at the same time and produce as much water as possible, as soon as possible. If the wells are installed and operated in this fashion, then expansion of the existing PGPTS will be necessary to accommodate the increased flow predicted over the first 5 years of alternative implementation. After the first 5 years, the predicted flow rates drop below the current capacity of the existing system.

To avoid expanding the existing treatment system to accommodate 5 years of increased production, perched groundwater extraction from the extraction wells within the main RDX plume (south and east of Playa 1) should be implemented first. These extraction wells are nearest the areas where the FGZ is more permeable, located within perched groundwater having highest RDX levels, and result in the most significant near term reduction in RDX migration. The wells near Playa 1 should then be brought on line and increased over time to make up any capacity not being met and eventually extract a volume similar to that predicted in Table 7-5.

Table 7-5. Summary of Average Predicted Pumping Rates over 5-year Periods for 30 years of Active Extraction (units are in gallons per minute).

5	150	382	21	553
10	90	193	7.4	290
15	77	134	3.5	215
20	71	104	2.1	177
25	66	88	1.6	156
30	63	79	1.5	144

Eliminating re-injection of treated groundwater substantially improves the performance of the existing PGPTS for reducing potential COC migration to the Ogallala Aquifer (compare Runs 5 and 8 in Table 7-1). Eliminating re-injection reduces the hydraulic gradient, which slows down the groundwater velocity, and the rate of COC migration. This results in more time for natural attenuation to occur. Furthermore, a two- to three-fold reduction in mass of COCs exiting the perched groundwater can be achieved by enhancing the existing PGPTS with no re-injection. For these reasons, the injection wells for the existing PGPTS are not included on Figure 7-7. The original design of the existing PGPTS included re-injection of treated groundwater to promote flow of impacted perched groundwater to the extraction wells for removal (Figure 7-2). The system continues to operate with some injection of treated effluent according to this design, although many of the original injection wells have been replaced because of decreasing capacity and surface leakage as described in Evaluation of the Perched Groundwater Pump & Treat System and Associated Well Field (Rainwater, 2003).

In addition to the proposed extraction wells, installation of a permeable reactive barrier and *in situ* bioremediation will be considered as part of the recommended alternative for targeted areas. A permeable reactive barrier may be installed in lieu of the nine vertical extraction wells southeast of the Plant (Figure 7-7) due to the uncertainties associated with the effectiveness of vertical extraction in this area. Installation of a 2,400-foot long permeable reactive barrier would require 40 injection wells (assuming 60-ft spacing) and 4 downgradient monitoring wells to monitor effectiveness.

An area (covering roughly 40 acres) upgradient of Reach 1 is identified for the continued evaluation of potential *in situ* treatment. This area coincides with increasing permeability in the FGZ surface as documented in the Groundwater RFI (Stoller, 2004b), and with the most significant predicted impact to the Ogallala Aquifer based upon fate and transport modeling completed for the HHRA (BWXT Pantex/SAIC, 2006) and this CMS/FS. Implementation of *in situ* treatment in this area would consist of two lines (one line 3,200 feet in length roughly 600 feet upgradient of Reach 1, and one line 2,400 feet in length coincident with Reach 1) of injection wells (56 total) for amendment delivery. A single line of 25 extraction wells would be installed to minimize the potential for increased flux across the FGZ during amendment delivery.

Exploratory borings to further delineate areas where the FGZ becomes more permeable may permit a more focused application of the *in situ* treatment technologies and mitigate, to the extent possible, the migration of perched groundwater (or any amendments) across the FGZ. Site-specific treatability studies are ongoing to provide additional information on the application of these technologies at Pantex. However, current uncertainties associated with the effectiveness of these technologies, the potential for increasing perched groundwater migration across the FGZ during amendment addition, the potential for mobilization of metals, and the cost of implementation preclude their recommendation for wide scale remediation of perched groundwater.

The recommended alternative combines the most effective features of Alternatives 4a, 4b, and 5 evaluated in detail in Sections 7.3.4 through 7.3.6. This alternative also provides the flexibility necessary to achieve the overall remedial action/corrective measure objectives for the perched groundwater at Pantex Plant. In summary, the alternative is evaluated briefly against the nine criteria.

Protection of Human Health and the Environment. This alternative would minimize human exposure to COCs in the perched groundwater both onsite and offsite. Overall, protection of human health and the environment would be adequate as long as the administrative controls are effectively implemented through public notification and are maintained. This alternative enhances treatment of the onsite perched groundwater, but would not capture COCs that have migrated offsite, nor would it fully capture COCs onsite due to the inability to create a 100% effective hydraulic containment in this complex hydrogeologic setting.

Attainment of Media-Specific Cleanup Standards. The recommended alternative is not expected to achieve media-specific cleanup standards within the 30-yr RCRA evaluation period. Applying institutional controls to restrict use of the perched groundwater will protect potential receptors, thus achieving the overall remedial action objective.

Control of Source Releases. As with Alternatives 2 through 5, controls implemented at release areas at the Plant have been effective at reducing impacts to the perched groundwater.

Compliance with Applicable Standards for Waste Management. The installation and operation of the proposed extraction and monitoring wells and the treatment and irrigation systems would comply with applicable standards for waste management.

Long-Term Reliability and Effectiveness. The estimated mass removal in 30 years of active remediation is approximately 3,800 kg of RDX, which is greater than all but Alternative 4b in terms of mass extracted. During the first 150 years, a total of 240 kg of RDX is estimated to leave the perched groundwater across all reaches. This is approximately 90% more effective than MNA alone.

Further, the extraction of perched groundwater at Playa 1 does reduce the upgradient driving head for all areas downgradient of Playa 1 resulting in longer term reduction in RDX mass flux out of the perched groundwater by increasing travel times and thereby permitting more time for degradation and other attenuation processes.

Pumping near Playa 1 also reduces the impacts of uncertainties associated with geologic heterogeneities in the perched groundwater flow system. More transmissive areas occur adjacent to less transmissive areas. Reduction of the upgradient hydraulic heads will affect both conditions and mitigate, to some extent, the need to know exactly where all of the more transmissive regions are located. Therefore, this alternative has similar or slightly better long-term reliability and effectiveness than extraction from within the RDX plume footprint only as was done in Alternative 4b.

Reduction in Toxicity, Mobility, or Volume of Waste. RDX mass removal rates for this recommended alternative are very similar to those in Alternative 4b. Predicted RDX mass flux across Reach 1 is approximately 90 kg in 30 years (compared to 80 kg for the same time in Alternative 4b) and 120 kg in 150 years (compared to 100 kg for same time in Alternative 4b). High volume groundwater extraction near Playa 1 further reduces the potential for long term migration by reduction of the upgradient hydraulic head. The total volume of perched groundwater removed is 4.02 billion gallons of water, and results in a net flux rate reduction in the southeast area that is similar to Alternative 4a. This alternative scores better than the other alternatives evaluated because it combines the high mass RDX mass removal rates (Alternative 4b) with the enhanced groundwater extraction (Alternative 4a) to minimize future impacts to the Ogallala Aquifer.

Short-Term Effectiveness and Safety. During the first 30 years of simulation, predicted RDX mass flux across all reaches is similar to Alternative 4b with an estimated 50 kg more RDX mass exiting perched groundwater in the recommended alternative. At Reach 1, the mass exiting the perched is very similar to Alternative 4b with an estimated 10 kg more RDX mass exiting.

Implementability. This alternative has the same considerations for installation of vertical extraction wells that comprise Alternative 4b. In addition, this alternative includes provisions for the implementation of a permeable reactive barrier or *in situ* bioremediation. Additional information from ongoing treatability testing will aid in the decision to implement these contingent technologies.

Cost. The estimated cost to implement the recommended alternative is $8,262,000. Thirty year O&M costs are estimated to be $88,939,000. Implementatation costs (vertical extraction wells) are lowest for the active extraction alternatives evaluated. O&M costs are similar to those presented for Alternative 4a. The estimated O&M costs are based upon the existing information for GAC units, ion exchange, controls and other miscellaneous costs derived from the current operation of the PGPTS, and represent the best available information at the time of this report. Further, the O&M costs are based upon the volume of water treated (carbon and ion exchange replacement are conservatively estimated to occur based on the volume of groundwater treated. Groundwater beneath Playa 1 has much lower RDX concentrations and may require less frequent treatment system changeouts than are included here). Close to twice the volume of groundwater is extracted in the recommended alternative, but the mass of RDX removed is similar to that in Alternative 4b. Therefore, O&M costs may be more similar to those presented for Alternative 4b.

Capital costs to implement the contingent calcium polysulfide permeable reactive barrier and in situ bioremediation are estimated to be $5,822,000 and $10,411,000, respectively. Due to the uncertainties associated with implementing these technologies, O&M costs could not be estimated at this time.

The site-specific pilot studies and the screening analysis conducted in the CMS/FS using a SLM greatly help guide the decision process. These are part of the analysis, and do not quantify the reduction in the predicted potential impact to the Ogallala Aquifer. As improved modeling capabilities become available to better simulate the fully transient coupled flow and transport of perched groundwater COCs, Pantex will further evaluate the existing perched groundwater conditions, in accordance with the *Compliance Plan (TCEQ 2003 b)*, and the recommended alternative. Also, based on the protectiveness of the above recommendation, additional refinements may be made to arrive at the preferred alternative that will be presented in the proposed plan, to be prepared and issued in accordance with 40 CFR 300.430(f)(1)(ii).

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A.0 GROUNDWATER FATE AND TRANSPORT MODELING IN CMS/FS

This appendix provides documentation of fate and transport modeling completed to support evaluation of corrective measures for the perched groundwater at Pantex Plant. Perched groundwater beneath Pantex Plant is impacted by HEs, VOCs, and inorganic constituents. The *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) evaluated the potential health impacts posed by contaminants in the environmental media, including the perched groundwater under current and future conditions. Under current conditions, constituents in perched groundwater exceed acceptable health based criteria both onsite and in offsite areas to the east and south of Pantex Plant. This perched groundwater is not currently used as a water supply; therefore, currently no exposure to the impacted perched groundwater exists. However, predictive modeling completed for the risk assessment (BWXT Pantex/SAIC, 2006) indicated the potential for migration of impacted perched groundwater to the Ogallala Aquifer in the future. Fate and transport modeling efforts documented in this appendix are aimed at the simulation of various remedial alternatives designed to reduce the migration of impacted perched groundwater to the underlying Ogallala Aquifer. This appendix:

- Summarizes previous investigations pertinent to the evaluation of remedial alternatives for the perched groundwater
- Provides documentation of a single layer screening model developed to evaluate various corrective measures
- Presents results and ranking of various remedial alternatives to identify the key alternatives to be evaluated in this CMS/FS
- Provides a summary of the key alternatives identified for further detailed evaluation within this CMS/FS.

Subsurface hydrogeologic characterization and fate and transport modeling performed to date is documented in primary or secondary sources in the following reports:

- *Groundwater RFIR* (Stoller, 2004b)
- *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004)
- *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006).

These reports provide the basis for the understanding of the geologic conditions, the hydrologic conditions, nature and extent of groundwater contamination, and the groundwater flow and transport regime at Pantex Plant. The *Baseline HHRA Report* and the *Subsurface Modeling Report* also provide detailed documentation of the numerical tools built to simulate contaminant fate and transport in groundwater at Pantex Plant.

The existing site-wide model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) formed the basis for the subsurface flow and transport evaluation. Three primary refinements were made to the site-wide model (BWXT Pantex/SAIC, 2004) to provide a better representation of the perched groundwater flow system. The refinements included the addition of a 10-ft thick layer within the perched groundwater flow system, adjusting the hydraulic conductivity of the (fine-grained zone) FGZ to more closely match the observed extent of saturation, and adjusting the recharge rates to refine the flow model calibration. The refinements in the adjusted site-wide model resulted in an increase in the predicted flux across the FGZ in the southeast area from 40 to 44 gallons per minute. The flow model calibration for the adjusted site-wide model provides an improvement to the calibration presented in the

Subsurface Modeling Report (BWXT Pantex/SAIC, 2004) and reflects improved understanding of the flow system as a whole. Results from the flow simulation predicted a perched groundwater volume of approximately 15 billion gallons after a 40-year period of Pantex Plant operation, increasing to 17.5 billion gallons between 190 to 240 years (approximately 150 to 190 years after simulated historical Pantex Plant discharges were discontinued in the model). Predicted flux across the FGZ increased as the volume of perched groundwater increased.

The *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006) documented subsurface fate and transport modeling completed to evaluate the groundwater pathway for impacted media at Pantex Plant. The Baseline HHRA utilized the current-time groundwater flow field (simulated 40-year flow field) to conduct the travel time analysis and to define boundary conditions for the FTM used to conduct transport modeling. The FTM simulated the fate and transport of COPCs identified in perched groundwater south and east of Playa 1, emanating from historical sources beneath Zone 12 and associated runoff pathways. Transport simulations were conducted using the steady-state flow field for RDX, TNT, 1,3,5-trinitrobenzene, 2,4-DNT, 2,6-DNT, HMX, boron, hexavalent chromium, 1,2-DCA, and TCE to predict future concentrations in perched groundwater and the Ogallala Aquifer. Transport simulations were nonreactive (only included effects of dispersion and diffusion) and were completed in the absence of any remediation effects. Predicted future groundwater concentrations for four COPCs (2-amino-4,6-DNT, 4-amino-2,6-DNT, 1,3-dinitrobenzene, and total chromium) were estimated from results for the modeled COPCs. Maximum predicted concentrations in perched groundwater and the Ogallala Aquifer offsite to the east and offsite to the south were tabulated for each COPC.

Potential maximum concentrations predicted in perched groundwater were calculated at the current maximum concentration for all except one COPC (1,3,5-trinitrobenzene). Each of these COPCs occurs at the fence line or offsite and declines to lower levels through the period of simulation. Concentrations of 1,3,5-trinitrobenzene slowly increased through the HHRA period of simulation as impacted perched groundwater onsite migrates offsite to the south. Potential maximum concentrations predicted in the Ogallala Aquifer exceed RBSVs for only two of the constituents (RDX and 2,4-DNT). RDX is predicted to occur above its RBSV offsite to the south and offsite to the east. 2,4-DNT is predicted to occur above its RBSV, but below RRS 1 levels. As noted, these predicted results do not include the effects of sorption nor degradation.

The remainder of this appendix is organized as follows:

- Section A.1 provides a summary of previous investigations including lab and field scale treatability studies completed to evaluate mechanisms for remediation of impacted perched groundwater. Specifically, information is presented pertaining to natural attenuation (NA) investigations and *in situ* chemical and biological treatment amendments.

- Section A.2 provides a description of the development and calibration of a screening model built to permit rapid evaluation of numerous potential corrective measures. This model consists of a single layer representing flow and transport in the perched groundwater flow system.

- Section A.3 provides documentation of the different corrective measures evaluated within the screening level model. Results of the various alternatives modeled are summarized and tabulated, including a ranking based upon predicted mass flux to the underlying Ogallala Aquifer and mass removed from the perched groundwater flow system.

- Section A.4 provides a more detailed description of the key alternatives identified in Section A.3 that provide the greatest potential for elimination or reduction of predicted potential impacts to the Ogallala Aquifer.

- Section A.5 provides a summary of results and key findings from the fate and transport screening-level modeling completed in support of this CMS/FS.

A.1 SUMMARY OF TREATMENT STUDIES

This section documents a review of remedial studies conducted at Pantex Plant utilizing biological and chemical amendments, and a brief summary of various NA data available for perched groundwater at the Plant.

A.1.1 NA Evaluation

An NA evaluation was necessary to determine the site-specific and chemical-specific sorption and degradation properties at Pantex Plant. The NA evaluation included review of site data in conjunction with modeling data to estimate site-specific rates for the constituent evaluated. The results were applied to the COPCs modeled in the Baseline HHRA.

The site-specific rates for degradation were assembled from two approaches:

- Determination of site-specific biodegradation half-lives using site observations and literature values (as documented in detail in N.8.1.3 of the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]).

- Limited modeling calculations bounded by literature values and site observations.

A.1.1.1 Determination of Site-Specific Biodegradation Half-Lives

Several guidance documents are currently available that can be used to advise and assist in assessing the feasibility and/or implementation of NA as a remedial alternative for contaminated sites. The relevant guidance documents listing the groundwater COPCs identified at the Pantex Plant include:

- *Draft Protocol for Evaluating, Selecting, and Implementing Monitored Natural Attenuation at Explosives-Contaminated Sites* (USACE, 1999)

- *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (EPA, 1998).

According to the USACE guidance, "...procedures for tracking microbial degradation processes for explosives in groundwater are limited to (a) monitoring concentrations of parent compounds and several transformation products and (b) monitoring subsurface conditions that are suitable for microbial activity in general, e.g., soil texture, organic carbon content, and nutrients." In addition, an evaluation of the potential for microbial degradation can contribute to the weight of evidence for NA as a remedial alternative. Soil mineralization radioassays provide evidence of degradation potential using soil taken from the aquifer (USACE, 1999).

A field-scale treatability study was conducted at Pantex Plant to determine the degree to which site conditions favor NA of HEs in the perched groundwater. The study concluded that RDX is likely slowly degrading in perched groundwater through natural biodegradation for three reasons (IT and Stoller, 2000):

1. A decrease in concentrations of RDX has been found away from the source area;
2. The presence of RDX degradation products: MNX, DNX, and TNX;
3. Indicator parameters sensitive to reduction/oxidation potential that suggest RDX breakdown can occur biologically under the site oxidation/reduction conditions have also been found.

In addition, a laboratory study on the bioremediation of RDX in the vadose zone beneath Pantex Plant was conducted to support a fate and transport evaluation of HEs in the vadose zone (Shull et al., 1999). This study concluded RDX degraders are indigenous to the Pantex Plant soil tested and microaerobic or anoxic conditions in the soil pore gas are required to promote significant biodegradation of RDX. Biodegradation of RDX under aerobic conditions is negligible.

The EPA established a technical protocol for the evaluation of NA through biological processes for remediation of groundwater contaminated with mixtures of fuels and chlorinated solvents (*Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* [EPA, 1998]). The EPA guidance presents a method that uses a biologically recalcitrant compound associated with the contaminant plume as a conservative tracer to normalize contaminant concentration and remove the effects of dispersion, dilution, and sorption. The selected tracer concentration is assumed to undergo the same attenuation processes (i.e., dilution, dispersion) as the contaminant and is not affected by biological processes. Therefore, the normalized down-gradient contaminant concentration is expected to be representative of the concentration if biodegradation was the only operating attenuation process (EPA, 1998). For chlorinated solvents, such as TCE, the sum of ionic chloride and organic chloride associated with the chlorinated compounds within the plume can be considered a conservative tracer (EPA, 1998). The total organic chloride can be estimated using the stoichiometry for chlorinated ethenes, as described in Section A.3.3.2.2 of the *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water* (EPA, 1998).

Following the EPA guidance (EPA, 1998), normalized concentrations of TCE are calculated using the attenuation of the tracer. The dilution of the tracer is calculated at each location by dividing the concentration of the tracer at the source (or most contaminated location) by the concentration of tracer at each down-gradient location. The normalized TCE concentration at each down-gradient location is then determined by multiplying the measured concentration of TCE at each down-gradient location by the dilution of the tracer determined at that location (Equation A-1).

Equation A-1. Corrected Downgradient Contaminant Concentration

$$C_{B,corr} = C_B(T_A/T_B)$$

where:

$C_{B,corr}$ = corrected contaminant concentration at a point B down-gradient
C_B = measured contaminant concentration at point B
T_A = tracer concentration at a point A up-gradient
T_B = tracer concentration at point B down-gradient

To determine the biodegradation rate constant, the normalized contaminant concentrations for wells along a downgradient flow path from a contaminant source can be plotted with travel time from the source.

Assuming first-order decay, the biodegradation rate constant can then be determined as the slope of the exponential regression line. These computations are complicated by the fact that the pump and treat system is located in the plume, and the gradients and concentrations are effected by the injection and extraction wells.

A.1.1.1.1 Site-Specific Biodegradation Rate Calculations

Groundwater analytical data from the Pantex Plant perched groundwater-monitoring wells in the vicinity of the Zone 12 source areas and areas downgradient were reviewed to determine site-specific biodegradation rates using the EPA (1998) guidance. Of the possible flow paths emanating from the Zone 12 TCE source areas, two flow paths were identified as candidates for the analysis of TCE degradation. The identified flow paths are displayed in Figure A-1.

Data results from samples collected from March 1993 to May 2005 for PCE, TCE, DCE, vinyl chloride, and chloride at each of the perched wells along the two identified flow paths were compiled, grouped by quarterly sampling event, and reviewed to assess whether sufficient information was available to calculate a site-specific biodegradation rate constant from the quarterly monitoring data. Table A-1 presents a summary of the data collected by sampling event along the two flow paths. Because of the high count of non-detect results (assumed to be zero in the EPA method) and/or the limited small sample size along each flow path per sampling event (typically three or less samples are available along a flow path from a single sampling event), reliable and representative rate constants cannot be calculated via the EPA method.

Although a degradation rate cannot be determined from the site-specific data, additional lines of evidence suggest that TCE degradation is occurring. Along Flow Path 1, TCE concentrations appear to be decreasing over time at the monitoring wells in the vicinity of the source area (Figure A-2). No discernible trend is observed for TCE concentration over time at monitoring well locations further downgradient of the source, however, TCE concentrations measured at the most distal end of the flow path (i.e., PTX08-1008) are consistently non-detect.

Along Flow Path 2 the affect of the current pump and treat system can be observed at PTX06-1005 (Figure A-3); this is apparent in the initial increase in TCE concentrations over time followed by the sharp decline in 2002. Due to the presence of the pump and treat system, no discernible trends are observed at monitoring wells downgradient of PTX06-1005, however, TCE concentrations measured at the most distal ends of the flow path are generally near or below the MCL.

In addition, the detection of TCE degradation products (i.e., DCE) at monitoring wells in the vicinity of the source area and at downgradient well locations provides evidence that TCE is degrading in the perched groundwater.

A.1.1.2 Summary of Applicable Published Biodegradation Half-Lives

In accordance with the EPA (1998) guidance, literature values may be used in a sensitivity analysis if it is not possible to determine site-specific biodegradation rates. Literature values were compiled through review of site-specific technical reports, internet searches, and library resources. Although the primary focus of the literature search was on published degradation rates for groundwater, soil rates were also tabulated when available. Table A-2 presents a summary of published degradation rates for thirteen COPCs; no degradation rates were identified for boron and total chromium. In addition to summarizing the published degradation rate(s) and/or half-lives, Table A-2 presents the associated media and any information relevant to the type of study (e.g., microcosm, field-scale) and redox conditions.

According to the EPA (1998) guidance, the compilation of literature values provides a basis for comparison of rate constants determined at a particular site to NA values as documented in the literature. The literature values are not intended to provide rate constants for the Plant. The rate constants used to describe behavior of a particular site must be extracted from site characterization information particular to that site. The use of site-specific information for the determination of degradation rates for the list of COPCs is presented in Section A.1.1.3.

Table A-1. TCE and Degradation Product Data by Flow Path

Location Code	Northing	Easting	Sample ID	Sample Date	PCE	TCE	DCE, Total	VC	Chloride
Flow Path #1									
PTX08-1008	3755696	637485	20010222M00020	20010222	ND	ND	ND	ND	6.53E+01
PTX10-1013	3759944	639664	20010417M00083	20010417	4.10E-03	4.02E-02	ND	ND	5.93E+01
PTX10-1014	3759770	639702	20010417M00084	20010417	ND	1.12E-02	ND	ND	8.35E+01
OW-WR-45	3759812	639452	20010502M00121	20010502	ND	2.80E-03	ND	ND	8.68E+01
PTX06-1008	3759325	639442	20010417M00085	20010417	ND	1.92E-02	ND	ND	5.59E+01
PTX08-1007	3758430	638898	20010423M00101	20010423	2.40E-03	1.24E-02	ND	ND	4.11E+01
PTX08-1008	3755696	637485	20020211M00032	20020211	ND	ND	ND	ND	7.06E+01
PTX10-1013	3759944	639664	20020509M00118	20020509	3.80E-03	2.21E-02	ND	ND	1.07E+02
OW-WR-45	3759812	639452	20020424M00077	20020424	7.30E-04	1.20E-02	ND	ND	9.41E+01
PTX10-1014	3759770	639702	20020523M00146	20020523	ND	7.40E-03	ND	ND	8.79E+01
PTX06-1008	3759325	639442	20020523M00145	20020523	ND	2.88E-02	ND	ND	5.14E+01
PTX08-1007	3758430	638898	20020807M00242	20020807	ND	1.21E-02	ND	ND	6.77E+01
PTX08-1008	3755696	637485	20030128M00040	20030128	ND	ND	ND	ND	7.16E+01
PTX10-1013	3759944	639664	20030507M00152	20030507	4.20E-03	2.13E-02	ND	ND	1.32E+02
OW-WR-45	3759812	639452	20030513M00159	20030513	4.90E-04	1.20E-02	ND	ND	3.28E+01
PTX10-1014	3759770	639702	20030513M00158	20030513	ND	7.50E-03	ND	ND	8.65E+01
PTX06-1008	3759325	639442	20030429M00130	20030429	ND	1.49E-02	ND	ND	5.26E+01
PTX08-1007	3758430	638898	20030730M00278	20030730	ND	1.38E-02	ND	ND	8.14E+01
PTX08-1008	3755696	637485	20030827M00333	20030827	ND	ND	ND	ND	7.12E+01
PTX08-1008	3755696	637485	20040210M00029	20040210	ND	ND	ND	ND	6.45E+01
Flow Path #2									
PTX06-1045	3752202	642594	20000912M00111	20000912	ND	ND	ND	ND	2.24E+01
PTX06-1046	3752171	643797	20000911M00106	20000911	ND	9.60E-04	ND	ND	2.11E+01
PTX06-1047A	3752004	643817	20000911M00107	20000911	ND	ND	ND	ND	1.37E+01
PTX06-1045	3752202	642594	20001128M00164	20001128	ND	ND	ND	ND	2.12E+01
PTX06-1046	3752171	643797	20001127M00160	20001127	ND	1.20E-03	ND	ND	1.95E+01
PTX06-1047A	3752004	643817	20001127M00159	20001127	ND	ND	ND	ND	1.56E+01
PTX06-1005	3756140	640545	20010222M00023	20010222	4.60E-04	9.80E-03	3.30E-04	ND	3.14E+01

Table A-1. TCE and Degradation Product Data by Flow Path (continued)

Location Code	Northing	Easting	Sample ID	Sample Date	PCE	TCE	DCE, Total	VC	Chloride
PTX06-1046	3752171	643797	20010227M00028	20010227	ND	1.00E-03	ND	ND	2.07E+01
PTX06-1047A	3752004	643817	20010227M00030	20010227	ND	ND	ND	ND	1.76E+01
PTX06-1045	3752202	642594	20010425M00103	20010425	ND	ND	ND	ND	2.16E+01
PTX06-1046	3752171	643797	20010508M00129	20010508	ND	1.10E-03	ND	ND	1.88E+01
PTX06-1047A	3752004	643817	20010508M00130	20010508	ND	ND	ND	ND	1.99E+01
PTX06-1045	3752202	642594	20011024M00214	20011024	ND	2.70E-04	ND	ND	2.43E+01
PTX06-1046	3752171	643797	20011024M00215	20011024	ND	1.10E-03	ND	ND	2.38E+01
PTX06-1047A	3752004	643817	20011024M00216	20011024	ND	ND	ND	ND	2.72E+01
PTX06-1005	3756140	640545	20020129M00030	20020129	4.10E-04	1.50E-02	ND	ND	4.16E+01
PTX06-1045	3752202	642594	20020501M00095	20020501	ND	ND	ND	ND	2.00E+01
PTX06-1046	3752171	643797	20020513M00123	20020513	ND	7.90E-04	ND	ND	2.03E+01
PTX06-1047A	3752004	643817	20020501M00094	20020501	ND	ND	ND	ND	3.88E+01
PTX06-1045	3752202	642594	20021119M00343	20021119	ND	ND	ND	ND	2.05E+01
PTX06-1046	3752171	643797	20021107M00309	20021107	ND	1.20E-03	ND	ND	2.27E+01
PTX06-1047A	3752004	643817	20021107M00310	20021107	ND	ND	ND	ND	3.31E+01
PTX06-1005	3756140	640545	20030204M00055	20030204	ND	4.80E-03	ND	ND	3.11E+01
PTX06-1088	3757059	639902	20030611M00214	20030611	8.60E-04	2.24E-01	ND	ND	2.87E+01
PTX06-1045	3752202	642594	20030506M00145	20030506	ND	ND	ND	ND	2.12E+01
PTX06-1046	3752171	643797	20030506M00146	20030506	ND	7.30E-04	ND	ND	2.19E+01
PTX06-1047A	3752004	643817	20030506M00147	20030506	ND	ND	ND	ND	2.78E+01
PTX06-1088	3757059	639902	20030730M00279	20030730	1.40E-03	1.76E-01	ND	ND	3.83E+01
PTX06-1046	3752171	643797	20030813M00303	20030813	ND	7.50E-04	ND	ND	2.14E+01
PTX06-1088	3757059	639902	20031028M00372	20031028	4.30E-03	1.31E-01	4.20E-04	ND	5.38E+01
PTX06-1045	3752202	642594	20031028M00370	20031028	ND	ND	ND	ND	2.21E+01
PTX06-1047A	3752004	643817	20031028M00371	20031028	ND	ND	ND	ND	2.50E+01
PTX06-1088	3757059	639902	20040219M00067	20040219	1.50E-03	1.48E-01	ND	ND	3.88E+01
PTX06-1046	3752171	643797	20040224M00080	20040224	ND	8.10E-04	ND	ND	2.47E+01

ND - Not detected.
Unless total DCE was reported for a specific sample, all DCE isomers (*cis*-DCE, *trans*-DCE, 1,1-DCE) were combined together and assumed to be the daughter product of biodegradation.

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	1,3-Dinitrobenzene	99-65-0	0.031 - 0.046	15 - 23	Groundwater and aquifer soils	Rate varies depending on soil type in column testing (step input, 4 types of soils with onsite contaminated groundwater) & batch testing (nitrogen atmosphere, 20°C, 'in the dark') Pseudo-1st Order, anaerobic	Pennington et al., 1999
			0.0019 - 0.34	2 - 360	Groundwater	Scientific judgment based upon estimated unacclimated aqueous aerobic (high half-life) and anaerobic (low half-life) biodegradation half-lives.	Howard et al., 1991
			0.0039 - 0.025	28 - 180	Soil	Scientific judgment based upon estimated unacclimated aqueous aerobic biodegradation half-life	Howard et al., 1991
			0.037	18.8	Groundwater (estimated from soil experiments)[1]	Experimental evidence was collected from biodegradation experiments conducted at 22°C with a previously contaminated soil sample.	Miyares and Jenkins, 2000
			0.07	9.9	Soil	Experimental evidence was collected from biodegradation experiments conducted at 22°C with a previously contaminated soil sample.	Miyares and Jenkins, 2000
			0.03	23	Water	Photolytic half-life reaction is sensitized by humic substances.	ATSDR, 1995
			--	degrades	Water and soil	Aerobic, microbial	ATSDR, 1995
			--	degrades	Water and soil	Anaerobic, microbial	ATSDR, 1995
HE	1,3,5-Trinitrobenzene	99-35-4	0.20 - 1.4	0.49 - 3.4	Groundwater (estimated from soil experiments)[1]	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay).	Miyares and Jenkins, 2000
			0.41 - 1.4	0.49 - 1.7	Soil	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay).	Miyares and Jenkins, 2000
			0.012 - 0.070	10 - 60	Groundwater and aquifer soils	Rate varies depending on soil type in column testing (step input, 4 types of soils with onsite contaminated groundwater) & batch testing (nitrogen atmosphere, 20°C, 'in the dark'). Reaction is pseudo-1st order, anaerobic.	Pennington et al., 1999
			--	--	Water and soil	Reacts with reducing material, vapor half-life 35 years photolysis	Spectrum Laboratories Inc., 2005a

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	2,4-Dinitrotoluene	121-14-2	0.041 - 0.41	1.7 - 17	Groundwater and aquifer soils	Rate varies depending on soil type in column testing (step input, 4 types of soils with onsite contaminated groundwater) & batch testing (nitrogen atmosphere, 20°C, 'in the dark') Pseudo-1st Order, anaerobic	Pennington et al., 1999
			0.05	14	Sewage	Anaerobic, microbial	ATSDR, 1998
			0.0019 - 0.34	2 - 360	Groundwater	Scientific judgment based upon estimated unacclimated aqueous aerobic (high half-life) and anaerobic (low half-life) biodegradation half-lives.	Howard et al., 1991
			0.0039 - 0.025	28 - 180	Soil	Scientific judgment based upon estimated unacclimated aqueous aerobic biodegradation half-life	Howard et al., 1991
			0.013 - 0.46	1.5 - 53	Soil	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay).	Miyares and Jenkins, 2000
			0.0043 - 0.46	1.5 - 106	Groundwater (estimated from soil experiments)[1]	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay).	Miyares and Jenkins, 2000
			0.41 - 1.5	0.45 - 1.7	Natural waters	One study estimated higher half-life for Rhine River	Spectrum Laboratories Inc., 2005b
HE	2,6-Dinitrotoluene	606-20-2	0.025	28	unacclimated sewage	Anaerobic, microbial	ATSDR, 1998
			0.0019 - 0.34	2 - 360	Groundwater	Scientific judgment based upon estimated unacclimated aqueous anaerobic half-life for 2,4-dinitrotoluene (low half-life) and estimated unacclimated aqueous aerobic biodegradation half-life for 2,6-dinitrotoluene(high $t_{0.5}$).	Howard et al., 1991
			0.0039 - 0.025	28 - 180	Soil	Scientific judgment based upon estimated unacclimated aqueous aerobic biodegradation half-life	Howard et al., 1991
			0.039	18	Soil	Experimental evidence was collected from biodegradation experiments conducted at 22°C with a previously contaminated soil sample.	Miyares and Jenkins, 2000
			0.019	36	Groundwater (estimated from soil experiments)[1]	Experimental evidence was collected from biodegradation experiments conducted at 22°C with a previously contaminated soil sample.	Miyares and Jenkins, 2000

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	2-Amino-4,6-Dinitrotoluene	35572-78-2	0.24	2.83	Anaerobic digester sludge	Experimental evidence was collected from batch reactors containing anaerobic digester sludge incubated with DNT2A for 3 days.	Hwang et al., 2000
			0.16	4.3	Soil and aquifer material	Column tests - faster than in the field 1st Order, aerobic soils	Brannon and Myers, 1997
			1.2	0.63	Soil and aquifer material	Column tests - faster than in the field 1st Order, anaerobic soils	Brannon and Myers, 1997
HE	4-Amino-2,6-Dinitrotoluene	19406-51-0	0.105 - 0.23	2.99 - 6.4	Groundwater (estimated from culture assays and soil experiments)[1]	Experimental evidence was collected from field scale studies undergoing biological treatment (high half-life) with addition of organic material (sucrose) as well as laboratory culture assays (low half-life).[2]	Lenke et al., 1998
			0.27 - 1.1	0.63 - 2.6	Groundwater and aquifer soils	Column tests - faster than in the field, 1st Order, aerobic (high half-life) & anaerobic (low half-life) soils	Brannon et al. in Prep. (referenced in Brannon and Myers, 1997)
HE	HMX	2691-41-0	0.015 - 0.02	34 - 45	HE contaminated soil	Anaerobic Biodegradation Studies with various pure cultures (*Morganella morganii, Pseudomonas rettgeri, C. freundii*)[2]	Kitts et al., 1994 (referenced in Card et al., 1998)
			--	--	River Water and Wastewater	Aerobic reaction can happen with organic nutrients added	ATSDR, 1997a
			--	--	River Water and Wastewater	Anaerobic reaction can happen with organic nutrients added	ATSDR, 1997a
			0 - 0.086	0 - 8.1	Groundwater	1st Order transformation rate constant in groundwater	Myers et al. in Prep. (referenced in Townsend and Myers, 1996)
			2.16	0.32	Groundwater	1st Order transformation rate constant in groundwater	Pennington et al., 1995 (referenced in Townsend and Myers, 1996)
			0.011	66	Groundwater and aquifer soils	Column testing (step input, Clean Clay from LAAP soils with onsite contaminated groundwater) & batch testing (nitrogen atmosphere, 20°C, 'in the dark') Pseudo-1st Order, anaerobic	Pennington et al., 1999

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	HMX	2691-41-0	0	0	Surface soil	Column tests, oxidizing conditions, 1st Order	Price, Brannon, and Hayes, 1997 (referenced in Brannon et al., 1999)
			0	0	Surface soil	Column tests, mildly reducing conditions, 1st Order	Price, Brannon, and Hayes, 1997 (referenced in Brannon et al., 1999)
			0 - 1.44	0 - 0.48	Surface soil	Column tests, highly reducing conditions, 1st Order	Price, Brannon, and Hayes, 1997 (referenced in Brannon et al., 1999)
			0.012 - 1.08	0.64 - 57.8	Soil	Rate depending on Eh/pH Incubations treatment -organic matter from a basin was added as an energy source to increase the rate of reduction in the soil by the native microbial community; tested at different pH ranges and redox potentials 1st Order, anaerobic	Price, Brannon, and Yost, 1998
			0 - 0.0096	0 - 72	Groundwater and aquifer soils	Column tests, 1st Order	Pennington et al., 1997 (referenced in Brannon et al., 1999)
HE	RDX	121-82-4	0.001	690	Pantex Soils	Batch experiment, aerobic	Shull et al., 1999
			0.0005	1390	Pantex Soils	Batch experiment, aerobic w/phosphorus	Shull et al., 1999
			0.012	60	Pantex Soils	Batch experiment, microaerobic	Shull et al., 1999
			0.016	43	Pantex Soils	Batch experiment, microaerobic w/phosphorus	Shull et al., 1999
			0.01	68	Pantex Soils	Batch experiment, anoxic	Shull et al., 1999
			0.011	64	Pantex Soils	Batch experiment, anoxic w/phosphorus	Shull et al., 1999
			0.019	36	Pantex Soils	Batch experiment, anoxic w/carbon	Shull et al., 1999
			0.018	38	Pantex Soils	Batch experiment, anoxic w/carbon & phosphorus	Shull et al., 1999
			0.657	1.05	Water	Biodegradation of RDX by a microbial consortia obtained from anaerobic and activated sewage sludge. 100% reduction of 50 ppm RDX in 7 days. For calculation of degradation rate, final concentration assumed to be 1% of original concentration.	McCormick et al., 1981 (referenced in Card et al., 1998)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	RDX	121-82-4	0 - 0.034	0 - 4.4	Soil	Column tests 1st Order; aerobic soil. No RDX transformation noted for sandy soils.	Myers et al. in Prep., (referenced in Townsend and Myers, 1996)
			0 - 2.4	0 - 0.29	Soil	Batch-1 biotic and abiotic adsorption tests (aerobic soil); column tests (anaerobic soil) 1st-Order	Pennington et al., 1995 (referenced in Townsend and Myers, 1996)
			0 - 0.17	0 - 4.1	Soil	Laboratory study to assess rate of reduction at varying Eh/pH conditions. Organic matter was added as an energy source to increase the rate of reduction in the soil by the native microbial community. Results fit to pseudo-1st order kinetic equation. Oxidizing conditions (Eh +500 mV)	Price, Brannon, and Yost, 1998
			0 - 0.19	0 - 3.6	Soil	Laboratory study to assess rate of reduction at varying Eh/pH conditions. Organic matter was added as an energy source to increase the rate of reduction in the soil by the native microbial community. Results fit to pseudo-1st order kinetic equation. Mildly reducing conditions (Eh +250 mV)	Price, Brannon, and Yost, 1998
			2.9 - 5.8	0.12 - 0.24	Soil	Laboratory study to assess rate of reduction at varying Eh/pH conditions. Organic matter was added as an energy source to increase the rate of reduction in the soil by the native microbial community. Results fit to pseudo-1st order kinetic equation. Highly reducing conditions (Eh -150 mV)	Price, Brannon, and Yost, 1998
			0.0022 - 0.0072	96 - 315	Groundwater and aquifer soils	First-order rate coefficients (k and half-lives) for explosives in four LAAP aquifer soils under anaerobic conditions (solution phase consisted of undiluted contaminated water)	Pennington et al., 1999
			<0.002	>350	Groundwater and aquifer soils	Rates based on each type of soil. Batch laboratory adsorption to LAAP testing for use in modeling purposes, water from MW085U Pseudo-1st Order, aerobic	Pennington et al., 1999
			<0.0001 - 0.002	323 - >3900	Groundwater and aquifer soils	Apparent aerobic first order removal rate constants for uptake of RDX from groundwater on uncontaminated LAAP soils. Radiorespirometry tests run at 23.3°C± 3.2°C, results were the basis for the decay rates used in the model.	Pennington et al., 1999

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	RDX	121-82-4	8.13×10^{-6}	85240	Groundwater and aquifer soils	Apparent aerobic first order decay rate used in modeling based on radiorespirometry results and model calibration using field concentration data.	Pennington et al., 1999
HE	TNT	118-96-7	0.0019 - 0.025	28 - 360	Groundwater	Scientific judgment based upon estimated unacclimated aqueous anaerobic (low half-life) and aerobic (high half-life) biodegradation half-lives	Howard et al., 1991
			0.0039 - 0.025	28 - 180	Soil	Scientific judgment based upon estimated unacclimated aqueous aerobic biodegradation half-life	Howard et al., 1991
			0.0024 - 0.69	< 1 - 280	Groundwater (estimated from soil experiments)[1]	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay, deep aquifer soils).	Miyares and Jenkins, 2000
			0.005 - 0.69	< 1 - 140	Soil	Experimental evidence was collected from biodegradation experiments conducted at 22°C using previously contaminated soil samples (silt, sandy loam, clay, deep aquifer soils).	Miyares and Jenkins, 2000
			0.014 - 0.034	21 - 48	Groundwater and aquifer soils	batch laboratory adsorption to LAAP testing for use in modeling purposes, water from MW085U Pseudo-1st Order, aerobic	Pennington et al., 1999
			<0.0001 - 0.0022	320 - >3900	Groundwater and aquifer soils	Apparent aerobic first order removal rate constants for uptake of TNT from groundwater on uncontaminated LAAP soils. Radiorespirometry tests run at 23.3°C± 3.2°C, results were the basis for the decay rates used in the model.	Pennington et al., 1999
			1×10^{-5}	69300	Groundwater and aquifer soils	Apparent aerobic first order decay rate used in modeling based on radiorespirometry results and model calibration using field concentration data.	Pennington et al., 1999
			0.077 - 3.4	0.21 - 9.0	Groundwater	Pseudo-1st Order transformation rate constant in groundwater	Myers et al., in Prep. (referenced in Townsend and Myers, 1996)
			0.041 - 0.21	3.3 - 16.9	Groundwater	Pseudo-1st Order transformation rate constant in groundwater	Ainsworth et al., 1993 (referenced in Townsend and Myers, 1996)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
HE	TNT	118-96-7	0.19 - 0.6	1.2 - 3.6	Soil	Pseudo-1st Order transformation rate constant in groundwater	Townsend et al., 1995 (referenced in Townsend and Myers, 1996)
			--	--	Soil and water	Eh/pH Incubations-organic matter from a basin was added as an energy source to increase the rate of reduction in the soil by the native microbial community; tested at different pH ranges and redox potentials. 1st Order, anaerobic	Price, Brannon, and Hayes, 1995
			0.13	5.5	Soil	First order rate coefficients for disappearance of TNT; aerobic soil conditions; abiotic	Brannon et al. in Prep. (referenced in Brannon and Myers, 1997)
			0.39	1.8	Soil	First order rate coefficients for disappearance of TNT; aerobic soil conditions; biotic	Brannon et al. in Prep. (referenced in Brannon and Myers, 1997)
			0.14	5.0	Soil	First order rate coefficients for disappearance of TNT; anaerobic soil conditions; abiotic	Brannon et al. in Prep. (referenced in Brannon and Myers, 1997)
			1.5	0.5	Soil	First order rate coefficients for disappearance of TNT; anaerobic soil conditions; biotic	Brannon et al. in Prep. (referenced in Brannon and Myers, 1997)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
MET	Chromium, Hexavalent	18540-29-9	0.005 - 0.17	4 - 140	Water, sediment, and soil	Oxidation and reduction rates were evaluated in single phase water systems and in two phase water-solid systems. Natural and reference waters, sediments and soils representing a broad range of characteristics were used.	Saleh, et al., 1989
			0.00076	913	Sand Aquifer	Cr(IV) reduction to Cr(III) was observed to be slow at near neutral conditions in the Trinity Sand Aquifer (TX).	Reddy and Chinthamreddy, 1999
			--	--	Groundwater	Cr(VI) can be reduced to the nontoxic Cr (III) under alkaline to slightly acidic conditions	Palmer and Puls, 1994
			--	--	Groundwater	When a contamination plume containing hexavalent chromium enters the subsurface, it displaces the groundwater containing the dissolved reductants. There is little mixing of the waters containing the reducing agents and the Cr(VI)-contaminant plume.	Palmer and Puls, 1994
MISC	Perchlorate	14797-73-0	0.13 - 0.46	1.5 - 5.3	Water and Sediment	Experimental evidence collected from microcosm studies with 4 perchlorate contaminated soils and sediments. Microcosms consisted of 120 mL of a 1:3 sediment to water slurry (w/w). Lag times varied between 0 and 60 days.	Tan et al., 2004
			0.23	3.0	Soil	3 days to chlorate anaerobic	Yue, (no date)
VOC	1,2-Dichlorethane	107-06-2	0.0019 - 0.0069	100 - 360	Groundwater	Scientific judgment based upon unacclimated grab sample of aerobic soil from groundwater aquifers (low half-life) and acclimated river die away rate data (high half-life).	Howard et al., 1991
			0.0039 - 0.0069	100 - 180	Soil	Scientific judgment based upon estimated aqueous aerobic biodegradation half-life.	Howard et al., 1991
			0.0042 - 0.011	64 - 165	Groundwater	Field studies carried out at a Gulf Coast manufacturing site (methanogenic site). Both aerobic and anaerobic degradation by-products (2-chloroethanol, ethanol, ethene, ethane) were observed in the groundwater.	Lee et al., 1996 (referenced in Klecka, 1998)
			6.3×10^{-5} - 0.0018	<365 - 10950	Groundwater	VC manufacturing plant where 1,2, DCA was the primary contaminant (estimated along groundwater flow path).	Bosma et al., 1997 (referenced in Klecka, 1998)
			0.000026	26280	Water	Approximate half-lives of abiotic hydrolysis and dehydrohalogenation reactions involving chlorinated solvents	Jeffers et al., 1989 (referenced in Wiedemeier et al., 1998)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
VOC	1,2-Dichlorethane	107-06-2	0.000083	8395	Groundwater	Hydrolysis with groundwater conditions, pH=7 and 15C, and sodium sulfide present	Barbash and Reinhard, 1989 (referenced in IPCS, 1995)
			0.0069	100	Water	aerobic - kinetic experiments	ATSDR, 2001 (references Capel and Larson, 1995)
			0.0017	400	Water	anaerobic- kinetic experiments	ATSDR, 2001 (references Capel and Larson, 1995)
			0.0019 - 0.0069	100 - 365	Groundwater	First-order biodegradation Rate Constants with microcosms	Henson et al., 1989 (referenced in Wiedemeier et al., 1996)
VOC	Trichloroethene	79-01-6	1.46×10^{-9} - 0.0027	255.5 - 4.75×10^{8}	Groundwater	Approximate Half-Lives of Abiotic Hydrolysis and Dehydrohalogenation Reactions Involving Chlorinated Solvents	Wiedemeier et al., 1998
			0.00011 - 0.35	1.98 - 6300	Groundwater	Laboratory and field derived rate constants	Wiedemeier et al., 1999 (referenced in Aziz et al., 2000)
			0.0033	210	Groundwater	Median field-scale biodegradation anaerobic rate constants estimated for 35 plumes using the BIOCHLOR model. BIOCHLOR is an analytical model that assumes first order sequential kinetics for reductive dechlorination, thereby accounting for daughter product generation and degradation.	Aziz et al., 2000
			0.00082 - 0.0088	79 - 845	Groundwater	Anaerobic BIOCHLOR model derived values	Aziz et al., 2000
			0.00074	936	Groundwater	Biodegradation rate computed using a conservative tracer from commingled fuel and solvent plumes at Tinker AFB Area A. Indicative of reductive dechlorination rates in an anaerobic, reducing environment.	AFCEE, 1999

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
VOC	Trichloroethene	79-01-6	5.14×10^{-5} - 0.00188	369 - 13482	Groundwater	Result derived assuming steady-state analytical solution to the advection/dispersion equation presented by Bear (1979) (Buscheck & Alcantar, 1995). The Buscheck and Alcantar (1995) method assumes that the plume is in steady-state equilibrium, and yields total destructive attenuation rates that account for chemical (abiotic) decay and biological (aerobic and anaerobic) decay.	AFCEE, 1999
			--	--	--	Cometabolism with natural gas 100% in 2 weeks to CO2; must be perfect balance between co-substrate and TCE - never is in nature, therefore doesn't usually degrade readily aerobic	ATSDR, 1997b
			--	--	--	100% to vinyl chloride in 10 days, degrades but produces toxic compounds along the way; anaerobic	ATSDR, 1997b
			0.00014 - 0.0025	277 - 4950	Groundwater	Reductive dechlorination anaerobic	Aronson and Howard, 1997
			0.0019 - 0 0039	180 - 360	Soil	Scientific judgment based upon estimated aqueous aerobic biodegradation half-life.	Howard et al., 1991
			0.00042 - 0.0022	321 - 1653	Groundwater	Scientific judgment based upon hydrolysis half-life and anaerobic sediment grab sample data.	Howard et al., 1991
			0.0034	201	Groundwater	Median range from reductive dechlorination laboratory and field experiments	Suarez and Rifai, 1999
			0 - 0.023	0 - 30.1	Groundwater	Range from reductive dechlorination field experiments first-order decay rates	Suarez and Rifai, 1999
			0 - 3.13	0 - 0.22	Groundwater	Range from reductive dechlorination laboratory experiments first-order decay rates	Suarez and Rifai, 1999
			0.00082 - 0.0047	147-845	Groundwater	Field-scale first-order biodegradation rate constants	Weaver et al., 1996 (referenced in Wiedemeier et al.,1996)
			0.0005	1386	Groundwater	Field-scale dechlorination rate first-order biodegradation rate constant	Swanson et al., 1991 (referenced in Wiedemeier et al., 1996)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
VOC	Trichloroethene	79-01-6	0.002 - 0.006	115 - 347	Groundwater	Field-scale first-order biodegradation rate constants	Gorder et al.,1996 (referenced in Wiedemeier et al.,1996)
			0.0001 - 0.003	231 - 6930	Groundwater	Microcosm first-order biodegradation rate constants	Wilson et al., 1991 (referenced in Wiedemeier et al.,1996)
			0.0033 - 0.0038	182 - 210	Groundwater	Field-scale first-order biodegradation rate constants	Ehlke et al., 1994 (referenced in Wiedemeier et al.,1996)
			0.00088	788	Groundwater	Field-scale first-order biodegradation rate constant	Benker et al., 1994 (referenced in Wiedemeier et al.,1996)
			0.0019	365	Groundwater	Field-scale first-order biodegradation rate constant	Benker et al., 1994 (referenced in Wiedemeier et al.,1996)
			0.003	231	Groundwater	Field-scale first-order biodegradation rate constant	Cox et al., 1995 (referenced in Wiedemeier et al.,1996)
			0.0033 - 0.0049	141 - 210	Groundwater	Microcosm first-order biodegradation rate constants	Haston et al., 1994 (referenced in Wiedemeier et al.,1996)
			0.0049	141	Groundwater	Microcosm first-order biodegradation rate constant	Wilson et al., 1990 (referenced in Wiedemeier et al.,1996)
			0.01	69	Groundwater	Microcosm first-order biodegradation rate constant	Wilson et al., 1996 (referenced in Wiedemeier et al.,1996)

Table A-2. Summary of Biodegradation Rates and Half-Life Estimates for Contaminants in Groundwater at Pantex Plant (continued)

Group	Constituent	CAS	Rate (per day)	Half-Life (days)	Media	Comments	Reference
VOC	Trichloroethene	79-01-6	0.0011 - 0.0016	433 - 630	Groundwater	Field-scale first-order biodegradation rate constants	Wilson et al., 1996 (referenced in Wiedemeier et al.,1996)
			0.00063 - 0.0035	198 - 1100	Groundwater	Field-scale first-order biodegradation rate constants	Wiedemeier et al., 1996 (referenced in Wiedemeier et al.,1996)
			0.00045 - 0.00079	877 - 1540	Groundwater	TCE to DCE: field-scale first-order biodegradation rate constants	Ellis et al., 1996 (referenced in Wiedemeier et al.,1996)
			0.0006 - 0.0007	990 - 1156	Groundwater	Field-scale first-order biodegradation rate constants	Dupont et al., 1996 (referenced in Wiedemeier et al.,1996)
			0.0077 - 0.021	33 - 90	Groundwater	Microcosm first-order biodegradation rate constants	Barrio-Lage et al., 1987 (referenced in Wiedemeier et al.,1996)
			0.29	2.4	Groundwater	Anaerobic microcosm first-order biodegradation rate constant	Fogel et al., 1986 (referenced in Wiedemeier et al.,1996)
			0.0078	88.8	Groundwater	anaerobic microcosms first-order biodegradation rate constant	Wilson et al., 1996 (referenced in Wiedemeier et al.,1996)

[1]Groundwater estimates for half-life were calculated using the method used by Howard et al., 1991 wherein the higher limit of the range for half-lives for a constituent in groundwater is double the higher limit estimated for soils.
The lower limit for half-life was not changed. For example, the half-life for a 1,2 -DCA in soil was estimated to be between 100 - 180 days and in groundwater was calculated as 100-360 days.
[2]Half-lives and rate constants were calculated using first order kinetics.
– not reported

A.1.1.3 Estimated Degradation from Observed Site Data

Biodegradation rates were estimated using observed site data and modeling results. Flow modeling results yielded a perched groundwater volume of 8 billion gallons prior to industrial operations of the Plant. Operations at the Plant were estimated through modeling to increase the perched groundwater volume to 16 billion gallons. Assuming that the COPC was at solubility concentrations when entering the perched groundwater approximately 50 years ago, the first order decay rate constant was estimated as described below:

- Dilute the solubility concentration value by half to account for the general mixing of the pre-Plant operations perched groundwater volume (approximately 8 billion gallons of uncontaminated water [BWXT Pantex/SAIC, 2006]) and current perched water volume (approximately 16 billion gallons [BWXT Pantex/SAIC, 2006]).

- Obtain the current maximum value of the COPC in the perched groundwater in calendar year 2005.

- Assume the COPC was introduced to perched groundwater in the source area 50 years ago.

- Assume decay processes have been operating on a given COPC for 50 years and determine the first order decay rate necessary to reduce the concentration from half solubility concentration to the current maximum value in the perched groundwater within a 50-year time frame.

- The equation used to calculate the rate constant is the following:

Equation A-2. Decay Rate Constant

$$k = 0.6931 / t_{1/2}$$

where:

k = rate constant
$t_{1/2}$ = half-life

- Assuming first order decay, the rate constant was then used in the following equation to determine concentrations at 50 years under a range of half-lives:

Equation A-3. Predicted First Order Decay Constant

$$k = \frac{-\ln(C/Cs)}{T}$$

where:

C = concentration at a time T in the future
Cs = ½ solubility concentration of COPC
k = rate constant
T = time in the future (50 years for this calculation)

Based on the above calculations, a half-life was determined for each COPC based on which half-life or range of half-lives produced a concentration most closely approximating the current observed concentration of the COPC (Table A-3).

Table A-3. Degradation Rates Used for COPC Transport Simulations[a]

COPC	Dispersivity (ft:ft)	Degradation Rate (1/days)	Half-Life (days)	K_d (L/kg)
RDX[b]	50:05	7.57E-05	9160	0.1707
TNT[b]	50:05	3.07E-04	2260	0.1707
1,3,5-Trinitrobenzene	50:05	1.41E-04	4920	1.5805
2,4-Dinitrotoluene	50:05	3.93E-04	1760	0.1707
2,6-Dinitrotoluene	50:05	5.25E-04	1320	0.1707
HMX	50:05	5.56E-05	12500	0.1707
Boron	50:05	--	--	Nonreactive
Hexavalent Chromium	50:05	0	0	0.5854
1,2-Dichloroethane	50:05	6.78E-04	1020	0.1707
Trichloroethene[b]	50:05	4.28E-04	1620	0.1707

Dispersivity is presented as longitudinal dispersivity (ft) : transverse dispersivity (ft)
[a] Degradation rates listed were used for transport simulations conducted for the HHRA and are discussed in further detail in the Baseline HHRA Report (BWXT/SAIC, 2006)
-- No degradation rate due to the nonreactive nature of boron.

A.1.1.3.1 Uncertainty with Decay Rates Determined from Observed Site Data and Modeling

The determined degradation rates used in the Baseline HHRA simulations and the CMS/FS assume the initial concentration in the perched groundwater is half of the solubility and is fully mixed at the point of entry in perched groundwater. Utilization of the maximum observed COPC value assumes no mass was removed from the system due to sorption. The calculation further assumes the reduction in peak concentration is due only to first order decay and not from the physical dispersion of the peak concentrations in the system. The calculations also assume the first order decay rate was constant over the 50 years of COPC residence time in perched groundwater. If the initial mixed concentration was actually lower, a longer half-life (slower degradation rate) would be computed. Since the peak concentration was lowered by processes other than first order decay, such as dispersion and absorption, the actual degradation rate would also be slower.

A.1.1.4 Summary of Degradation

Analytical data in the perched groundwater at Pantex Plant were not amenable for use in standard USACE or EPA protocols for the calculating of site-specific degradation rates for HEs and VOCs. The data do indicate, however, that degradation is occurring for these compounds. The method presented in Section A.1.1.3 to estimate site-specific first order decay were either consistent with or slower than reported literature values from other researchers at other sites. Figure A-4 presents a comprehensive depiction of the estimated site-specific biodegradation rates in relation to the range of published degradation rates. Figure A-4 clearly shows the wide range in reported values for degradation rates of COPCs of interest to Pantex Plant, and the need for specific, detailed studies of site geochemical conditions controlling these NA rates. Modeling calculations conducted for these COPCs utilize degradation rates consistently on the lower end of the scale of reported values shown in Figure A-4.

Hexavalent chromium reduction was not evaluated in the Baseline HHRA (BWXT Pantex/SAIC, 2006), but NA was evaluated through the application of K_d values. Site-specific biodegradation rate estimates for RDX (7.57×10^{-5} day^{-1}), TNT (3.07×10^{-4} day^{-1}), and TCE (4.28×10^{-4} day^{-1}) appear to be within the range of published degradation rates (Figure A-4). However, a closer review of the literature values presented in Table A-2 show the estimated site-specific biodegradation rates are, in fact, slower than

many of the field-scale degradation rates published in the available literature. The range of rates presented in Figure A-4 does not differentiate among field-scale and laboratory-scale numbers. The site-specific biodegradation rates estimated for the remaining constituents are conservatively an order-of-magnitude or more below the published degradation rates.

A.1.2 *In Situ* Chemical and Biological Treatment Amendments

The effects of various chemical and biological amendments to groundwater have been evaluated for potential remedial action at Pantex Plant. This was conducted in two stages; first a review of available technologies and literature relevant for the *in situ* treatment of RDX and bioremediation in general, and second; the site-specific treatability studies conducted at the Pantex Plant.

A.1.2.1. SERDDP and ESTCP Research Summary of RDX treatment Technologies and Approaches

Various methods of remediating RDX and its byproducts *in situ* are being conducted by the SERDP and Environmental Security Technology Certification Program (ESTCP) organizations. The SERDP projects are intended to be aligned with basic research, understanding and advancing the knowledge / science while the ESTCP projects are more aligned with proof of concept as field applications.

Representative projects being performed by SERDP include:

- Biodegradation of Nitroaromatic Compounds by Stimulating Humic Substance- and Fe(III)-Reduction (SERDP Project # 1377)
- Enhancement of *In Situ* Bioremediation of Energetic Compounds by Coupled Abiotic/Biotic Processes (SERDP Project # 1376)
- Fate of Plant Tissue Associated RDX in Surface Soil (SERDP Project # 1412)
- Fe(0)-Based Bioremediation of RDX-Contaminated Groundwater (SERDP Project # 1231)
- Fe(O)-Based-Bioremediation of RDX-Contaminated Aquifers (SERDP Exploratory Development [SEED] Project) (SERDP Project # 1175)
- Genetic and Biochemical Basis for the Transformation of Energetic Materials (RDX, TNT, DNTs) by Plants (SERDP Project # 1319)
- Groundwater Chemistry and Microbial Ecology Effects on Explosives Biodegradation (SERDP Project # 1378)
- Identification of Metabolic Routes and Catabolic Enzymes Involved in Phytoremediation of the Nitro-Substituted Explosives TNT, RDX, and HMX (SERDP Project # 1317)
- Immobilization of Energetics on Live Fire Ranges (SERDP Project # 1229)
- *In Situ* Remediation of Explosives Contaminated Groundwater with Sequential Reactive Treatment Zones (SEED Project # 1176)
- Microbial Degradation of RDX and HMX (SERDP Project # 1213)

- NA of Explosives in Soil and Water Systems at DoD Sites (SERDP Project # 1043)
- Novel Pathways of Nitroaromatic Metabolism: Hydroxylamine Formation, Reactivity and Potential for Ring Fission for Destruction of TNT (SERDP Project # 1214)
- Sequential Electrolytic Degradation of Energetic Compounds in Groundwater (SERDP Project # 1234).

These reports and fact sheets are available from www.serdp.org. From the above work, an understanding of the basic scientific processes of the *in situ* destruction of the RDX and by products is formulated. For example, the bioremediation of RDX results in its auto decomposition to produce nitrous oxide and carbon dioxide, and SERDP project #1213 provides a final report on their findings in this area. Understanding of the technological process with validation on, at least, the pilot scale enables the evaluation of a technology with a greater degree of confidence. The SERDP program performs this function through their RDX/energetic initiative.

Projects performed by ESCTP involve primarily technological proof of concept at the field scale, or information for up-scaling research to the field scale. Field scale deployments provide, and help to resolve, the issues from transforming results from the lab-scale to the field scale. Whereas the basic research allows for generalized science knowledge advancement, field scale deployments are site-specific responses. A successful remedial design requires the understanding of the basic science and an understanding at the field-scale level gained from a site-specific pilot study. Representative RDX remediation projects being performed by ESTCP include:

- Treatment of RDX & HMX Plumes Using Mulch Biowalls (ESTCP Project # 0426)
- Biologically Active Zone Enhancement (BAZE) for *In Situ* RDX Degradation in Ground Water (ESTCP Project # 0110)
- Biotreatment of Explosives-Contaminated Soils in a Slurry Reactor (ESTCP Project # 9512)
- In Place Soil Treatments for Prevention of Explosives Contamination (ESTCP Project # 0434)
- *In Situ* Bioremediation of Energetic Compounds in Groundwater (ESTCP Project # 0425)
- Phytoremediation of Explosives-Contaminated Groundwater in Constructed Wetlands (ESTCP Project # 9520)
- Remediation of TNT and RDX in Groundwater Using Zero-Valent Iron Permeable Reactive Barriers (ESTCP Project # 0223)
- Monitored NA of Explosives in Groundwater (ESTCP Project # 9518).

These reports and fact sheets are available from www.estcp.org.

In addition to the work conducted by SERDP/ESTCP, the Interstate Technology Regulatory Council (ITRC) is another widely recognized group that evaluates remediation technologies. ITRCs activities with documentation of bioremediation at sites project description is located on the BioNAPL web page (http://www.itrcweb.org/teampublic_BioDNAPLs.asp) (Table A-4). The value of this work is that it documents the design and operation of enhanced bioremediation at sites around the country using

different amendments in different geologic settings. This documented case studies along with the SERDP/ESTCP efforts above and the Pantex Plant site-specific field scale tests below provide a strong line of evidence for the effectiveness of the proposed remediation plan.

Table A-4. Summary of Case Studies Documenting the Effectiveness of Enhanced Bioremediation in Aquifer Settings[a]

BioNAPL Report Case #	Title of Presentation	Bio-amendment used
1	Test Area North Case Study	Sodium Lactate, Whey powder
2	Biodegradation of DNAPLs through Bioaugmentation of Source Zones	Ethanol/methanol & Wilclear Sodium Lactate
3	Launch Complex 34 Kennedy Space Centre	Ethanol
4	Manufacturing Facility – PCE DNAPL Case Study	Molasses
5	Portland Oregon Dry Cleaners	HRC
6	Enhanced Anaerobic Bioremediation of a TCE Source Area using EOS.	Soybean oil, vitamins and nutrients.
Modeling Approaches	Simulation and Optimization of Subsurface Impacts with a focus on BioNAPL Chlanneges.	Models and optimizers developed by various researchers, primary focus on work of Pinder, G. F., Katyal, A. and Deschaine, L. M.

[a]Presentations given at the ITRC BioNAPL meeting in Long Beach, California, 2006.

The major conclusions of this work are that bioremediation does work and biologically active/augmented zones can be reliably designed and developed *in situ*. When combined with the SERDP/ESTCP efforts with RDX, this provides a line of evidence that a reliable treatment system for the RDX can be designed and implemented.

The above documents represent knowledge of the industry with respect to *in situ* RDX treatment and bioreactive remediation (Table A-4) in a general sense. This information is important to understand and interpret the results of performance of how remedial technologies might perform under Pantex Plant-specific conditions. This next section summarizes the pertinent laboratory and field studies as they relate to Pantex Plant-specific COPCs tested under Pantex Plant-specific field conditions.

A.1.2.1 *In Situ* Chemical Oxidation ($KMnO_4$) Laboratory and Field Treatability Studies

In situ chemical oxidation involves the subsurface addition of an oxidant chemical to treat contaminants without excavation or transportation. Oxidants that can be used for *in situ* chemical oxidation are (in decreasing order of oxidant strength): 1) hydroxyl radicals (generated as a subsurface reaction product of ferrous iron and hydrogen peroxide called "Fenton's Reagent"); 2) ozone (ozone is generated onsite using high voltage electrical equipment and is subsequently injected into the subsurface where it dissolves in groundwater and oxidizes contaminants); and 3) permanganate ion (introduced as a liquid solution of either potassium permanganate [$KMnO_4$] or sodium permanganate [$NaMnO_4$]).

The permanganate ion is a less aggressive oxidant compared to hydroxyl radicals or ozone, which are strong oxidants. However, stronger oxidants are inherently less stable and more short-lived, making control over delivery to the subsurface and transport to contaminated zones generally more difficult. In the case of Fenton's Reagent, hydroxyl radicals persist for only a few seconds, thereby requiring close well spacing, which would be problematic and costly on large sites such as Pantex Plant. Likewise, ozone treatment would require installation of permanent sparge injection points with close spacing. In contrast, permanganate offers the advantage of being highly stable and able to persist in the subsurface for periods of up to several months. Increased persistence in the subsurface allows for application using a wider

injection point spacing and diffusion into and flow across impacted zones. Therefore, $KMnO_4$ injection to treat HE-contaminated soils at Pantex Plant was selected to be the focus for both laboratory (Section A.1.2.1.1) and field testing (Section A.1.2.1.2).

A.1.2.1.1 *Laboratory Treatability Studies and Results*

An *in situ* chemical oxidation laboratory study was conducted to evaluate the remediation of HEs through the addition of $KMnO_4$.

The objectives for the $KMnO_4$ laboratory treatability test (IT and Stoller, 2000) were to determine:

- The description HE degradation over time
- $KMnO_4$ consumption per mass soil and contaminant treated over time
- The effects of $KMnO_4$ concentration
- The effects of $KMnO_4$ on the mobility of redox-sensitive metals (e.g., calcium, chromium, iron, magnesium, manganese, sodium, and vanadium)
- Mass balance on nitrogen
- HE oxidation products and their potential for oxidative treatment (if present)
- Potential for changes in aqueous toxicity.

Summary of Test Methods and Results

Laboratory testing of *in situ* chemical oxidation using $KMnO_4$ involved background testing, interim laboratory testing, and full laboratory testing.

- **Background Testing:** Before testing, background soil and groundwater samples were analyzed to characterize conditions prior to creating batch slurries used in laboratory studies. Results of the background testing showed that background results were similar to those reported for control systems during interim and full lab studies.

- **Interim Laboratory Test:** Interim laboratory testing consisted of a bench-scale batch test on three slurry systems (vessels A, B, C). The purpose was to assess the feasibility of treating HE compounds with $KMnO_4$. Vessel A was sacrificed at the beginning to establish baseline conditions; vessel B was the control; and vessel C was amended with 48,000 mg/L $KMnO_4$. Vessels B and C operated for 5 days (120 hours) and were subsequently sacrificed to determine endpoint RDX and HMX concentrations. Water samples were analyzed for HEs (RDX and HMX), $KMnO_4$, pH, electrical conductivity, and ORP. Soil was only analyzed for HEs. RDX concentration decreased from 2,400 µg/L to 2.5 µg/L using 48,000 mg/L $KMnO_4$ (99.9% reduction over 5 days). HMX decreased from 280 µg/L to 33 µg/L (88.2% reduction over 5 days).

- **Full Laboratory Test:** Full laboratory testing consisted of four series of test systems:

    - Series A: Four control systems

- Series B: Six treatment systems using 20,000 mg/L KMnO4
- Series C: Six treatment systems using 4,000 mg/L $KMnO_4$
- Series D: Five treatment systems using 400 mg/L $KMnO_4$.

System slurries were stirred to equilibrium and sampled at regular time intervals over 7 days. All water samples were analyzed for pH, ORP, electrical conductivity, HEs, nitroaroamines, Kjeldahl N, ammonia, anions, and aqueous metals. Soil samples were analyzed for HEs, nitroaroamines, and TOC. At the conclusion of the laboratory testing, the following observations were made (IT and Stoller, 2000):

- **Series B (20,000 mg/L KMnO4)**: RDX decreased from an initial concentration of approximately 2,600 µg/L to a final concentration of 62.9 µg/L over 7 days. RDX first order rate constant was estimated to be 0.0206 1/hr (half-life of 1.4 days).

- **Series C (4,000 mg/L KMnO4):** RDX decreased from an initial concentration of approximately 2,600 µg/L to a final concentration of 1142.12 µg/L over 7 days. RDX first order rate constant was estimated to be 0.0048 1/hr (half-life of 6 days).

- **Series D (400 mg/L KMnO4):** RDX decreased from an initial concentration of approximately 2,600 µg/L to a final concentration of 2,277 µg/L over 7 days. RDX first order rate constant was estimated to be 0.0005 1/hr (half-life of 58 days).

Conclusions of Laboratory Treatability Studies

The following are conclusions reached after evaluations of the results of the laboratory testing of *in situ* chemical oxidation using $KMnO_4$ (IT and Stoller, 2000):

- HEs can be successfully treated with $KMnO_4$.

- Reaction kinetics are slow (pseudo-first order), which is favorable for oxidant subsurface delivery and transport.

- Total organic compound (TOC) (mainly natural organic materials) comprised most of the oxidant demand, which could be minimized by decreasing the $KMnO_4$ concentration in system.

- Redox-sensitive metals concentrations increased upon initial introduction of $KMnO_4$, but returned to original concentrations.

- Nitrogen mass balance was attempted to determine mineralization of HEs, but was not completed due to insufficient data.

- Two unknown compounds were identified on raw HE chromatograms that also existed in the background system. During testing, the unknowns either remained constant or decreased with time.

- $KMnO_4$ does increase microtoxicity, but no inferences could be made regarding microtoxicity of HE oxidation by-products.

- Further testing was recommended to determine/confirm that transformation by-products are neither persistent nor harmful.

A.1.2.1.2 In Situ Field Treatability Studies and Results

Due to the favorable results of the laboratory testing (Section A.1.2.1.1), a field-scale treatability study consisting of a series of single well "push-pull" tests was conducted. The primary goals of this study were to obtain proof of concept in the field and to quantify specific parameters that relate to technology performance (IT and Stoller, 2000). Specific objectives included assessing the $KMnO_4$ dose rates needed to achieve the required level of treatment, treatment rates, the persistence of $KMnO_4$ in the subsurface, and the degree of HE treatment.

Summary of Test Methods

Push-pull testing utilized three existing extraction wells (PTX06-EW-1, -EW-2, and -EW-3). The duration of the test was limited to 72 hours to minimize loss of injected fluid away from test wells. The test was designed to assess treatment design parameters as opposed to maximum treatment levels. The $KMnO_4$ solution (20,000 mg/L) and a bromide tracer (10 g/L) were initially added (pushed) to the well. Following a defined rest period, groundwater extraction (pull) was initiated to recover the $KMnO_4$-treated groundwater and tracer from the well. Test periods occurred at 24, 48, and 72 hours. During extraction, sampling and analyses were performed to determine concentration changes over time for $KMnO_4$, the bromide tracer, contaminants, and selected reaction products ("recovery breakthrough"). A control test also was performed that involved injection of the bromide tracer without $KMnO_4$.

Test Results/Conclusions

The results and conclusions of the field treatability testing of chemical oxidation ($KMnO_4$) were:

- *In situ* field treatability test results confirmed the laboratory oxidation treatability test results.
- RDX half-life is approximately 4 days at 7,000 mg/L $KMnO_4$. This is slightly slower than the half-life determined under laboratory conditions; this can be attributed to subsurface mass transfer and diffusion of $KMnO_4$ as well as HEs limiting the overall treatment process. Slower reaction rates are considered favorable.
- $KMnO_4$ consumption rates were unable to be precisely determined from test data, though $KMnO_4$ persisted in test wells for several weeks after tests ended.
- Precipitation of MnO_4 on the well screens resulting from the altered geochemistry of the system lessened the extraction effectiveness of the pump and treat system.
- Mobilization of redox-sensitive metals (including hexavalent chromium) was determined to be transient as the mobilized metals concentrations were declining by the end of the study.
- An RDX transformation product (TNX), which was present in the background sample, was shown to have been treated.
- Additional large scale testing was recommended to determine realistic cost and performance data for possible full-scale application.

A.1.2.1.3 *Conceptual Deployment Scenarios*

In situ chemical oxidation using $KMnO_4$ was described to be deployed as batch injection areal treatment for a 40-acre target area with a length and width of 1,320 ft and a saturated thickness of 10 ft. Aquifer Solutions (2002) presents ranges of values for deployment characteristics; however, the likely scenario will at least include the following essential elements:

- Well spacing of about 400 ft
- 12 injection wells per cell
- $KMnO_4$ solution concentration of 0.5%
- 1,500,000 pounds $KMnO_4$
- 360 days active $KMnO_4$ injection at 60 gpm, one or two wells per time
- 180 days of clean water flush at 60 gpm, one or two wells per time.

Aquifer Solutions cites the previous laboratory and field chemical oxidation testing results on RDX conducted by IT Corporation (IT and Stoller, 2000). In addition, test results obtained by the University of Nebraska, Lincoln (Adam, et al., 2002) confirmed reaction rates obtained by the IT laboratory and field testing, and indicated greater than 85% RDX mineralization to carbon dioxide (CO_2) using $KMnO_4$.

A.1.2.2 Enhanced *In Situ* Bioremediation – Bench Scale Study

An *in situ* enhanced bioremediation laboratory treatability study was conducted that focused on the remediation of HEs. This provided the necessary information for the data gaps needed to perform a detailed technology evaluation and remedial alternatives selection as part of the CMS/FS process.

The laboratory bench-scale treatability study was designed to assess the following parameters (IT and Stoller, 2000):

- The types of microbial activity that can be stimulated to degrade HEs, especially RDX
- The conditions under which the microbial activity is stimulated
- The capability of indigenous microflora and bio-augmented systems to degrade RDX and other HEs in groundwater
- Characterization of transformation products that have been reported to result from the degradation process.

A.1.2.2.1 *Summary of Test Methods*

The test included a two-part anaerobic serum bottle test and an aerobic respirometer test to evaluate the objectives presented above. The following microcosms were evaluated:

- **Anaerobic Microcosm Test I (RDX spike = 10 mg/L):** Four different microcosm treatments were prepared in duplicate. Each anaerobic microcosm consisted of groundwater and soil amended with rezasurin (microbial growth indicator), molasses (carbon source), and Restore 375 (50% ammonium chloride, 20% disodium phosphate, 12.5% monosodium phosphate, and 12.5% sodium tripolyphosphate). Specific microcosms evaluated included an abiotic control spiked with 10 mg/L RDX, an anaerobic microcosm spiked with 10 mg/L RDX, an anaerobic microcosm without RDX addition, and a microcosm spiked with 10 mg/L RDX and bioaugmented with

WWTF anaerobic digester sludge. Duplicate serum bottles were sampled at days 0, 20, and 46. Aqueous and soil fractions were analyzed for methane production, pH, and HEs.

- **Anaerobic Microcosm Test II (RDX spike = 2 mg/L):** The setup protocol for Anaerobic Microcosm Test II was similar to Test I with the exception of a reduced initial RDX concentration (2 mg/L) and the addition of sodium sulfide to promote a reducing environment. The test consisted of one sample with molasses and another sample with molasses and bioaugmentation. Abiotic and unamended controls were also evaluated. Duplicate serum bottles were sacrificed at days 0, 11, and 31 from each test condition. Analyses included methane production, pH, volatile fatty acids and HEs.

- **Aerobic Microcosm Test (RDX spike = 36 mg/L):** Experimental conditions were established to determine whether RDX could be utilized as a nitrogen source in the presence of a supplemental carbon source and whether RDX can be co-metabolized in the presence of a supplemental carbon and nitrogen source. Vessels were sacrificed at two intervals of approximately 30 days each and analyzed for pH, ammonia-nitrogen, nitrate-nitrogen, TOC, aerobic heterotrophic bacteria and HEs.

A.1.2.2.2 *Test Results*

The results of the bench-scale treatability study to assess enhanced *in situ* bioremediation were:

- **Anaerobic Microcosm Test I (RDX spike = 10 mg/L):**
  - RDX was degraded by the indigenous microflora with molasses as a carbon source.
  - RDX was degraded and intermediates were produced and then degraded, along with HMX, when the microcosm was augmented with WWTP sludge.
  - Microcosm receiving no molasses showed no loss of RDX.

- **Anaerobic Microcosm Test II (RDX spike = 2 mg/L):**
  - Microcosms amended with molasses showed rapid and efficient degradation of RDX and HMX.
    - RDX: Approximate initial concentration (C_0) = 3,000 µg/L; Approximate final concentration (C_f) < 5 µg/L (99.8% reduction over 30-day incubation).
    - HMX: C_0 = 300 µg/L; C_f < 4.7 µg/L (98.4% reduction over 30-day incubation).
  - Microcosms amended with molasses and augmented with WWTP sludge showed a more rapid and efficient degradation of RDX and HMX.
    - RDX: C_0 = 500 µg/L; C_f < 4.5 µg/L (99.1% reduction over 10-day incubation).
    - HMX: Treated to below detection limit (~100% reduction over 10-day incubation).

- Nitroso transformation products for RDX were observed at initial sampling, but were below detection limits in 10 days.
- No losses of RDX and HMX were observed in the abiotic and unamended controls.
- Test results indicate that methane fermentation was not necessary for RDX and HMX biodegradation.
- TOC concentrations remained unchanged indicating very little conversion of molasses to CO_2. However, under methanogenic conditions (bioaugmented microcosms) the degradation of RDX and HMX was more rapid with substantial production of methane and CO_2.

- **Aerobic Microcosm Test (RDX spike = 36 mg/L):**
  - Microcosms amended with carbon and inorganic nitrogen showed the most rapid and efficient degradation of RDX and HMX.
    - RDX: C_o = 1,500 µg/L; C_f < 1 µg/L (~100% reduction over 21-days).
    - HMX: C_o = 2,000 µg/L; C_f < 1 µg/L (~100% reduction over 21-days).
  - RDX in the unamended microcosms and in the carbon amended microcosms (i.e., where RDX was the only nitrogen source) showed a greater than 50% loss, which is similar to those observed in the unamended and abiotic controls. However, where RDX was the sole source of nitrogen, there were greater nitrate concentrations.

A.1.2.2.3 *Conceptual Deployment Scenarios*

A conceptual scenario was described by Aquifer Solutions (2002) for deployment of anaerobic ISB, in an areal treatment/recirculation mode as an active reactive barrier, for a 40-acre unit treatment area (referred to as Area A), located less than a quarter-mile southeast of Playa 1. Anaerobic ISB (as opposed to aerobic ISB) is considered in the scenario because it will treat HEs, TCE, and hexavalent chromium and because it is more readily implemented than aerobic ISB, which requires a continuous delivery of dissolved oxygen. Dissolved oxygen is consumed rapidly under aerobic conditions and is therefore difficult to deliver using large injection well spacing. In contrast, anaerobic ISB involves injection of a simple carbon source (such as lactate or sugars), which is more persistent than dissolved oxygen, and can be delivered using widely spaced injection wells.

The conceptual process for anaerobic ISB generally involves extraction of groundwater, amendment of untreated groundwater with nutrients and lactic acid, and re-injection of the amended groundwater. This process comprises a continuous recirculation process designed to develop optimal geochemical conditions for the anaerobic ISB process over the entire treatment zone. Deployment characteristics described by Aquifer Solutions (2002) are based on a 5-spot well pattern and assumes an average saturated thickness of 20 ft. Aquifer Solutions (2002) presents ranges of values for deployment characteristics; however, the likely scenario will at least include the following essential elements:

- Well spacing of approximately 200 ft
- 25 injection/extraction wells per 40-acre cell
- Total recirculation rate per cell of approximately 500 gpm

- Approximately 400,000 pounds lactic acid (carbon source) per 40-acre cell
- Approximately 200,000 pounds nitrogen and 200,000 pounds potassium nutrients per 40-acre cell
- Approximately 120 days active amendment delivery and recirculation per 40-acre cell.

Following amendment delivery across the target treatment area, groundwater recirculation can be discontinued to allow microbial degradation to proceed to completion. A key element of the process involves intensive subsurface monitoring of microbial response and COPC degradation to ensure that complete treatment is obtained. In some areas, several phases of amendment delivery may be needed to achieve complete treatment.

Aquifer Solutions (2002) describes previous evaluations and tests of remedial technologies including ISB, citing the testing performed by IT Corporation (IT and Stoller, 2000), discussed above in Sections C.4.2.2.1 and C.4.2.2.2, as well as testing of ISRM-treated water (as a follow-on treatment to ISRM treatment) (Adam, et al., 2002) that indicates follow-on ISB achieved approximately 40% mineralization of RDX. Other test results achieved by the University of Nebraska, Lincoln, indicated that "promising mineralization rates" were obtained under both aerobic and anaerobic conditions.

A.1.2.3 *In Situ* Chemical Reduction – Sodium Dithionite

As discussed previously, no treatability testing was performed using ISRM by IT Corp. and Stoller (IT and Stoller, 2000). However, ISRM was evaluated through a conceptual deployment scenario, as described by Aquifer Solutions (2002).

ISRM (using sodium dithionite) was described to be deployed as a passive reactive barrier in the Zone 12 perimeter. The deployment configuration is a 500-ft length linear unit cell with a saturated thickness of 20 ft. Aquifer Solutions (2002) presents ranges of values for deployment characteristics; however, the likely scenario will include the following essential elements:

- Injection/withdrawal well spacing of 20 ft, with an overlap of 1.2 times the radius
- 24 wells per unit cell
- Injection/withdrawal rate of 8 gpm
- 16,000 pounds sodium dithionite
- 120,000 gallons of solution per well, or approximately three pore volumes
- 12 pore volumes extracted to remove dithionite
- 30 months of active ISRM emplacement with one set of injection/extraction equipment per unit cell.

Aquifer Solutions (2002) cites a laboratory ISRM study performed by Pacific Northwest National Laboratory (Szecsody, et al., 2001) as showing "rapid and essentially complete" degradation of RDX in the presence of dithionite-reduced Pantex Plant sediments. The results demonstrated a small degree of RDX mineralization to CO_2 (<36%) was achieved, indicating that the RDX that was degraded was partially transformed to unidentified by-products (Aquifer Solutions, 2002).

A.1.2.3.1 Interim Test Deployment Scenario

In 2005, BWXT Pantex performed a pilot scale study by injecting sodium dithionite into two wells. BWXT Pantex is currently monitoring the results. Two injection wells and one monitoring well were installed in the perched groundwater in March 2005. The wells, drilled to a total depth of 290 ft bgs with approximately 20 ft of saturated section, were spaced 27 ft apart. The relatively close spacing between wells was due to the short chemical reaction half-life of the sodium dithionite (7 hours). The half-life of the chemical affected the radius of influence of the treatment zone. Treated groundwater from the pump

and treat system was mixed with the sodium dithionite and metered into both injection wells at an average diluted concentration of 0.95% sodium dithionite. Approximately 165,000 gallons of sodium dithionite solution was injected into the two wells. During the initial injection process, the dithionite degrades at an approximate 7-hour half-life to sulfate rich water. A portion of this solution (175,000 gallons) was extracted to minimize degradation of the effective porosity of the formation due to bio-fouling of the sulfate rich waters.

Three rounds of monitoring have shown the ISRM reactive barrier is effective in degrading HE, Cr+6, and TCE. HE concentrations range from a maximum of 470 µg/L before treatment to non-detect after treatment. Cr+6 ranged from 94.2 µg/L before treatment to non-detect after treatment. TCE ranged from 4.3 µg/L before treatment to 1.2 µg/L after treatment. Monitoring is continuing on a quarterly basis.

Initial evidence indicates the barrier is effective in degrading contaminants in the perched groundwater. The seven-hour reaction half-life of dithionite proved to a limiting factor on the treatment radius of influence that could be obtained; nevertheless, the injection rates and radius of influence observed at this site were favorable. A larger well spacing could possibly be implemented with modified injection volumes and pressures.

Although initial evidence indicates the barrier is effective in degrading contaminants in the perched groundwater, caution should be exercised in describing its success. The long-term effectiveness cannot be determined at this time. Additionally, the geology of the perched groundwater is known to be primarily fine sands grading coarser with depth. In some areas, the aquifer base is made up of coarse gravels and some cobbles. Heterogeneity within the formation adds uncertainty to the short and long-term effectiveness of the barrier. For example, preferential pathways (heterogeneous environments) may act to re-oxidize the reduced environments.

A.2 Screening Model Development and Construction

The research and field efforts performed by SERDP, ESTCP, ITRC, and BWXT Pantex provide an understanding of the basic science and issues with field implementations. Numerical models that integrate the groundwater flow and transport processes with these bioreactions is discussed. Specifically, to compare the relative effectiveness among many active and passive RDX remediation schemes in the perched groundwater, a rapidly-calculating, transient, flow and transport model was developed using MODFLOW-SURFACT (MS). This single-layer screening model was used to execute, evaluate, and rank multiple perturbations of various RDX remediation scenarios. The following section described the modeling objectives, the screening model construction, the screening model results, and the alternative screening process and results.

A.2.1 Objectives

The objective of this work is to compute the response and effectiveness of various remedial alternatives deployed in the perched groundwater using numerical models. The complete physics of the 3D flow system is described in the *Subsurface Modeling Report* (BWXT Pantex/SAIC 2004). Simulations of the perched groundwater within the 3D framework showed significant building and draining during the period of the start of the Pantex Plant discharges and well into the future. The volume of the perched continues to build after the Pantex Plant discharges ceased. This is the moisture held in the soils above the perched groundwater draining into it. Then, after the volume of the perched water reaches it's maximum, it begins to return to the pre-Pantex Plant volumes. The risk to the Ogallala Aquifer is now and in the near future. The CMS/FS actions, therefore, are focused on providing benefit to reduce or eliminate the risks (to the extent practicable and possible) in the short term. The CMS/FS evaluation period is 30-years.

This does not imply that the risk will be driven to zero in this time period, but that the most benefit of remedial action needs be in the short term. The RDX is expected to remain in the perched groundwater, vadose zone and FGZ sediments well beyond the 30-years, and some estimates have it residually present in the multiple hundred of years time frame, if not longer. RDX research is an area of active interest and research by multiple parties, such that the approaches taken in this CMS/FS may be refined in the future as more information is obtained by the industry. Some of the technologies are evaluated are still in their experimental stage, and have very high degrees of uncertainty with them. As late as 2000, researchers were still making the statements that "Efforts over the past two decades to biodegrade these two chemicals [RDX & HMX] have failed because the microbial processes and enzymes involved in degradation are poorly understood" (SERDP: CU-1213, 2000). BWXT Pantex has invested significant resources in the understanding of many of the remedial techniques as field scale test, as documented above. These tests greatly reduce the degree of reliance on just literature information and speculation regarding how the remedial approaches might behave in the field. The objective, therefore, is to present a set of computer simulations that quantify the cause and effect / benefits of various remedial options while clearly documenting what is known, unknown and uncertain with the approach.

To quantify these responses, a set of screening models were constructed to allow for the rapid testing and evaluation of various RDX remediation schemes. The primary model is capable of sufficient resolution of RDX mass and volume of water leaving the model boundary in areas spatially analogous to higher-flux areas within the Baseline HHRA transport simulation in the FTM. This is critical to the evaluation and ranking among various alternate remedial schemes. With well-defined model boundary reaches and a consistent hydraulic and contaminant property assignment consistent with the FTM, the screening model described herein provides an acceptable level of insight for the evaluation of potential RDX migration from the perched groundwater to the Ogallala Aquifer under various remedial schemes from a mass flux approach..

A.2.2 Conceptual Model

As described in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004), groundwater beneath Pantex Plant and vicinity occurs in two stratigraphic horizons within the Ogallala Formation and in the Dockum Group underlying the Ogallala Formation. The most significant quantities of groundwater are found in the Ogallala Aquifer, in the lowest part of the formation. Much smaller bodies of perched groundwater occur in the upper Ogallala Formation. Vertical flow between perched groundwater and the Ogallala Aquifer is limited by an aquitard, referred to as the FGZ. The average thickness of this aquitard is approximately 51 ft (16 m) beneath Pantex Plant.

Groundwater in this perched zone at the Plant tends to flow radially away from Playa 1 (Figure A-5). Flow to the north and directly east of Playa 1 is limited by the structure of the aquitard. Flow to the south and southwest has extended several miles from Playa 1 and is enhanced by recharge from Playas 2 and 4. The aquitard is believed to be more permeable (less fine-grained in texture) near the areas that are observed as the current extent of perching beneath the Pantex Plant. Whether the future perched groundwater extent is or remains controlled by the aquitard properties becoming more permeable in these areas, or simply a reflection of current extent of transient perching, is an uncertainty. Strategically located monitoring wells and continual water level monitoring is addressing this issue.

A groundwater treatment system (Figure A-6) is currently removing contaminants from the groundwater and limiting the further migration of contaminated groundwater to the southeast. As presented in the *Groundwater RFIR* (Stoller 2004b) the June 2003 perched saturated thickness is shown in Figure A-7.

A.2.2.1 Local Geology

The shallow subsurface stratigraphy in the area of Pantex Plant is comprised of the following geologic units (in order of increasing age of formation and depth below land surface):

- Blackwater Draw Formation (Pleistocene Epoch)
- Ogallala Formation (Pliocene Epoch)
- Dockum Group (Triassic Period)
- Permian Quartermaster Formation (Permian Period) where the Dockum Group is not present.

The perched groundwater zone lies within the Ogallala Formation above the FGZ materials. The FGZ is a fining-upward sequence within the Ogallala, which acts as an aquitard and limits vertical migration of water throughout much of the area of interest. More detailed information regarding the local geology is presented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004).

A.2.2.2 Meteorology and Climatology

Climatic data for the vicinity of Pantex Plant have been summarized in numerous documents, including the annual environmental reports and the environmental information documents. The climate in the Texas Panhandle is typical of continental interiors. It is mainly semi-arid, with mild winters and hot, dry summers and is characterized by large variations in daily temperature extremes, low relative humidity, and irregular rainfall of moderate amounts. Thunderstorms occur approximately 49 days per year and can produce tornadoes (TTU, 1994). Pantex Plant is in a windy area and in a moderate- to high-hazard zone for tornadoes.

Based on NWS records, average annual precipitation for Amarillo is 19.9 inches (50.5 cm). The gross lake-surface evaporation rate averages 73 inches (185 cm) per year, as measured from 1950 through 1975 (BPX/MHC, 1997).The average annual temperature is 57.1°F (13.9°C), with a normal low temperature in January of 21.2°F (-6.0°C) and a normal high temperature in July of 91.7°F (33.2°C). Average wind speeds at the Amarillo NWS station are 13.1 mph (21.1 kph) based on a 33-year period of record (BPX/MHC, 1998a). The prevailing wind direction is from the south for May through September and from the southwest for the remainder of the year (DOC, 1997). Analysis of NWS meteorological data for 1990 indicates local winds were predominantly from the south and southwest directions approximately 41% of the time with an average wind speed of 13.42 mph (21.60 kph).

A.2.2.3 Perched Groundwater Hydrologic Boundaries

As previously described, localized bodies of perched groundwater occur above the Ogallala Aquifer throughout the Southern High Plains (Mullican, *et al.*, 1995). These localized zones occur where focused recharge from playa lakes has ponded on top of the FGZ. The largest area of perched groundwater underlying Pantex Plant is associated with natural recharge from Playas 1, 2, and 4, treated wastewater discharge to Playa 1, and historical releases to the ditches draining Zones 11 and 12.

Perched groundwater does not discharge to the surface, is not a source of drinking water for Pantex Plant, nor is it used for any Pantex Plant industrial operations. Treated effluent from the PGPTS, and treated wastewater meeting Pantex Plant permitted discharge requirements, is used for subsurface irrigation onsite. Because perched groundwater is the shallowest water-bearing zone in the area, it is the first groundwater unit affected by the migration of contaminants released from Pantex Plant SWMUs. Contaminated soils at the surface are separated from groundwater in either the perched groundwater or the Ogallala Aquifer by a 200- to 500-ft (61- to 153-m) thick unsaturated zone. Vertical flow between

perched groundwater and the Ogallala Aquifer is limited by the FGZ in many areas. In areas where perched groundwater is present, a second unsaturated zone occurs between the perched groundwater and the Ogallala Aquifer.

Because of the thin saturated thickness of perched groundwater (Figure A-7), flow in the perched groundwater is largely controlled by the topography of the FGZ and by the hydraulic gradients induced from localized sources of recharge, such as Playas 1, 2 and 4. As a result, groundwater flow directions in the perched groundwater vary spatially in response to local topography and recharge. The furthest extent of the perched groundwater is also thought to be controlled by the balance between the lateral flux of perched water and the changing vertical permeability of the FGZ near the edge of saturation. Where the vertical permeability is equal or exceeding the lateral flux of water is the extent of saturation in these areas. On the western side of Pantex Plant, perched groundwater flows westward, but the main perched groundwater does not extend westward beyond the western boundary of Pantex Plant along FM 683, although it does extend on to TTU property in the west. On the eastern side of the Plant, perched groundwater generally flows eastward towards the Plant boundary, with portions also flowing south onto TTU property. Perched groundwater northeast of Playa 1 is limited to Pantex Plant because of the extent of the perched groundwater in that area.

A.2.2.4 Hydraulic Properties

A.2.2.4.1 Perched Groundwater Hydraulic Conductivity

Hydraulic conductivity values for the perched groundwater zone have been calculated by analyzing aquifer pumping tests and slug tests. The information provided here is primarily from multi-well pumping tests, considered to be more representative of average conditions than the smaller scale slug withdrawal/injection tests (Bradbury and Muldoon, 1990).

e^2M, Inc. and Ogden Environmental and Energy Services, Inc. (1995) reported results of a multi-well pumping test performed in well PTX06-1014 in the perched groundwater with piezometer PTX06-1017 used as an observation well. Hydraulic conductivity values determined from the analysis of the pumping and recovery test data ranged from 51.3 to 115 ft/day (1.81×10^{-2} to 4.06×10^{-2} cm/s) with a storage coefficient ranging from 0.03 to 0.34. Analysis of pumping test data from PTX06-1017 resulted in a hydraulic conductivity of 55.6 ft/day (1.96×10^{-2} cm/s) and a specific yield of 0.34.

The Higher Education Consortium (Charbeneau et al., 1995) conducted a multi-well pumping test in the perched groundwater zone using well PTX10-1008 as the pumping well and wells OW-WR-44 and PTX10-1007 as observation wells. The tests for PTX10-1008 resulted in consistent estimates of hydraulic conductivity ranging from 12.0 to 13.0 ft/day (4.2×10^{-3} to 4.6×10^{-3} cm/s). Hydraulic conductivity was calculated for test data from well OW-WR-44 at 25 ft/day (8.82×10^{-3} cm/s) based on delayed yield analysis. Storage coefficients of 0.01 to 0.04 were estimated from the aquifer test data.

The Bureau of Economic Geology (BEG) performed a multi-well pumping test in an area formerly occupied by a wastewater discharge pond. The four wells used during the BEG test (1114-MW1 through 1114-MW4) were placed as part of the pond closure investigation and had been tested previously as part of that investigation. Reanalysis of data from the original investigation resulted in a mean hydraulic conductivity of 18.0 ft/day (6.4×10^{-3} cm/s) (Mullican et al., 1995). Analysis of the BEG multi-well pumping tests based on delayed yield provided a mean hydraulic conductivity of 17.9 ft/day (6.3×10^{-3} cm/s) and specific yield ranging from 0.001 to 0.028. A complete listing of aquifer tests conducted in the perched groundwater zone is presented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004).

In addition to the pumping tests performed in the field, laboratory estimates of vertical hydraulic conductivity were determined through the use of permeameters (Mullican et al., 1994a). Vertical hydraulic conductivity was measured in sediment samples collected from both the perched groundwater and the FGZ. The estimates were determined using laboratory permeameter techniques in which both ambient and overburden pressures could be simulated. The sediment samples were collected from wells PTX-BEG-2, PTX-BEG-3, PTX08-1008, and PTX06-1004. The estimated values for the perched groundwater sediments range from 1.5×10^{-3} to 87.9 ft/day (5.44×10^{-7} to 3.10×10^{2} cm/s) under ambient pressure and range from 7.2×10^{-4} to 82.2 ft/day (2.53×10^{-7} to 2.90×10^{-2} cm/s) under estimated overburden pressures. A complete listing of laboratory hydraulic conductivity tests conducted in the perched groundwater zone is presented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004).

A.2.2.4.2 *Recharge*

Groundwater recharge on the Southern High Plains is focused below and near the edges of playas, while infiltration in upland (interplaya) settings is negligible. Numerous investigations have designated playas as primary sources of recharge to perched groundwater and the Ogallala Aquifer. Mullican et al. (1995) identified 24 investigations in which recharge rates to the Ogallala Aquifer on the Southern High Plains were calculated. Most studies conclude that a significant portion of recharge to the Ogallala Aquifer is through the floors and/or annular areas of playas in the region. More recent investigations have documented the playas as the focal points of recharge to the Ogallala Aquifer, including U.S. Bureau of Reclamation (1982), Stone (1984, 1990), Wood and Osterkamp (1987), Mollhagen et al. (1993), Gustavson (1994), Scanlon et al. (1994), and Wood et al. (1997). Studies conducted by BEG have investigated the nature of recharge through the vadose zone in the vicinity of Pantex Plant. Scanlon et al. (1994) reported that hydraulic and hydrochemical data from the playa and interplaya settings are consistent and suggest that subsurface water movement is focused beneath playas and is negligible in interplaya settings. As noted by Gustavson et al. (1994), upland soils have coarser texture than playa soils and are therefore likely to have higher saturated hydraulic conductivity than playa soils. However, the higher recharge associated with playas is a function of water availability and macropore recharge. Whereas infiltration in upland settings is limited by evapotranspiration and runoff, overland runoff is collected in playa basins. Wood et al. (1997) estimated that 95 percent of the groundwater recharge flux occurs through macropores and interstitial recharge in playa basins, while only 5 percent of total recharge occurs in the interplaya areas.

Infiltration and evaporation for the five Pantex Plant playa lakes were studied by Greer (1994). Recharge from the playas was estimated to range from as low as 20.4 inches/year (520 mm/year) in Playa 3 to as high as 144 inches/year (3,700 mm/year) in Playa 5. The range of recharge values among playas has been attributed to facies variability within playas and suggests that some playas may be sites of significant recharge and others sites of minimal recharge (Gustavson, 1994). Fayer et al. (1996) developed estimates of deep drainage rates for the various land uses at Pantex Plant to permit quantification of the spatial distribution of recharge to groundwater. Deep drainage rates were quantified for the ditches and playas and for interplaya areas. Deep drainage rates beneath the ditches and playas were developed based on Plant operational discharges and overland flow from precipitation and irrigation activities. In the interplaya areas, deep drainage rates were developed based on the infiltration of precipitation and irrigation water and the nature of surface soils and vegetation. The recommended infiltration rates for the playas ranged from 28.8 inches/year (730 mm/year) for Playa 5 to 66 inches/year (1,680 mm/year) for Playa 1. The recommended infiltration rates for channel bottoms (ditches) ranged from 126 to 263 inches/year (3,200 to 6,680 mm/year). Interplaya recharge rates ranged from less than 0.02 inches/year (0.4 mm/year) for grassland areas to 16.5 inches/year (418 mm/year) for unvegetated surfaces with gravel cover.

Scanlon et al. (1994) quantified unsaturated flow beneath playa and interplaya settings based on information collected primarily at the Wink and Texas Department of Criminal Justice playa basins, located near Pantex Plant. A variety of techniques, including physical, chemical, and isotopic methods, were used to quantify unsaturated flow beneath the playa and interplaya areas. Results indicate water fluxes range from 2.4 to 3.9 inches/year (61 to 100 mm/year) beneath the playa basins and less than 0.004 inches/year (0.1 mm/year) beneath interplaya areas. Tracer experiments in this study showed that preferential flow occurred along roots and desiccation cracks through clays underlying the playas and contributed to the higher rates of recharge beneath playas. Scanlon et al. (1994) conclude that unsaturated flow is focused beneath playas with negligible water movement occurring in interplaya regions not subject to ponding.

Ramsey et al. (1995) conducted a series of infiltration studies in the ditches and playas at Pantex Plant using double-ring infiltrometers. At the time of the study, only Playas 2, 3, and 4 contained no water. The lowest infiltration rates were observed in Playa 3, and the highest rates were observed in Playa 2. Infiltration studies conducted in the ditches indicated the shallow ditches in Zones 11 and 12 constructed in Pullman soils exhibit relatively little infiltration with historical percolation rates estimated at 43.6 ft^3 of water per ft^2 of ditch bottom per year (13.3 m^3/m^2-year). In contrast, the historical percolation rate for the channel of the main ditch east of Zone 12 was estimated at 287 ft^3/ft^2-year (87.6 m^3/m^2-year).

Wood et al. (1997) used physical, chemical, and isotopic methods to quantify recharge at Playas 2 and 3. The results indicate that the total recharge flux ranges from 44.9 to 107 inches/year (1,140 to 2,720 mm/year) in Playa 2 and from 29.5 to 63.8 inches/year (750 to 1620 mm/year) in Playa 3. Interstitial recharge was determined to range from 0.79 to 1.57 inches/year (20 to 40 mm/year) in these playas, indicating that macropore recharge is 25 to 100 times greater than interstitial recharge. On a regional scale, Wood et al. estimated that only 5 percent of the 0.43 inches/year (11 mm/year) average groundwater recharge flux, or about 0.02 inches/year (0.5 mm/year), occurs in upland areas between the playa floors.

In 2003, Scanlon et al. completed a comprehensive review of recharge research in Texas. The group examined and evaluated various methods for estimating recharge. Among the goals of the review was to compile recharge values and to conceptually characterize the recharge systems in the major aquifer systems in Texas. In summarizing the conceptual model of recharge to the Ogallala Aquifer, Scanlon et al. (2003) emphasize the importance of the thick vadose zone that typically overlies the Ogallala Aquifer and the role of focused recharge through the playas. Scanlon et al. (2003) agree with previous researchers that the absence of calcic soils and low carbonate levels in the subsurface beneath playas may be field indicators of increased recharge rates beneath playas.

The 1997 groundwater model developed by Battelle assigned recharge rates of 0.044 inches/year (1 mm/year) for interplaya areas, 2.4 to 48 inches/year (610 to 1200 mm/year) for playas, and 72 inches/year (1,800 mm/year) for the ditches. Areas in Zones 10, 11 and 12 may also be subject to slightly elevated recharge associated with poor stormwater drainage from some areas. The high recharge values presented for the ditches are representative of historical conditions when process wastewaters were discharged to the ditches. Improved waste management practices have eliminated discharge of untreated process waters to the ditches, thus limiting recharge through ditches for current and future conditions. The 2004 *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) presents and summarizes all application recharge estimates for the Pantex Plant area.

A.2.2.4.3 Bulk Density

Measured values of particle density for the perched groundwater and FGZ sediments were reported by Mullican et al. (1995) as 2.61 to 2.66 g/cm^3. The sediment samples used to determine these values were

not specified. Data contained in RFI reports for Pantex Plant indicate that dry bulk density ranges from 1.6 to 1.8 g/cm^3 for the perched groundwater sediments (Stoller, 2004b).

A.2.2.4.4 Porosity and Specific Yield

The effective porosity of a formation is a measure of the volume of void spaces in a rock or sediment through which water can travel, divided by the total volume of the rock or sediment. The total range in porosity determined during triaxial permeability measurements completed on core samples is from 19 to 45 percent. Literature values of porosity are in the range of 24 to 61 percent for perched groundwater sediment types (silts, sands, and gravels). The values fall within the range presented in the literature for these types of sediments.

Specific yield data for the perched groundwater zone have been estimated from several tests completed at the Plant. Analysis of pumping test data from PTX06-1017 resulted in a specific yield of 0.34 (e^2M, 1995). Charbeneau et al. (1995) estimated storage coefficients of 0.01 to 0.04 from aquifer test data from a multi-well pumping test using well PTX10-1008 as the pumping well and wells OW-WR-44 and PTX10-1007 as observation wells. BEG analysis of multi-well pumping tests in the area formerly occupied by the Building 11-14 wastewater discharge pond provided a specific yield of 0.001 to 0.028 based on delayed yield.

Porosity values for the Ogallala Aquifer are based on estimates of the specific yield of the Ogallala Aquifer. The effective porosity of a formation can be loosely estimated through the determination of specific yield, but the specific yield is often less than the measured effective porosity of a formation. Analysis of aquifer test data collected at City of Amarillo Well 623 indicates a specific yield of 0.14. Estimates of specific yield for the Ogallala Aquifer in the Southern High Plains have been determined through the analysis of sediment cores. Specific yield determined on cores retrieved from 41 test holes ranged from 0.072 to 0.195 with an average of 0.161. Nativ (1988) noted that patterns of high specific yield coincide with areas of high percentages of sand and gravel along major depositional axes. High core specific yield values (>0.18) lay along the main fluvial valleys in the Ogallala. Low core specific yield values (0.07 to 0.10) occur in the finer sediments. Nativ (1988) presented an average specific yield of 0.16 for both field and laboratory testing. Gutentag et al. (1984) calculated a range of specific yields in Texas of 0.05 to 0.30 with an average of 0.156.

A.2.2.5 Perched Groundwater Stresses

The only source or sink of perched groundwater at Pantex Plant is the ISM groundwater treatment system. This system consists of a network of extraction, injection, and monitoring wells located on USDOE/NNSA and TTRF property in the southeastern area of the Plant. The system pumps contaminated groundwater from the perched groundwater, removes select metals, high explosives, and organic contaminants by microfiltration and granular activated carbon processes, and injects the treated effluent back into the perched groundwater. A summary of the design and operation of the ISM groundwater treatment system is presented in Appendix E of the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004). The rates utilized in the modeling effort here are presented in Table A-5, and are averaged rates over the first three years of system operation as presented in Appendix E of the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004).

A.2.2.6 Water Budget

Inflow to perched groundwater consists primarily of infiltrating water from playas and other areas of focused recharge. Outflow of perched groundwater occurs primarily through vertical leakage of water into the FGZ, primarily near the margin of perched groundwater. The groundwater treatment system

removes and injects water to the perched groundwater. Because each body of perched groundwater occurs as a separate, isolated flow system, lateral flux is negligible.

Water inflow to the FGZ consists of leakage from overlying perched groundwater and infiltration of surface water in areas where perched groundwater is not present. Water outflow consists of vertical leakage to the underlying lower Ogallala Formation unsaturated zone. Lateral flow of groundwater in the FGZ is assumed to be negligible.

A.2.2.7 Contamination Distribution and Loading

As a result of historical waste management practices from the early 1950s to approximately the 1980s, portions of the main perched groundwater are contaminated, primarily in the areas beneath and downgradient of Zones 11 and 12 and Playa 1. Pantex Plant was an ordnance facility from 1941 through 1945, providing explosives for WWII. The most prevalent contaminant in perched groundwater is RDX, an HE compound used at Pantex Plant since it began operations. The highest concentrations of RDX are observed south of the Plant boundary on TTU property, and along the eastern Plant boundary. Current concentrations observed near the known source areas (WMG 6/7, SWMU 5-13c, and Playa 1) are much lower. The lower concentrations near the source areas indicate that influx of RDX to the perched groundwater was much greater in the past, the observed nature and extent of RDX contamination is a result of historical releases, and improved waste management practices have mitigated continuing influx of RDX to the perched groundwater.

A.2.3 Code Selection

Once the conceptual model has been formulated, it is translated into a numerical representation of the groundwater flow system. In general, a modeling code is first selected that is appropriate to the hydrogeologic features represented in the conceptual model. Next, a grid or mesh is geographically superimposed over the system. Aquifer properties, stresses, and boundary conditions are assigned to discrete points or volumes within the grid or mesh. Based on these parameters, the modeling code then calculates head and flux at each discrete point within the grid or mesh. Parameter values are adjusted until acceptable agreement is reached between the simulated and observed values for a given parameter, such as hydraulic head. The selected modeling software is discussed below.

MODFLOW-SURFACT (HydroGeoLogic, 1996) (version 2,2) was chosen to perform the screening simulation of the perched groundwater and Ogallala Aquifer. It is a fully integrated groundwater flow and solute transport code developed by HydroGeoLogic, Inc., it is compatible with, and is based to some extent on the United States Geological Survey groundwater modeling code, MODFLOW. Specifically, it does the following:

- Extends the applicability of the MODFLOW code to represent more of the aspects of this complex field problem by solving flow and transport a thin saturated aquifer without having cells that dewater and become inactive.

- Automatically adjusts the rate of withdrawal from an extraction well to withdraw only as much water is available. This allows the rate of extraction well to decrease as the perched groundwater thickness diminishes. The fractured well package overcomes MODFLOW limitations when simulating pumping wells in areas of thin saturated thickness, which results in model cells drying out and becoming inactive are needed "rewetting".

- Adaptive time stepping and output control to allow outputting results at anytime desired during the simulation.

- Compatibility with MODFLOW packages used by the regional Groundwater Availability Model

- The Analysis of Contaminant Transport (ACT) modules provide capability to perform single-species and multi-component transport analyses including numerical solution of the advective-dispersive transport equation in transient or steady-state flow fields for up to five solute species. Single species of COPCs are simulated, using reactive and non-reactive transport for retardation calculations and a first order biological decay rate (half-life) for degradation.

A.2.4 Model Construction

The conceptual model described in Section A.2.2 was translated into a single-layer, finite-difference numerical approximation of groundwater flow and transport. The SLM specifically solves the most important area of the model – that which contains the most mobile portion of the RDX mass flux, the fully saturated perched groundwater zone.

Specific processes not simulated in the SLM are:

- The SLM is a saturated flow and transport model. It does not account for any of the variably saturated flow in the subsurface.

- The SLM does not model the thinnest fringes of the perched groundwater.

- The RDX in the vadose zone, including the RDX in the soil moisture continuing to drain into the perched groundwater and the RDX in the capillary fringe, either from natural forces or remaining after the perched groundwater dewaters.

- The RDX in the FGZ clays, which can act as a continuing source of contamination into the faster flowing perched flow regime.

- The transient response and lag times between the recharge at the land surface and the perched groundwater. The recharge is directly applied to the perched groundwater.

- The perched groundwater and Ogallala Aquifer are simulated as independent systems, they are not formally coupled. They are linked using an approximation of the flux out of the SLM perched groundwater model boundaries as input into the perched.

- Biodegradation is simulated as a single component using first order decay without transform products.

Importantly, these simplifications were needed to rapidly screen many remedial approaches. The SLM model computes the reduced mass flux form the most mobile portion of the flow system in a matter of minutes to hours. Then, the most viable approaches are tested using the comprehensive 3D site-wide model documented in the *Subsurface Modeling Report*, and currently being extended. This model is not subject to any of the simplifications listed above. This 3D model is not subject to any of the simplifications listed above, but requires a simulation time on the order of weeks to calculate the coupled, transient, flow and transport solution of the integrated vadose zone, perched groundwater system.

Since the SLM focuses on the mass flux in the saturated perched zone, and ignores the other elements, it can only be used to screen the remedial options in terms of relative mass flux reduction. The results of residual mass/concentrations in the system will, by the design of the model, show clean-up faster than can

be expected in the actual field system Those computations will be assessed for the preferred alternative using the BioFT3D site wide model currently in development. The development of the SLM numerical model is described below.

A.2.4.1 Model Domain

A.2.4.1.1 Finite-Difference Grid

The finite difference grid, superimposed over the study area, is a regular grid of 100 ft by 100 ft cells (Figure A-8). A total of 28,621 active cells exist within the numerical model. The summed area of the active cells is 286,210,000 ft^2, or 6,570 acres. The 100 by 100 ft dimensions of the cells can reasonably model the groundwater flow, including the existing extraction system, and particle tracking at sufficient resolution to allow for the necessary evaluation. Because flow in the perched groundwater zone is radial, orientation of the grid along a particular flow path is not possible; rather, the finite difference grid superimposed over the study area is oriented at 0° from the north.

A.2.4.1.2 Hydraulic Parameters

Aquifer properties such as aquifer elevations, hydraulic conductivity (K), recharge (R), storage (S), and porosity (N) and bulk density (ρ_b) are assigned at the nodes of the model based on a combination of site-specific measurements; literature values reported for the region and model calibration. In most instances, hydraulic properties were imported directly from corresponding properties assigned within the site-wide model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006). This property value consistency among models allows for a better comparison of the mass and water flux values computed in the models. The following sections discuss assignment of these properties.

Bottom Elevation

Conceptually, the top of the FGZ serves as a boundary to the more mobile portion of the perched groundwater flow; therefore, the definition of this contact represents the bottom no-flow boundary of the screening model. The *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) summarizes the geologic data used to determine the top elevation of the FGZ.

Model bottom elevations were interpolated after being imported directly from definition of the top of the FGZ at nodal locations in the site-wide model documented in *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004). Otherwise, no changes were made to that surface beyond the interpolation to the finite-difference grid. The FGZ acts as an aquitard separating the sandy geologic material of the perched zone from the underlying Ogallala Aquifer material. The FGZ layer, which is generally defined as successive fining-upward sequences, changes in thickness and relative composition throughout the study area. The fining-upward sequences appear to be absent, or in transition to a more coarse-grained composition, in the southeastern area of Pantex Plant. The bottom surface elevation of the model is shown in Figure A-9.

Top Elevation

Conceptually, the top of the model was selected as the bottom of the caliche layer. Model top elevations were interpolated after being imported directly from definition of the bottom of the caliche layer at nodal locations in the site-wide model documented in *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004). Otherwise, no changes were made to that surface beyond the interpolation to the finite-difference grid. The top surface elevation of the model domain is shown in Figure A-10.

Hydraulic Conductivity (K)

Figure A-11 depicts the K field used in the screening model simulations. This parameter was imported from nodal K data from the site-wide model perched layer as documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004), and then interpolated to the screening model grid. No changes were made to the K field beyond the interpolation to the finite-difference grid.

Recharge (R)

Figure A-12 depicts the recharge field used in the screening model simulations. This parameter was imported from nodal recharge data from the site-wide model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004), and then interpolated to the screening model grid. The recharge field selected for these simulations is the present-day recharge condition. These conditions represent less flow through the ditches and playas at the Plant because the Plant no longer discharges of process water to onsite playas and ditches. A simplification with the single layer is not incorporating the additional flux rate over time from the soil moisture still draining into the perched groundwater. No changes were made to the recharge field beyond the interpolation to the finite-difference grid.

Storage (S)

The perched groundwater zone was simulated in the screening model under unconfined conditions. The specific yield applied throughout the model domain was 0.20, which is consistent with values presented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004).

Porosity (N)

The perched groundwater zone was simulated in the screening model with an effective transport porosity value equal to 0.25, which is consistent with values for this type of geologic material. This type of model does not allow for a different porosity values, one for flow (total porosity) and transport (effective or kinematic porosity).

Bulk Density (ρ_b)

Bulk Density in the model is assigned as 1.64 g/cubic centimeters. This is the same value utilized in the *Baseline HHRA* (BWXT Pantex/SAIC, 2006). It is also consistent with the conceptual understanding of this property described in Section A.2.2.4.3.

A.2.4.1.3 *Initial Heads*

Initial heads, or water levels, were assigned at the June 2003 measured water levels. These water levels are thought to be representative of conditions at the end of historically high Pantex Plant operation recharge effects (roughly 40 year period of high recharge rates beneath ditches and Playa 1 reflective of past operations at the Plant). The June 2003 water levels are somewhat indicative of the higher-recharge period when Pantex Plant was still discharging much water to the ditches and playas. There is a conceptual difference in the measured June 2003 water levels versus the water table generated in the *Subsurface Modeling Report*. In that report, additional mounding is noted beneath Playa 4, such that a groundwater trough (saddle) is noted between the southern Plant boundary and the playa. This is not evident in the June 2003 water table map as there is an absence of measured data at this location. Not including the groundwater saddle has the effect of increasing the rate of southerly migration, providing for a measure of conservativeness in the CMS/FS analysis.

A.2.4.1.4 RDX Contamination Parameters

RDX Transport Parameters

Consistent with the Baseline HHRA FTM simulations (BWXT Pantex/SAIC, 2006) and the previously presented literature and site evaluation, reactive RDX transport includes the effects of biodegradation (with half-life of 25 years) and soil adsorption (with a soil-water partitioning coefficient [K_d] of 0.1707 L/kg). The Baseline HHRA utilized nonreactive conditions to calculate risk, and provided results for RDX using half-life values of 25 years and 100 years as part of the uncertainty analysis.

RDX Initial Concentration

Initial conditions for RDX are shown in Figure A-13. Initial conditions used in the screening model were imported directly from the FTM model representation of the RDX distribution in the perched groundwater as presented in the Baseline HHRA (BWXT Pantex/SAIC, 2006). The RDX initial conditions represent the distribution (magnitude and extent) of RDX contamination in the perched groundwater at simulation time equal to zero (representative of current conditions). As presented in the Baseline HHRA (BWXT Pantex/SAIC, 2006), observed concentrations in perched groundwater are used to develop the initial conditions for RDX for those areas with the potential to migrate to a point of exposure.

RDX Source Locations

Figure A-14 depicts the RDX source areas active for the first 50 years of simulation time in the screening model. The concentrations were applied to the recharge term in these areas, and represent directly imported and interpolated values from the FTM model RDX source areas.

RDX source area locations were simulated for three source areas with the actual perched groundwater. This method represents the ongoing impacts to perched groundwater from residual drainage or leaching from the vadose zone. The three areas and concentrations specified as in the Baseline HHRA (BWXT Pantex/SAIC, 2006), and are:

- WMG 6/7 source area within HE closure extent is defined in the Zone 12 RFIR; it includes SWMU 122b and associated drainage features. A concentration of 417 µg/L based upon the trend results from PTX06-1088 is applied to this source area.

- SWMU 5-12a and 5-13c ditch source drains northward to Playa 1. A concentration of 277 µg/L based upon trend results from PTX08-1002 is applied to this source area. Results from PTX08-1002 were selected for this source area because downgradient concentrations from this source and the Playa 1 source are similar in magnitude.

- Playa 1 source is the area near the mouth of the SWMU 5-13c ditch. A concentration of 277 µg/L based upon trend results from PTX08-1002 is applied to this source area. The source node locations were selected in the southeast area of Playa 1. The entire area of Playa 1 was not selected as a continuing source because the observed distribution of RDX within the perched groundwater indicated greater impacts beneath the southeast portion of the playa near the mouth of the SWMU 5-13c ditch.

A.2.4.1.5 *Sources and Sinks*

As described in the conceptual model, the only sources of water to perched groundwater are recharge and the injection associated with the pump and treat system. The only sink of water associated with the perched groundwater is the extraction wells (BWXT Pantex/SAIC, 2004) and at the site boundaries. This historically-averaged extraction and injection rates as presented in Appendix E of the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) were assigned to the pump-and-treat wells for the 3 year period of model calibration in the model at rates and locations shown in Figure A-6, and are listed in Table A-5.

A.2.4.1.6 *Boundary Conditions*

No Flow Boundary

The screening model boundary conditions are presented in Figure A-15. This single layer model is bounded on the bottom by the assignment of a no-flow condition corresponding to the FGZ. No vertically downward flux is possible out of this model. The lateral flux exiting the model boundary is a proxy for the flux of water moving vertically to the Ogallala Aquifer in the screening model. No flow conditions also exist within the model domain corresponding to observed dry areas in Zone 11 and in the southeast area of the model domain. These are consistent with the *Groundwater RFIR* interpretation of perched groundwater conditions in these areas (Stoller, 2004b).

General Head Boundary

Specified head and specified flux boundaries can be simulated as a head-dependent flux across the model's outer boundary allowing water to be supplied to a boundary cell in the modeled area at a rate proportional to the current head difference between a "source" or "sink" of water outside the modeled area and the boundary cell. This type of boundary condition is called a general head boundary (GHB). The GHB is generally a more robust boundary condition than the constant head boundary because the combination of the specified head and conductance allows some level of control over the head and the flow at the boundary. The location of the GHB cells around the model domain is also presented in Figure A-15. In the screening model of perched groundwater, the thin saturated thickness at the edge of the model was simulated everywhere with a head equal to 0.5 ft above the bottom elevation of the model and a conductance term of 15 ft^2 per day. This conductance term was developed through trial and error matching of the volumetric flux leaving the model area that was computed using the 3D BIOF&T3D model in the southeast corner of the SLM screening model (45 gallons per minute) to the documented volumetric flux (44 gpm) leaving the same area vertically in the Baseline HHRA FTM (BWXT Pantex/SAIC, 2006). This process is discussed further in the following subsections.

A.2.4.1.7 *Calibration Targets and Goals*

The calibration targets were chosen to be the measured June 2003 water levels and the volumetric flux leaving the southeast corner of the FTM model area as documented in the Baseline HHRA (BWXT Pantex/SAIC, 2006). The measured June 2003 water levels provide a realistic set of head targets to evaluate model calibration. The calculated flux in the southeast area of the model, in the absence of any measured flux terms from the perched groundwater, provides a method to ensure consistency between this model and the FTM used to assess risk at Pantex Plant.

Head Targets

The screening model was calibrated against the June 2003 water levels, which account for approximately 3 years of operation of the pump and treat system at Pantex Plant as presented in Table A-5. The 80 target water levels and model-computed water levels are tabulated and compared in Table A-6. The simulated water levels match very well with the observed water levels. The error in the simulated water levels ranges from -5.18 ft to 5.07 ft, with an absolute residual mean error (AME) of 1.78 ft. The correlation coefficient (R^2) of the observed versus measured water levels is 0.987 . The location and magnitude of the targets are plotted in Figure A-16.

Flux Targets

Figure A-16 also depicts the area of qualitative flux calibration in the southeast area of the model. The Baseline HHRA (BWXT Pantex/SAIC, 2006) documented a volumetric flux from the perched groundwater across the FGZ in this area at approximately 44 gallons per minute. The screening model shows a volumetric flux rate of 45 gallons per minute out of the GHB cells in this same area, which supports the use of the flux out of the GHB cells as a proxy for the water moving vertically out of the perched groundwater in the BIOF&T3D subsurface model for the same area.

Table A-5. Pump and treat System Pumping Rates Assigned in Model (3-year simulation)

Well ID	Existing System Assigned Pumping Rates (gpm, (-) extraction, (+) injection)
INJ-1	85.0
INJ-2	52.3
INJ-3	15.6
INJ-4	0.2
INJ-5	0.4
INJ-6	4.2
INJ-7	22.0
INJ-8	2.1
INJ-9	6.3
PTX06-EW-1	-25.2
PTX06-EW-10	-2.6
PTX06-EW-11	-1.0
PTX06-EW-12	-7.0
PTX06-EW-13	0.0
PTX06-EW-14	0.0
PTX06-EW-15	-1.2
PTX06-EW-16	-17.6
PTX06-EW-17	-3.2
PTX06-EW-18	-2.4
PTX06-EW-19	-2.0
PTX06-EW-2	-22.6
PTX06-EW-20	-0.8
PTX06-EW-21	-3.7
PTX06-EW-22	-4.4
PTX06-EW-23	-5.9
PTX06-EW-24	-1.6

Table A-5. Pump and treat System Pumping Rates Assigned in Model (continued)

Well ID	Existing System Assigned Pumping Rates (gpm; (-) extraction, (+) injection)
PTX06-EW-25	-3.7
PTX06-EW-26	-6.1
PTX06-EW-27	-3.7
PTX06-EW-28	-0.4
PTX06-EW-29	-1.6
PTX06-EW-3	-21.4
PTX06-EW-30	-2.2
PTX06-EW-31	-2.8
PTX06-EW-32	-3.7
PTX06-EW-33	-2.3
PTX06-EW-34	-3.8
PTX06-EW-35	-0.1
PTX06-EW-36	-3.1
PTX06-EW-37	-0.6
PTX06-EW-38	-0.9
PTX06-EW-39	-0.4
PTX06-EW-4	-15.1
PTX06-EW-40	-0.1
PTX06-EW-41	-0.6
PTX06-EW-42	-0.7
PTX06-EW-43	-2.7
PTX06-EW-44	-2.3
PTX06-EW-45	-1.8
PTX06-EW-46	-2.7
PTX06-EW-47	-0.2
PTX06-EW-48	-3.8
PTX06-EW-49	-1.5
PTX06-EW-5	-0.6
PTX06-EW-6	-2.2
PTX06-EW-7	-10.6
PTX06-EW-8	0.0
PTX06-EW-9	-1.4

Table A-6. June 2003 Calibration Statistics

Well ID	Observed Head (ft)*	Computed Head (ft)	Residual (ft)**
PTX06-1045	3244.2	3246.82	-2.62
PTX06-1046	3245.1	3244.71	0.39
PTX06-1015	3246.4	3249.24	-2.84
PTX06-1047A	3246.7	3244.32	2.38
PTX06-1031	3246.9	3247.48	-0.58
PTX06-1037	3247.1	3249.52	-2.42
PTX06-1036	3251.4	3253.43	-2.03
PTX06-1030	3253.3	3254.83	-1.53
FPOP-Z9-MW-02	3254.4	3258.94	-4.54
FPOP-Z9-MW-04	3255.6	3256.15	-0.55
FPOP-Z9-MW-05	3258	3258.22	-0.22
FPOP-Z9-MW-06	3258.3	3258.92	-0.62
PTX06-1017	3259.4	3259.24	0.16
PTX06-1014	3260	3259.24	0.76
FPOP-Z9-MW-03	3260.5	3261.56	-1.06
PTX06-1042	3263	3259.77	3.23
PTX07-1Q02	3263.1	3266.53	-3.43
PTX06-1052	3263.2	3261.60	1.60
PTX07-1Q01	3263.4	3266.48	-3.08
PTX06-1035	3265.2	3267.57	-2.37
PTX07-1Q03	3265.6	3267.73	-2.13
PTX08-1009	3265.9	3267.15	-1.25
PTX06-1005	3265.9	3270.24	-4.34
PTX06-1085	3266.1	3269.51	-3.41
PTX06-1012	3267.6	3269.12	-1.52
PTX08-1008	3269.2	3269.69	-0.49
PTX06-1053	3269.3	3267.61	1.69
PTX06-1087	3270.1	3272.68	-2.58
PTX08-1005	3271	3271.09	-0.09
PTX10-1008	3271.3	3273.76	-2.46
PTX10-1007	3271.3	3274.42	-3.12
PTX06-1041	3272	3270.93	1.07
PTX06-1040	3272.6	3272.59	0.01
PTX08-1006	3272.9	3272.29	0.61
PTX06-1011	3273.1	3274.18	-1.08
PTX06-1088	3273.7	3275.21	-1.51
PTX06-1006	3275.2	3275.07	0.13
PTX08-1003	3275.4	3277.87	-2.47
1114-MW1	3275.7	3276.11	-0.41

Table A-6. June 2003 Calibration Statistics (continued)

Well ID	Observed Head (ft)*	Computed Head (ft)	Residual (ft)**
PTX06-1039A	3275.8	3274.12	1.68
1114-MW2	3275.9	3276.11	-0.21
1114-MW4	3275.9	3275.51	0.39
1114-MW3	3276	3276.11	-0.11
PTX06-1069	3277.8	3275.76	2.04
PTX08-1007	3278.3	3279.94	-1.64
PTX06-1049	3278.5	3280.99	-2.49
PTX06-1007	3279.9	3281.67	-1.77
PTX06-1077A	3282.2	3283.25	-1.05
PTX06-1010	3284.3	3282.59	1.71
PTX06-1008	3284.4	3288.36	-3.96
PTX06-1003	3284.4	3289.58	-5.18
PTX06-PZ02	3287.6	3289.51	-1.91
PTX06-PZ01	3287.7	3288.41	-0.71
PTX06-1002A	3289.2	3290.12	-0.92
PTX06-PZ03	3290.1	3290.28	-0.18
OW-WR-45	3290.3	3289.16	1.14
PTX10-1014	3291.1	3289.90	1.20
PTX10-1013	3292.3	3289.90	2.40
PTX07-1O06	3292.8	3291.41	1.39
PTX06-1001A	3293	3291.25	1.75
PTX06-PZ04	3295.2	3293.65	1.55
PTX06-1013	3296.1	3295.20	0.90
PTX07-1P03	3296.4	3294.29	2.11
PTX07-1P06	3296.8	3294.47	2.33
PTX07-1P01	3297.6	3296.30	1.30
PTX07-1O04	3297.7	3296.99	0.71
PTX07-1O05	3298.1	3293.78	4.32
PTX07-1P05	3298.2	3296.25	1.95
PTX07-1O01	3298.3	3298.39	-0.09
PTX07-1O02	3298.7	3295.05	3.65
PTX07-1P04	3299	3297.86	1.14
PTX06-1023	3300.7	3298.63	2.07
PTX06-1050	3301.2	3296.13	5.07
PTX07-1P02	3301.3	3299.20	2.10
PTX08-1002	3301.3	3299.82	1.48
PTX07-1O03	3301.6	3300.02	1.58
PTX08-1001	3302.8	3301.25	1.55
OW-WR-19	3305.6	3301.80	3.80

Table A-6. June 2003 Calibration Statistics (continued)

Well ID	Observed Head (ft)*	Computed Head (ft)	Residual (ft)**
PTX06-1048A	3305.9	3302.21	3.69
OW-WR-38	3307	3306.42	0.58
Coordinates Texas State Plane North NAD 83			
Residual Mean Error (RME)			-0.09 ft
Residual Standard Deviation (STD)			2.17 ft
Sum of Squared Residuals (RSS)			378.55 ft^2
Absolute Residual Mean Error (AME)			1.78 ft
Minimum Residual			-5.18 ft
Maximum Residual			5.07 ft
Range in Target Head Values			62.80 ft
STD/Range in Target Head Values			3.5%

*June 2003measured water levels

** (-) residuals indicate a simulated water level higher than the measured water level, (+) residuals indicate a simulated water level less than the measured water level

A.2.4.1.8 Water Balance

Table A-7 presents the results of the water balance of the transient solution corresponding to the June 2003 calibration time frame. The water balance error at the June 2003 time frame is less than 2%. The majority of the water mass in the system is introduced from recharge and is exiting at the GHB cells surrounding the model.

Table A-7. Mass Balance

Source/Sink	Transient Solution at June 2003		
	INFLOW ft^3/day	OUTFLOW ft^3/day	NET ft^3/day
Storage	25238.73	23795.20	1444
Wells	36207	39286	-3079
General Head Boundary	114	34280	-34166
Recharge	34150	0	34150
Total	95709.7	97361.4	-1652
%Error		1.696%	

A.3 SCREENING MODEL EVALUATION

The screening level model provides a consistent framework for comparison of different alternatives under consideration for perched groundwater remediation. This model is a single layer model possessing a lower no-flow boundary and lateral general head boundaries. This means the model does not calculate leakage of perched groundwater across the lower model boundary. Therefore, the model does not calculate the spatial, vertical flux of perched groundwater across the FGZ to the underlying Ogallala Aquifer. This calculation has been completed for the variably-saturated flow and transport modeling within the BIOF&T3D site-wide and focused transport models as part of the risk assessment calculations, but has not been done for the evaluation of the many alternatives investigated here. The screening level

model provides the necessary resolution to distinguish the most effective remedial strategies presented in this CMS/FS in a timely manner.

A.3.1 Definition of Evaluation Metrics

The screening level model calculates the lateral flux of perched groundwater across the general head boundaries, which is analogous to the vertical flux of perched groundwater across the FGZ to the underlying Ogallala Aquifer. By assuming the lateral flux out of the model is equal to the perched groundwater flux to the Ogallala Aquifer (as was shown to be similar in magnitude in Section A.2.4.1.7), alternatives can be evaluated and compared based upon the change in water or mass flux leaving the lateral model boundaries. Again, the screening level model is not intended for calculation of spatial vertical flux across the FGZ beneath the footprint of the perched groundwater, nor time to remediate the perched groundwater. The screening level uses the same hydraulic conductivity field and recharge rates as the BIOF&T3D variably saturated flow and transport model used in the risk assessment. Further, the calculated water flux out of the screening level models matches the flux migrating across the FGZ calculated by the variably saturated flow and transport model. Therefore, the lateral flux across the general head boundaries in the screening level model provides a relative measure of the RDX and volumetric water flux to the underlying Ogallala Aquifer and is the primary metric for evaluation of different potential alternatives.

The general head boundaries that ring the simulated perched groundwater flow system have been divided into segments (referred to as reaches) for further refinement of the alternatives evaluation as shown in Figure A-15 and described below:

- **Reach 0:** Represents the entire simulated lateral extent of the perched groundwater flow system with the exception of Reaches 1 through 4; corresponds to the total predicted water and mass flux out of the perched groundwater flow system along southern boundary west of Reach 1, along the western model boundary, and along the northern and eastern model boundaries north of Reach 4.

- **Reach 1:** Occurs along the southern boundary (lateral extent) of perched groundwater flow system, corresponding to the location where risk assessment modeling efforts predicted the initial and most significant break through of impacted perched groundwater across the FGZ; Reach 1 is the most critical reach for comparison of RDX mass flux and volumetric water flux out of the perched groundwater among the various scenarios.

- **Reach 2:** Occurs east of and adjacent to Reach 1, corresponding to the southeast-most extent of the perched groundwater flow system.

- **Reach 3:** Occurs north of and adjacent to Reach 2 along the eastern boundary (lateral extent) of perched groundwater east of Zone 12.

- **Reach 4:** Occurs north of and adjacent to Reach 3 along the eastern boundary (lateral extent) of perched groundwater northeast of Zone 12 and southeast of Playa 1.

Each alternative modeled can then be compared based upon the predicted water and mass flux leaving the lateral boundaries of the perched groundwater flow system, either for the system as a whole or for one or more individual reach. As an initial screening of the alternatives modeled, the following metrics were tabulated and used to compare and rank the alternatives:

- RDX represents the primary risk driver and was the only constituent used in the screening level model fate and transport evaluation of alternatives. In addition to being the primary risk driver, the extent of RDX impacted perched groundwater spatially encompasses the locations of other constituents in perched groundwater identified as risk drivers in the risk assessment.

- Predicted cumulative water volumetric flux and RDX mass flux for each reach over time was tabulated.

- Predicted instantaneous water volumetric flux and RDX mass flux for each reach over time was tabulated.

- Each alternative simulated in the screening level model is ranked based upon the relative reduction in RDX mass flux out of the model (the lower the mass flux out, the higher the ranking).

- Average concentration exiting reaches over time calculated from the instantaneous water and RDX mass exiting each reach.

The evaluation completed here focused on the relative reduction of mass flux across the lateral boundaries of the simulated perched groundwater flow system. An initial simulation comparable to the BRA effort was complete using the screening level model to provide both a baseline for comparison against the risk assessment results, and a baseline for comparison of each alternative evaluated.

A.3.2 Alternative Test Accounting

Thirty-eight, separate remedial scenarios were simulated within the screening model for comparison among each other and to the Baseline HHRA RDX transport simulations. The scenarios can generally be grouped into five major categories, from which several smaller perturbations were evaluated (Table A-8). These five major groups are:

- **Baseline Human Health Scenarios:** These scenarios comprise simulations in which no pump and treat system is operative over the 30-year life span of an expected remediation system. Models were conducted in this flow environment that evaluated the inclusion of reactive transport (inclusion of retarded contaminant flow and a degradation half-life) and reduced recharge at the ditches and playas.

- **Existing System Scenarios:** These scenarios comprise simulations in which the existing extraction system is operative over the 30-year life span of an expected remediation system. All models in this category were conducted with the historical average pumping rate applied at existing wells only. The other various components evaluated in this set of simulations included the inclusion and exclusion of injection of water in the existing injection wells, reactive and non reactive transport, reduced recharge at ditches and playas, and the extension of the period of operation of the existing extraction system to 60 years of operation.

- **Horizontal Well Scenarios:** These scenarios comprise simulations in which the placement of one or more horizontal wells in key areas of the model domain are supplemental to the operation of the existing extraction system over the 30-year life span of an expected remediation system. The effects of a horizontal well were simulated through the use of the drain cell boundary condition. All models in this category were conducted with the historical average pumping rate applied at existing wells. The other various components evaluated in this set of simulations included the

application and exclusion of injection of water in the existing injection wells, reactive and non reactive transport, reduced recharge at ditches and playas, and the extension of the period of operation to 60 years.

- **Vertical Extraction Well Scenarios:** These scenarios comprise simulations in which the placement of lines of vertical wells in key areas of the model domain are supplemental to the operation of the existing extraction system over the 30-year life span of an expected remediation system. All models in this category were conducted with the historical average pumping rate applied at existing wells. The other various components evaluated in this set of simulations included the application and exclusion of injection of water in the existing injection wells, reduced recharge at ditches and playas, and the extension of the period of operation to 60 years.

- **Enhanced Decay Scenarios:** These scenarios comprise simulations in which the placement of zones with high rates of decay spaced approximately at locations of 10-year travel times throughout the RDX plume from the source areas to the boundary of the model.

Table A-8. Model Accounting Summary

Baseline Human Health Scenarios							Cumulative Flux Exiting GHB		Peak Instantaneous Flux
Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	RDX (kg)	Water (million gallons)	RDX (kg/year)
Baseline Human Health Scenarios									
1	MSPerched_20051108D_TRB	No	No	No	Yes	Baseline HHRA FTM	3,368	28,596	60.94 kg/Year (at T=5 Years)
2	MSPerched_20051108E_TRB	Yes	No	No	Yes	Baseline HHRA FTM with retardation and decay	2,773	28,596	68.70 kg/Year (at T=10 Years)
3	MSPerched011306	Yes	No	No	No (1)	MSPerched_20051108E_TRB with reduced recharge at Playas and Ditches	2,449	12,522	66.38 kg/Year (at T=10 Years)
4	MSPerched_20051127B_TRB	No	No	No	No (1)	Model MSPerched_20051108D_TRB with reduced recharge at Playas and Ditches	3,022	12,522	60.49 kg/Year (at T=5 Years)
Existing System Scenarios									
5	MSPerched_20051108B_TRB	Yes	Yes	Yes	Yes	Base model evaluation of existing system pumping, injection and reactive transport	2,015	28,482	58.86 kg/Year (at T=7 Years)
6	MSPerched_20051127A_TRB	Yes	Yes	Yes	No (1)	Model MSPerched_20051108B_TRB with reduced recharge at Playas and Ditches	1,777	12,496	54.10 kg/Year (at T=5 Years)
7	MSPerched_20051108C_TRB	No	Yes	Yes	Yes	Base model evaluation of existing system pumping, injection and nonreactive transport	2,380	28,484	54.11 kg/Year (at T=5 Years)
8	MSPerched_20051122B_TRB	Yes	Yes	No	Yes	Model MSPerched_20051108B_TRB without injection in stress period 2	995	26,772	40.97 kg/Year (at T=5 Years)
9	MSPerched_20051122C_TRB	No	Yes	No	Yes	Model MSPerched_20051108C_TRB without injection in stress period 2	2,028	26,772	49.76 kg/Year (at T=5 Years)
10	MSPerched_20051127C_TRB (2)	No	Yes	Yes	Yes	Model MSPerched_20051108c_TRB with 60 years of active remediation	1,885	28,390	54.87 kg/Year (at T=10 Years)

Table A-8. Model Accounting Summary (continued)

Baseline Human Health Scenarios							Cumulative Flux Exiting GHB		Peak Instantaneous Flux
Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	RDX (kg)	Water (million gallons)	RDX (kg/year)
11	MSPerched_20051127D_TRB [2]	Yes	Yes	Yes	Yes	Model MSPerched_20051108B_TRB with 60 years of active remediation	1,885	28,390	54.87 kg/Year (at T=10 Years)
12	MSPerched121205a [2]	Yes	Yes	No	Yes	Model MSPerched1127D_TRBb without injection in stress period 2, extended pumping to 60 years	831	25,523	40.97 kg/Year (at T=5 Years)
Horizontal Well Scenarios									
13	MSPerched110805b	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 10	1,898	26,476	54.80 kg/Year (at T=10 Years)
14	MSPerched110805c	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 11	1,336	27,583	49.93 kg/Year (at T=5 Years)
15	MSPerched110905a	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 12	1,293	27,589	33.32 kg/Year (at T=5 Years)
16	MSPerched110905b	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 13	1,820	28,297	54.57 kg/Year (at T=5 Years)
17	MSPerched110905c	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 14	1,323	28,223	30.74 kg/Year (at T=5 Years)
18	MSPerched110905d	Yes	Yes	Yes	Yes	2 horizontal wells simulated during stress period 2 with DRAIN REACHES 14 and 15	1,128	27,948	23.49 kg/Year (at T=0 Years)
19	MSPerched111005a	Yes	Yes	Yes	Yes	6 horizontal wells simulated during stress period 2 with DRAIN REACHES 10, 11,12,13,14 and 15	608	24,952	23.49 kg/Year (at T=0 Years)
20	MSPerched112905a	Yes	Yes	Yes	Yes	8 horizontal wells simulated during stress period 2 with DRAIN REACHES 10, 11,12,13,14,15, 20 and 21	567	24,100	23.49 kg/Year (at T=0 Years)
21	MSPerched112905b	Yes	Yes	Yes	Yes	10 horizontal wells simulated during stress period 2 with all DRAIN REACHES	584	21,336	23.77 kg/Year (at T=0 Years)
22	MSPerched_20051201a_TRB	Yes	Yes	No	Yes	Model MSPerched111005a without injection in stress period 2	518	24,419	23.49 kg/Year (at T=0 Years)

Table A-8. Model Accounting Summary (continued)

Baseline Human Health Scenarios							Cumulative Flux Exiting GHB		Peak Instantaneous Flux
Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	RDX (kg)	Water (million gallons)	RDX (kg/year)
23	MSPerched_20051202a_TRB	Yes	Yes	No	Yes	Model MSPerched112905a without injection in stress period 2	480	23,599	23.49 kg/Year (at T=0 Years)
24	MSPerched_20051202c_TRB	Yes	Yes	No	No (1)	Model MSPerched112905a with reduced recharge at Playas and Ditches, no injection during stress period 2	514	9,018	23.49 kg/Year (at T=0 Years)
25	MSPerched_20051202b_TRB	Yes	Yes	No	Yes	Model MSPerched112905b , no injection during stress period 2	497	20,834	23.77 kg/Year (at T=0 Years)
26	MSPerched121205b (2)	Yes	Yes	No	Yes	Model MSPerched1201A_TRBb without injection in stress period 2, extended pumping and horizontal wells to 60 years	396	22,479	23.54 kg/Year (at T=0 Years)
Vertical Extraction Well Scenarios									
27	MSPerched111405b	Yes	Yes	Yes	Yes	8 lines of extraction wells located throughout the RDX plume	192	26,717	23.49 kg/Year (at T=0 Years)
28	MSPerched111405c	Yes	Yes	Yes	Yes	7 lines of extraction wells located throughout the RDX plume	358	26,788	23.49 kg/Year (at T=0 Years)
29	MSPerched111405d	Yes	Yes	Yes	Yes	6 lines of extraction wells located throughout the RDX plume	501	26,839	23.49 kg/Year (at T=0 Years)
30	MSPerched111405e	Yes	Yes	Yes	Yes	5 lines of extraction wells located throughout the RDX plume	1,186	27,469	48.47 kg/Year (at T=5 Years)
31	MSPerched111405f	Yes	Yes	Yes	Yes	4 lines of extraction wells located throughout the RDX plume	1,290	27,534	51.70 kg/Year (at T=5 Years)
32	MSPerched111405g	Yes	Yes	Yes	Yes	3 lines of extraction wells located throughout the RDX plume	1,458	27,653	53.70 kg/Year (at T=5 Years)
33	MSPerched111405h	Yes	Yes	Yes	Yes	2 lines of extraction wells located throughout the RDX plume	1,629	27,826	54.18 kg/Year (at T=5 Years)
34	MSPerched111405i	Yes	Yes	Yes	Yes	1 lines of extraction wells located throughout the RDX plume	1,815	28,059	54.62 kg/Year (at T=5 Years)

Table A-8. Model Accounting Summary (continued)

Baseline Human Health Scenarios							Cumulative Flux Exiting GHB		Peak Instantaneous Flux
Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	RDX (kg)	Water (million gallons)	RDX (kg/year)
35	MSPerched120105a	Yes	Yes	No	Yes	Model MSPerched11405b without injection in stress period 2	161	26,015	23.49 kg/Year (at T=0 Years)
Enhanced decay Scenarios									
36	MSPerched_20051221b_TRB (3)	Yes	No	No	Yes	Biodecay amendment (T1/2=10 days) applied for 30-years. Base model MSPerched_20051108E_TRB	489	28,411	26.67 kg/Year (at T=5 Years)
37	MSPerched_20051222a_TRB (3)	Yes	Yes	Yes	Yes	Biodecay amendment (T1/2=10 days) applied for 30-years. Base model MSPerched_20051108B_TRB	393	28,172	23.46 kg/Year (at T=5 Years)
38	MSPerched_20060419b_TRB (3)	Yes	No	No	Yes	Biodecay amendment (T1/2=10 days) applied for 30-years in focused area.	646	28,284	23.46 kg/Year (at T=0 Years)

Unless otherwise noted, a model is composed of 4 stress periods:
Stress Period 1 = 3 years (model calibration; always includes historical pumping and injection)
Stress Period 2 = 30-years (pumping/Injection, where applicable, and constant RDX source applied)
Stress Period 3 = 20 years (constant RDX source applied)
Stress Period 4 = 250 years

Reactive transport assumes an RDX K_d =0.171 L/kg and an RDX degradation half-life of 25 years.

Historical extraction and injection rates presented in Table A-5.

(1) Recharge reduced by 10x at Playas and Ditches

(2) Model comprises 5 stress periods to account for an additional 30-years of pumping/injection:
Stress Period 1 = 3 years (model calibration; always includes historical pumping and injection)
Stress Period 2 = 30-years (pumping/Injection, where applicable, and constant source applied)
Stress Period 3 = 20 years (pumping/Injection, where applicable, and constant source applied)
Stress Period 4 = 10 years (pumping/Injection)
Stress Period 5 = 240 years

(3) Model stress periods are spread across three model stages to accommodate a time-varying RDX half-life (Each model stage is initiated with the output of the last).

Not all of the 38 simulations conducted as part of the screening evaluation are presented in detail in the remainder of this Appendix; however, all 38 scenarios are documented in Attachment 1A for completeness. Only the most illustrative or promising alternative simulations within each of the five main groups of alternatives are presented in this Appendix. These key screening model alternatives are described in the following section.

A.4 Key Screening Model Alternatives

This section details the most important simulations within each of the five groups of models. The key screening model alternatives are singled out here due to their close reproduction of HHRA simulations, their featuring of a particular remedial alternative in a unique fashion, or high performance within a group of simulations with regard to the lateral flux of RDX and water across the general head boundaries. As described in Section 3.1, the latter are the primary evaluation metrics in the use of the screening level models. Of the 38 screening model alternative simulations conducted in support of this CMS/FS, 12 are described here in detail. Predicted water and RDX mass removal from active remediation was tabulated and graphed in Figures A-17 through A-20 for key screening alternatives and was used as a secondary criterion for evaluation of alternatives.

A.4.1 Reproduction of Applicable Baseline HHRA Simulations

To provide a consistent basis for relative ranking of modeling alternatives, the Baseline HHRA simulations were first simulated in the screening model. Runs #1 through #4 were perturbations upon the basic HHRA FTM RDX simulations. Run #1 was the nonreactive simulation, conservative tracer simulation. Run #2 included the effects of reactive transport (sorption and degradation) through inclusion of a specified partition coefficient (K_d) and half-life term.

Run #3 and Run #4 included a reduction in the specified recharge application at all ditches and playas within the model domain by a factor of 10. Run #3, which tests the impacts of reduced recharge in a reactive transport model, and Run #4, which tests the impacts of reduced recharge in a nonreactive transport model. Of the Reduced recharge scenarios, only Run #3 is presented in detail here because the nonreactive Run #4 was conducted for comparison purposes only. The reduced recharge scenarios represent conditions in which engineering controls or institutional controls may be implemented to limit the amount of water infiltrating to the perched groundwater.

A.4.1.1 Run #1: Baseline Nonreactive Transport

The potential for future health impacts from perched groundwater was evaluated in the human health risk assessment (BWXT Pantex/SAIC, 2006) through predictive modeling. Flow and transport predictions were completed under nonreactive conditions. Under nonreactive conditions, only advection, dispersion, and diffusion are included in the transport calculations. The effects of sorption and degradation are not included. Using nonreactive conditions for future predictions is thought to be conservative with respect to risk calculations as it tends to over estimate future predicted concentrations and underestimate travel times. Evidence of contaminant degradation observed in groundwater analytical results and published sorption coefficients and degradation rates that span conditions observed at Pantex Plant support the conservative nature of nonreactive transport predictions. This conservative approach was implemented at the HHRA stage to ensure risks for COPCs were not underestimated. For comparison with risk assessment results and to establish a baseline within the screening level model, the nonreactive baseline risk assessment simulation is reproduced within the screening level model.

The nonreactive baseline risk assessment simulation is identified as Run #1 (Model Identifier = MSPerched_20051108D_TRB) in Table A-8. Table A-8 indicates that Run #1 is specified as:

- Nonreactive contaminant transport (the effects of sorption and degradation are not included)
- No active extraction system is in operation
- No active injection system is in operation
- Normal rates of recharge (same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* [BWXT Pantex/SAIC, 2004] and in Appendix N of the *Baseline HHRA Report* [BWXT Pantex/SAIC, 2006]).

As noted above, the transport simulation includes the effects of dispersion and diffusion only (nonreactive).

A.4.1.1.1 *Run #1 Results*

RDX transport was simulated for a period of 300-years. The volume of water and mass of RDX migrating across each reach are tabulated over time in Table A-9, and provide a baseline for evaluation of other alternatives examined within this CMS/FS. The results over time may also be compared against the Baseline HHRA (BWXT Pantex/SAIC, 2006) results.

Table A-9. Run #1 Reach Reports

Run #1 Model MSPerched_20051108D_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	2005	618	178	195	209	3206
50	3207	1021	301	317	312	5158
100	6172	1998	597	606	541	9915
150	9100	2961	888	888	761	14599
200	12019	3921	1178	1169	980	19267
250	14936	4880	1469	1449	1198	23932
300	17852	5840	1759	1729	1416	28596
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	8	1050	369	472	443	2342
50	9	1148	426	562	565	2710
100	9	1296	504	709	682	3199
150	10	1311	548	770	710	3349
200	10	1313	559	775	711	3368
250	11	1313	559	775	711	3368
300	11	1313	559	775	711	3368

Table A-9 shows the greatest volume of perched groundwater (17.85 billion gallons) migrates across Reach Zero over the 300-year simulation time. As described in Section 3.1, Reach 0 covers the vast

majority of the perched groundwater perimeter. Reaches One through Four represent the area of flux of water and mass migration in the southeast area where perched groundwater impacts offsite occur and are predicted to reach the Ogallala Aquifer in the absence of remediation. Other than Reach Zero, Reach 1 has the highest flux of water, totaling 5.84 billion gallons over the 300-year period of simulation. Volumetric water fluxes are similar over Reaches Two and Three, having 1.76 and 1.73 billion gallons, respectively, over 300-years of simulation. 1.42 billion gallons of perched groundwater is transmitted across Reach 4 over the 300-year period. The most significant RDX mass flux occurs across Reach 1 (1,313 kg) followed by Reach 3 (774 kg), Reach 4 (711 kg), and Reach 2 (559 kg) over the 300-year period of simulation. Reach Zero had negligible mass flux, as expected. These results are consistent with the baseline risk assessment calculations (BWXT Pantex/SAIC, 2006), which predicted the greatest impact to the Ogallala Aquifer beneath the Reach 1 area, with lesser impacts predicted beneath Reaches Two through Four (again, these impacts are in the absence of any remediation and do not account for sorption or degradation processes).

The data in Table A-9 show the majority of RDX mass migrates across each reach within the first 30-years and only marginally increases over time after 100 to 150 years while the flux of water continues at a relatively constant rate. Among the results presented over time, the results for the first 30-years are more directly reliable. The longer time periods may not capture well the effects of the residual RDX in the vadose zone, FGZ, and the non-kinematic pore water that are likely occurring the long-term future. These results are shown for information and comparison only, and do not represent as reliable a prediction of future mass fluxes as do the earlier time results. This same information is shown graphically in four charts shown in Figure A-21. The cumulative water volume over time (Figure A-21, lower left) shows a constant increase over time for each reach. The cumulative mass (Figure A-21, upper left) increases sharply in the first 30-years then gradually flattens after approximately 150 years, indicating that the SLM model indicates that the vast majority of RDX mass has migrated out of the simulated perched groundwater flow system within the first 150 years.

The instantaneous mass flux (Figure A-21, upper right) depicts the mass flux in kg/year migrating across each reach. The instantaneous mass flux shows a sharp increase followed by a sharp decrease in the first 50 years of simulation, which is indicative of areas of higher perched groundwater contamination adjacent to the perched groundwater extent migrating across the reaches. From 50 to 150 years, the instantaneous mass flux gradually decreases as the more distal and lower concentration portions of the RDX plume migrate to the perched groundwater periphery.

The instantaneous water flux (Figure A-21, lower right) depicts the volume of water in gallons per minute migrating across each reach. Reaches One through Four show increases in the first 20 to 30-years followed by slight declines (through simulation time of 100 to 150 years) before becoming nearly steady over the last 100 to 150 years of the simulation. Reach Zero shows a sharp decline in instantaneous water flux over the first 20 to 30-years, and then follows a similar pattern as the other four reaches. The pattern of water flux across the reaches is reflective of transient response of the perched groundwater flow system over time. The decline predicted over Reach Zero results represents an overall reduction in perched groundwater levels as water levels equilibrate to post Pantex Plant conditions (reduction in recharge rates following discontinued discharges to ditches and playas; note initial water levels were taken at the end of the Pantex Plant operational period during which higher recharge rates prevailed beneath ditches and playas). The increase observed at Reaches One through Four represents the migration of perched groundwater from beneath areas of focused recharge (ditches and playas) to the lateral margins of the perched groundwater. The instantaneous water flux depicted over the last 100 to 150 years of simulation at all reaches depicts a quasi-steady state condition in which the volume of water exiting the perched groundwater flow system is equal to the amount of recharge entering the perched groundwater flow system.

A.4.1.1.2 *Run #1 Summary*

The RDX nonreactive simulation provides a baseline – or reference model results - for comparison of all other alternatives evaluated in the screening level model, and a means for comparison with the Baseline HHRA results (BWXT Pantex/SAIC, 2006). The screening level model and the risk assessment calculations used the same hydraulic parameters, the same source term and initial conditions for RDX. The initial heads used in the screening level model were calculated from the site-wide model documented in the *Baseline HHRA Report* (BWXT Pantex/SAIC, 2006). The calculated water flux out of the screening level model matches the calculated water flux across the FGZ determined in the risk assessment. The screening level model and the modeling completed for the risk assessment are in good agreement for perched groundwater flow conditions.

The baseline RDX simulation provides a metric for comparison of the effectiveness of different corrective measures. In the absence of remediation and under nonreactive transport conditions, 28.6 billion gallons of water will exit the perched groundwater flow system within the next 300-years. For purposes of this corrective measure, water leaving the perched groundwater flow system is assumed to migrate vertically across the FGZ to the underlying Ogallala Aquifer. In this same 300-year period, 3,368 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions. Concentrations of RDX will be higher at the beginning and lower at the end. Additional mass of RDX from the vadose and FGZ portions of the system will increase these mass flux estimates. This is true for the results reported below and well, and implicitly implied through the remainder of the text and results interpretation.

A.4.1.2 Run #2: Baseline Reactive Transport

The reactive baseline risk assessment simulation is identified as Run #2 (MSPerched_20051108E_TRB) in Table A-8. Run #2 represents the NA of RDX in the perched groundwater flow system. Table A-8 indicates that Run #2 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days, or an equivalent 25 year half-life] are included). The approach used to estimate the first order decay rate is discussed above. The actual biodecay processes are more complex than first order decay simplification, and are redox zone dependent.

- No active extraction system is in operation

- No active injection system is in operation

- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.1.2.1 *Run #2 Results*

RDX reactive transport was simulated for a period of 300-years. The volume of water and mass of RDX migrating across each reach are tabulated (Table A-10). The volume of water leaving each reach of the model is exactly the same as was calculated for Run #1, which is expected due the assignment of the same groundwater flow stresses; therefore, no further description is warranted.

The inclusion of sorption in the transport calculation results in a retardation factor of 2.1, meaning RDX migrates 2.1 times slower under reactive transport relative to the nonreactive baseline case. The inclusion of degradation results in a reduction of mass in the perched groundwater flow system. At the rate simulated, roughly one half the mass in the perched groundwater flow system degrades every 25 years.

The data in Table A-10 show significant differences between the baseline nonreactive simulation (Run #1) and Run #2. In Run #2, the total RDX mass exiting the perched groundwater drops from 3,368 kg (Run #1) in the baseline simulation to 2,773 kg (Run #2). The most significant changes in cumulative mass for the 300-year period of simulation occur at Reaches Two (559 kg to 250 kg), Three (774 kg to 445 kg), and Four (711 kg to 327 kg) when comparing Run #1 to Run #2. Reach 1 exhibited a higher overall cumulative mass exiting the perched groundwater with the inclusion of sorption and decay (1,313 kg to 1,737 kg). The inclusion of a partition coefficient in the transport simulation allowed for an accounting of the equilibrium RDX mass available in the soil to interact with the mass in the water. In the areas of the highest RDX concentrations in water (upgradient of Reach 1), this effectively adds more mass to the modeled system, which translates to a greater potential mass exiting the system through Reach 1.

Table A-10. Run #2 Reach Reports

Run #2 Model MSPerched_20051108E_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	2005	618	178	195	209	3206
50	3207	1021	301	317	312	5158
100	6172	1998	597	606	541	9915
150	9100	2960	209	888	761	14599
200	12019	3921	1178	1169	980	19267
250	14936	4880	1469	1445	1198	23932
300	17852	5840	1759	1729	1416	28596
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	3	1449	87	277	194	2011
50	4	1668	187	384	272	2515
100	4	1728	256	439	321	2749
150	4	1736	259	444	326	2770
200	4	1737	259	445	327	2773
250	4	1737	260	445	327	2773
300	4	1737	260	445	327	2773

This same information is shown graphically in four charts shown in Figure A-22. The cumulative water volume over time (Figure A-22, lower left) and instantaneous water flux (Figure A-22, lower right) are the same as shown in Figure A-21 for Run #1. The cumulative mass (Figure A-22, upper left) shows a steady increase over the first 50 to 75 years then gradually flattens indicating that nearly all mass has migrated out of the perched groundwater flow system within this 75 to 100 year period of time.

The instantaneous mass flux (Figure A-22, upper right) depicts the mass flux in kg/year migrating across each reach. The peak instantaneous mass flux has increased to a maximum of 68.7 kg/year in comparison to Run #1. The instantaneous mass flux shows a sharp increase in the first 10 years followed by gradual decrease through 100 years into the simulation.

A.4.1.2.2 Run #2 Summary

Run #2 incorporates the effects of sorption and degradation and represents NA of RDX. No active remediation was included in Run #2 past the 3 years of calibration simulation. The volume of water moving across each reach was identical to the baseline simulation (Run #1). In the absence of remediation and under reactive transport conditions, 28.6 billion gallons of water is simulated to exit the perched groundwater flow system within the next 300-years. In this same 300-year period, a total of 2,773 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a nonreactive baseline result of 3,368 kg. The peak instantaneous RDX mass flux out of the perched groundwater flow system increases from 60.9 kg/year in the Run #1 simulation to 68.7 kg/year under Run #2. Therefore, if no other measures are enacted, the mass flux of RDX out of the perched groundwater flow system is expected to decrease by a factor of 1.2 by naturally-occurring processes (assuming the parameters for sorption and degradation are representative).

A.4.1.3 Run #3: Baseline Reactive Transport with Reduced Playa and Ditch Recharge

Run #3 (MSPerched011306) the NA of RDX in the perched groundwater flow system with the superposition of a reduced recharge regime when compared to Run #1 and Run #2. Table A-8 indicates that Run #3 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- No active extraction system is in operation
- No active injection system is in operation
- Reduced rates of recharge. [This represents a ten-fold reduction in recharge rates in all areas of ditches and playas compared to "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006). Otherwise, interplaya recharge rates are unchanged.]

A.4.1.3.1 Run #3 Results

RDX reactive transport was simulated for a period of 300-years. The volume of water and mass of RDX migrating across each reach are tabulated (Table A-11). The volume of water leaving each reach of the model is highly reduced over time, which is expected due the assignment a much lower overall recharge rate in the model domain. The cumulative water exiting the model domain at 30-years and 300-years is 2.6 million gallons and 12.5 million gallons, respectively. This represents a 19% reduction in the volume of water exiting the perched groundwater model domain at 30-years of simulation and a 56% reduction at 300-years of simulation when compared to Runs #1 and #2. Therefore, the effects of an overall reduction in recharge to the perched groundwater system become more pronounced over time, but do not radically impact the system immediately.

Table A-11. Run #3 Reach Reports

Run #3 Model MSPerched011306						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1500	561	169	178	181	2591
50	2104	867	272	267	238	3749
100	3264	1483	484	425	319	5975
150	4198	1994	666	543	372	7773
200	5046	2463	837	646	417	9409
250	5857	2916	1003	743	460	10979
300	6653	3362	1168	838	502	12522
Cumulative Mass Across GHB Reaches (kg)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2	1373	77	250	163	1865
50	3	1567	156	330	207	2263
100	3	1618	215	370	231	2437
150	3	1621	218	372	233	2448
200	3	1622	218	373	233	2449
250	3	1622	218	373	233	2449
300	3	1622	218	373	233	2449

The data in Table A-11 show significant differences between the baseline reactive simulation Run #2 and Run #3. In Run #3, the total RDX mass exiting the perched groundwater drops from 2,773 kg (Run #2) in the baseline reactive simulation to 2,449 kg (Run #3). The most significant change in cumulative mass for the 300-year period of simulation occurs at Reach 1 (1,737 kg to 1,621 kg). The reduced recharge effects in mass flux also appear later in time, but are sustained over the 300-year simulation, so long-term cumulative RDX mass flux effects are greater than short-term effects.

This same information is shown graphically in four charts shown in Figure A-23. The cumulative water volume over time (Figure A-23, lower left) and instantaneous water flux (Figure A-23, lower right) are much different from Runs #1 (Figure A-21) and #2 (Figure A-22) from Run #3 (Figure A-23). The cumulative mass (Figure A-23, upper left) shows a steady increase over the first 50 to 100 years then gradually flattens indicating that nearly all mass has migrated out of the perched groundwater flow system within this 100-year period of time, which is consistent with Runs #1 and #2.

The instantaneous mass flux (Figure A-23, upper right) depicts the mass flux in kg/year migrating across each reach. The peak instantaneous mass flux has dropped to a maximum of approximately 66.4 kg/year in comparison to between 68.7 kg/year in Run #2. The instantaneous mass flux shows a sharp increase in the first 15 years followed by gradual decrease through 50 to 75 years into the simulation.

A.4.1.3.2 Run #3 Summary

Run #3 incorporates the effects of reduced recharge in the areas of playas and ditches, sorption, and degradation. No active remediation was included in Run #3. The volume of water moving across each reach was similar to Runs #1 and #2 in early time, but varied significantly in later time results. In the absence of remediation and under reactive transport conditions, 12.5 billion gallons of water is simulated

to exit the perched groundwater flow system within the next 300-years, as opposed to 28.6 billion gallons under normal recharge conditions. In this same 300-year period, a total of 2,449 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to the normal recharge, reactive baseline result of 2,773 kg. This is a reduction of approximately 12% of RDX mass cumulative mass flux over time. Therefore, if no other measures are enacted, the mass flux of RDX out of the perched groundwater flow system is expected to decrease by approximately 12% when implementing a recharge reduction plan when compared to the assumed current recharge conditions.

A.4.2 Existing System Scenarios

These runs comprise simulations in which the existing extraction system is operative over the 30-year life span of an expected remediation system. All runs in this category were conducted with the historical average pumping rate applied at existing wells only. The other various components evaluated in this set of simulations included the inclusion and exclusion of injection of water in the existing injection wells, reactive and non reactive transport, reduced recharge at ditches and playas, and the extension of the period of operation of the existing extraction system to 60 years of operation.

Of the existing system scenarios simulated, Run #5 and Run #8 are described in detail here. Both scenarios include reactive transport and normal recharge conditions. Run #5 represents the operation of the current extraction and injection system over 30-years of system operation. Run #8 eliminated re-injection during the 30-years of system operation, effectively reducing mobility by lowering hydraulic gradients. All other runs in this set of simulations are documented in Attachment 1A, but are not brought out in detail here.

A.4.2.1 Run #5: Reactive Transport with Extraction and Injection

Reactive transport is simulated in conjunction with the existing groundwater pump and treat system in Run #5 (MSPerched_20051108B_TRB) in Table A-8. Run #5 is representative of the NA (similar to Run #2) in combination with active groundwater pump and treat. The existing pump and treat system is simulated for a period of 30-years and includes the re-injection of treated groundwater back into the perched groundwater flow system. Groundwater withdrawal and re-injection rates for the 30-year period were based the average rates over 3 years of system operation from 2000 to 2003, and are presented in Figure A-6 and Table A-5.

Table A-8 indicates that Run #5 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- Active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.2.1.1 Run #5 Results

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system, including re-injection of treated groundwater, was operational. After 30-years, the pump and treat system was shut down, and only reactive transport (NA processes) was simulated for the remaining 270 years. The inclusion of sorption in the transport calculation results in a retardation factor of 2.1, meaning RDX migrates 2.1 times slower under reactive transport relative to the nonreactive baseline case. The inclusion of degradation results in a reduction of mass in the perched groundwater flow system. At the rate simulated, roughly one half the mass in the perched groundwater flow system degrades every 25 years.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-12). The volume of water leaving each reach of the model is similar to the baseline simulation (Run #2) with the total volume of water exiting the perched groundwater flow system through the GHB cells is calculated at 28.5 billion gallons.

Table A-12. Run #5 Reach Reports

Run # 5 Model MSPerched_20051108B_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2010	524	140	120	161	2955
50	3249	922	251	233	269	4923
100	6270	1919	552	530	509	9780
150	9210	2885	845	813	731	14483
200	12130	3845	1135	1094	950	19154
250	15048	4805	1425	1374	1168	23820
300	17964	5764	1715	1655	1386	28484
Cumulative Mass Across GHB Reaches (kg)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	3	1107	45	135	131	1421
50	7	1260	125	226	206	1822
100	4	1297	194	262	244	2001
150	4	1302	194	264	249	2012
200	4	1302	194	265	249	2014
250	4	1302	194	265	249	2015
300	4	1302	194	265	249	2015

Table A-12 shows the greatest volume of perched groundwater (17.96 billion gallons) migrates across Reach Zero over the 300-year simulation time, which is to be expected since this reach covers the majority of the perched groundwater perimeter. In the southeast area, Reach 1 has the highest flux of water, totaling 5.76 billion gallons over the 300-year period of simulation. Reaches Two and Three are similar, having 1.72 and 1.65 billion gallons, respectively. 1.39 billion gallons of perched groundwater is transmitted across Reach 4 over 300-years. Overall, Reach Zero shows a slight increase in total groundwater volume, while Reaches One through Four show slight decreases when compared to the baseline simulation results in Runs #1 and #2.

Overall, Run #5 with the operation of the groundwater pump and treat system, including re-injection, results in a reduction of 758 kg of RDX exiting the perched groundwater flow system relative to the reactive transport-only (Run #2 - NA) simulation. The most significant difference (436 kg reduction from Run #2 to Run #5) occurs across Reach 1 with smaller cumulative RDX mass reductions at Reaches Three and Four. The differences (between Run #2 and Run #5) in RDX cumulative mass flux results from the operation of the groundwater pump and treat system. Figure A-24 shows the same four charts for Run #5. The cumulative water volume exiting the perched groundwater flow system (Figure A-24, lower left) over time is similar to Runs #1 and #2. The cumulative RDX mass flux (Figure A-24, upper left) is similar to Run #2, but illustrates the reduction in cumulative mass flux out of Reaches One, Three, and Four when compared to the same chart on Figure A-22.

The instantaneous water flux (Figure A-24, lower right) and instantaneous RDX mass flux (Figure A-24, upper right) clearly depict the affects from the operation of the groundwater pump and treat system. The instantaneous water flux increases to just over 30 gpm for Reach 1 in Run #5 compared to 40 gpm for Runs #1 and #2, a reduction of roughly 10 gpm in water flux exiting the perched groundwater flow system. Similarly, the peak instantaneous RDX mass flux shows a reduction of approximately 7.5 kg/year at Reach 1 during the 30-year period of pump and treat system operation. Smaller magnitude reductions in instantaneous RDX mass flux are also apparent in Reaches Three and Four.

During the 30-year period of operation, the groundwater pump and treat system removes 2,561 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and can not migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system alters the perched groundwater flow field causing the observed changes in water and mass flux exiting the perched groundwater flow system.

A.4.2.1.2 Run #5 Summary

Run #5 incorporates the effects of the 30-years operation of the groundwater pump and treat system with reactive transport (sorption and degradation). The only difference between Run #2 and this simulation (Run #5) is the 30-years of groundwater pump and treat system operation, which results in a 758 kg reduction of RDX mass exiting the perched groundwater flow system. The volume of water moving across each reach was similar to the baseline simulation (Run #2) and totaled 28.5 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 2,015 kg of RDX is predicted to exit the perched groundwater flow system compared to a baseline reactive result of 2,773 kg. This is a reduction of approximately 27% of the cumulative RDX baseline reactive results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 58.9 kg/year under Run #5. Therefore, operation of the groundwater pump and treat system for a period of 30-years, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by about 27% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.2.2 Run #8: Reactive Transport with Extraction and No Injection

Reactive transport is simulated in conjunction with the existing groundwater pump and treat system (with no re-injection) in Run #8 (MSPerched_20051122B_TRB) from Table A-8. Run #8 is identical to Run #5 with the only exception being that re-injection of treated groundwater is removed from the simulation. The current pump and treat system was designed with re-injection of treated groundwater to permit flushing of impacted perched groundwater to the extraction wells for removal. Re-injection of treated groundwater helps maintain perched groundwater levels and flow directions in the area of the treatment system. Elimination of re-injection reduces the volume of groundwater flushed through the system, and

overall perched groundwater levels. This in turn reduces the vertical flow gradients across the FGZ as there will be less driving head remaining above the FGZ over time. Table A-8 indicates that Run #8 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- No active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.2.2.1 *Run #8 Results*

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system with no re-injection of treated groundwater, was operational. After 30-years, the pump and treat system was shut down, and only reactive transport (NA processes) was simulated for the remaining 270 years. Sorption and degradation are included as before in Runs #2 and #5.

The volume of water leaving each reach of the model is calculated at 26.8 billion gallons, which is a reduction of 1.8 billion gallons relative to the baseline simulation (and a reduction of 1.7 billion gallons relative to Run #5 where re-injection of treated groundwater was included in the calculations).

Table A-13 shows the greatest volume of perched groundwater (17.5 billion gallons) migrates across Reach Zero over the 300-year simulation time. In the southeast area, Reach 1 has the highest flux of water, totaling 5.1 billion gallons over the 300-year period of simulation. Reaches Two and Three are similar, having 1.5 and 1.4 billion gallons, respectively. 1.2 billion gallons of perched groundwater is transmitted across Reach 4 over 300-years. As noted above, the total cumulative water flux drops by 1.7 billion gallons relative to Run #5, in which the only difference was exclusion of re-injection. The most significant decrease occurs across Reach 1, which dropped by 650 million gallons.

Table A-13. Run #8 Reach Reports

Run #8 Model MSPerched_20051122B_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1915	238	97	62	88	2400
50	3014	409	141	85	117	3766
100	5848	1284	397	325	304	8158
150	8745	2236	685	602	519	12787
200	11658	3194	975	882	737	17445
250	14573	4153	1265	1162	955	22108
300	17489	5112	1555	1442	1173	26772
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	2	580	16	62	54	714
50	3	633	31	73	64	804
100	3	668	87	119	94	971
150	3	674	92	125	98	991
200	3	675	92	126	99	994
250	3	675	92	126	99	995
300	3	675	92	126	99	995

The decrease in water flux across the reaches translates directly into a reduction in the RDX mass flux across the reaches. The data in Table A-13 show significant differences between the baseline reactive simulation (Run #2) and Run #8. In Run #8, the total RDX mass exiting the perched ground drops from 2,773 kg (Run #2) in the baseline simulation to 995 kg (Run #8). The cumulative mass exiting the perched groundwater flow system in Run #8 (995 kg) is less than half the total from Run #5 (2,015 kg). The removal of re-injection clearly creates a depressed water table in the vicinity of the RDX plume, which served to stagnate the RDX plume and allow natural attention to act on the plume for a longer period of time.

Significant changes in cumulative mass for the 300-year period of simulation occur at Reaches One through Four when comparing baseline simulation results (Run #2) to Run #8 (Reach 1, 1,737 kg to 675 kg; Reach 2, 260 kg to 98 kg; Reach 3, 445 kg to 126 kg; and Reach 4, 327 kg to 99 kg).

The operation of the groundwater pump and treat system, excluding re-injection, results in a reduction of 1,020 kg of RDX exiting the perched groundwater flow system relative to Run #5, which included re-injection. Therefore, the elimination of re-injecting treated perched groundwater decreases predicted RDX mass flux by 1,020 kg over the 300-year period of simulation.

The cumulative and instantaneous flux of water and RDX across each of the reaches is depicted graphically in Figure A-25. The cumulative water flux (Figure A-25, lower left) is similar to results presented for previous simulations, but close examination reveals the decrease in cumulative water flux for each reach. The cumulative RDX mass (Figure A-25, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-25, upper right) decreases from about 41 kg/year to 2 to 3 kg/year coincident with the operation of the pump and treat

system. Following shut down of the system, the rate increases to nearly 3 kg/y around 50 years, then slowly declines to negligible rates (< 1 kg/y) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and a slight rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi-steady state rates between 100 to 150 years into the simulation.

During the 30-year period of operation, the groundwater pump and treat system removes 2,798 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and cannot migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 1.5 billion gallons (an average reduction of 9.4 gpm) over the 300-year period of simulation.

A.4.2.2.2 *Run #8 Summary*

Run #8 incorporates the effects of the 30-years operation of the groundwater pump and treat system with no re-injection and reactive transport (sorption and degradation). Run #8 is identical to Run #5 with the only exception being that re-injection of treated groundwater is removed from the simulation. The volume of water exiting the perched groundwater flow system dropped by 1.8 billion gallons relative to the baseline simulation (Run #1) and totaled 26.8 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 995 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline result of 2,773 kg. This is a reduction of 64% when compared to the cumulative RDX reactive baseline results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 41 kg/year under Run #8. Therefore, operation of the groundwater pump and treat system for a period of 30-years with no re-injection, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by a factor of 64% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.3 Horizontal Well Scenarios

These runs comprise simulations in which the placement of one or more horizontal wells in key areas of the model domain are supplemental to the operation of the existing extraction system over the 30-year life span of an expected remediation system. The effects of a horizontal well were simulated through the use of the drain cell boundary condition. All runs in this category were conducted with the historical average pumping rate applied at existing wells. The other various components evaluated in this set of simulations included the application and exclusion of injection of water in the existing injection wells, reactive and non reactive transport, reduced recharge at ditches and playas, and the extension of the period of operation to 60 years.

A total of 14 separate horizontal well scenarios were modeled as a part of this CMS/FS effort. Each of these were perturbations of the number of wells, operation of the existing extraction and/or injection system, and the reduction of recharge at playas and ditches (Table A-8). Of these 14 simulations, 4 are described in detail here as key runs. These 4 were selected based on high performance in relation the stated evaluation metrics and the featured perturbation simulated in the model. The four key runs detailed here include the simulation of the operation of 6 horizontal wells with no injection (Run #22), 8 horizontal wells with no injection (Run #23), 8 horizontal wells with no injection and reduced recharge (Run #24), and 10 horizontal wells with no injection (Run #25).

A.4.3.1 Run #22: Reactive Transport with Extraction, No Injection and Six Horizontal Wells

Reactive transport is simulated in conjunction with six horizontal wells (Figure A-26), and the existing groundwater pump and treat system (with no re-injection) from Run #22 (MSPerched_20051201A_TRB) in Table A-8. The addition of six horizontal wells in areas selected based on a combination of higher saturated thickness and/or high concentration of RDX in groundwater further serves to reduce driving head to the edges of the perched groundwater, thus reducing mass of RDX and volumetric water flux out of the perched zone. Table A-8 indicates that Run #22 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- Six horizontal wells
- No active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.3.1.1 Run #22 Results

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system with no re-injection of treated groundwater, was operational. Additionally, six horizontal wells extracted water from the perched groundwater during the 30-year remediation life cycle. After 30-years, the pump and treat system was shut down, and only reactive transport (NA processes) was simulated for the remaining 270 years. Sorption and degradation are included.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-14). The volume of water leaving each reach of the model decreases relative to the baseline simulations (Runs #1 and #2) with the total volume of water exiting the perched groundwater flow system calculated at 24.4 billion gallons, a reduction of 4.2 billion gallons relative to the baseline simulation.

Table A-14 shows the greatest volume of perched groundwater (15.9 billion gallons) migrates across Reach Zero over the 300-year simulation time. The addition of horizontal wells in areas upgradient of the flow path to Reach Zero served to reduce flow across Reach 1 by 1.9 billion gallons from Run #1. In the southeast area, Reach 1 has the highest flux of water, totaling 4.7 billion gallons over the 300-year period of simulation. Reaches Two and Three are similar, having 1.5 and 1.3 billion gallons, respectively. 1.0 billion gallons of perched groundwater is transmitted across Reach 4 over 300-years. The most significant decrease from Run #1 occurs across Reach Zero, which dropped by 1.9 billion gallons. Reach 1 showed a predicted drop of 1.2 billion gallons over the 300-year period of simulation. Reach 2 (290 million gallons), Reach 3 (410 million gallons), and Reach 4 (400 million gallons) exhibited lesser declines.

Table A-14. Run #22 Reach Reports

Run #22 Model MSPerched_20051201a_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1497	109	85	51	64	1806
50	2269	203	118	59	74	2723
100	4512	921	325	228	180	6165
150	7231	1823	598	484	370	10507
200	10107	2772	884	760	583	15105
250	13015	3729	1174	1039	800	19757
300	15930	4688	1464	1319	1018	24419
Cumulative Mass Across GHB Reaches (kg)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2	266	8	49	33	357
50	2	290	15	53	36	396
100	2	321	46	77	46	493
150	2	327	52	84	50	514
200	2	328	52	85	51	517
250	2	328	52	85	51	518
300	2	328	52	85	51	518

The decrease in water flux across the reaches translates directly into a reduction in the RDX mass flux across the reaches. The data in Table A-14 show significant differences between the baseline reactive simulation (Run #2) and Run #22. In Run #22, the total RDX mass exiting the perched groundwater drops from 2,773 kg (Run #2) in the baseline simulation to 518 kg (Run #22), which is a resultant 81% reduction. The largest RDX flux reduction was demonstrated at Reach 1, with a 30 and 300-year cumulative RDX mass flux of 266 kg and 328 kg, respectively, compared to 1,450 kg and 1,737 kg in Run #2.

The operation of the groundwater pump and treat system, excluding re-injection, and the addition of the six horizontal wells results in a reduction of 447 kg of RDX exiting the perched groundwater flow system relative to Run #8, which excluded horizontal wells. Therefore, the inclusion of the six horizontal wells in the perched groundwater decreases predicted RDX mass flux by 447 kg over the 300-year period of simulation, or an approximate 45% improvement, relative to the existing pump and treat system with no re-injection alone.

The cumulative and instantaneous flux of water and RDX across each of the reaches is depicted graphically in Figure A-27. The cumulative water flux (Figure A-27, lower left) is similar to other horizontal well runs presented earlier. The cumulative RDX mass (Figure A-27, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-27, upper right) decreases from about 23.5 kg/year to <1 kg/year coincident with the operation of the pump and treat system and horizontal wells. Following shut down of the system, the rate increases to around 2 kg/year between 50 and 75 years, then slowly declines to negligible rates (<1 kg/y) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and a slight

rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi-steady state rates between 150 to 200 years into the simulation.

During the 30-year period of operation, the groundwater pump and treat system with the six horizontal wells removes 3,126 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and cannot migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 2.3 billion gallons relative to Runs #1 and #2 (an average reduction of 14.6 gpm) over the 300-year period of simulation.

A.4.3.1.2 Run #22 Summary

Run #22 incorporates the effects of 30-years of operation of the groundwater pump and treat system with no re-injection, six horizontal wells and reactive transport (sorption and degradation). The volume of water exiting the perched groundwater flow system dropped by 4.2 billion gallons relative to the baseline simulation (Run #1) and totaled 24.4 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 518 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline reactive result of 2,773 kg. This is a reduction of 81% when compared to the cumulative RDX baseline reactive results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.5 kg/year under Run #22. Therefore, operation of the groundwater pump and treat system for a period of 30-years with no re-injection, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by 81% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.3.2 Run #23: Reactive Transport with Extraction, No Injection and Eight Horizontal Wells

Reactive transport is simulated in conjunction with eight horizontal wells (Figure A-26) and the existing groundwater pump and treat system (with no re-injection) in Run #23 (MSPerched_20051202a_TRB) in Table A-8. The addition of eight horizontal wells (wells 10-15, 20 and 21 in Figure A-26) in areas selected based on a combination of higher saturated thickness and/or high concentration of RDX in groundwater further serves to reduce driving head to the edges of the perched groundwater, thus reducing mass of RDX and volumetric water flux out of the perched zone. Table A-8 indicates that Run #23 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- Eight horizontal wells
- No active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.3.2.1 Run #23 Results

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system with no re-injection of treated groundwater, was operational. Additionally, eight horizontal wells extracted water from the perched groundwater during the 30-year remediation life cycle. After 30-years, the pump and treat system was shut down, and only reactive transport (NA processes) were simulated for the remaining 270 years. Sorption and degradation are included.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-15). The volume of water leaving each reach of the model decreases relative to the baseline simulation (Run #1) with the total volume of water exiting the perched groundwater flow system calculated at 23.6 billion gallons, a reduction of 5.0 billion gallons relative to the baseline simulation.

Table A-15. Run #23 Reach Reports

Run #23 Model MSPerched_20051202a_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1420	102	85	51	62	1719
50	2105	141	114	56	69	2484
100	4152	740	286	180	143	5501
150	6800	1619	552	425	322	9717
200	9660	2562	837	699	533	14291
250	12565	3619	1126	978	750	18938
300	15480	4477	1416	1285	968	23599
Cumulative Mass Across GHB Reaches (kg)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1	265	8	49	32	355
50	1	277	14	52	34	379
100	1	309	38	65	40	453
150	1	315	44	73	43	476
200	1	317	44	74	44	480
250	1	317	44	74	44	480
300	1	317	44	74	44	480

Table A-15 shows the greatest volume of perched groundwater (15.5 billion gallons) migrates across Reach Zero over the 300-year simulation time. The addition of horizontal wells in areas upgradient of the flow path to Reach Zero reduces this number by 2.3 billion gallons from Run #1. In the southeast area, Reach 1 has the highest flux of water, totaling 4.5 billion gallons over the 300-year period of simulation. The most significant decrease from Run #1 occurs across Reach Zero, which dropped by 2.3 billion gallons. Reach 1 showed a predicted drop of 1.4 billion gallons over the 300-year period of simulation. Reach 2 (340 million gallons), Reach 3 (470 million gallons), and Reach 4 (450 million gallons) exhibited lesser declines.

The decrease in water flux across the reaches translates directly into a reduction in the RDX mass flux across the reaches. The data in Table A-15 show significant differences between the baseline reactive

simulation (Run #2) and Run #23. In Run #23, the total RDX mass exiting the perched ground drops from 2,773 kg (Run #2) in the baseline simulation to 480 kg (Run #23), which is an improvement of 83%. The largest RDX flux improvement was demonstrated at Reach 1, with a 30 and 300-year cumulative RDX mass flux of 265 kg and 317 kg, respectively, compared to 1,459 kg and 1,737 kg in Run #2.

The operation of the groundwater pump and treat system, excluding re-injection, and the addition of the eight horizontal wells results in a reduction of 2,293 kg of RDX exiting the perched groundwater flow system relative to Run #8, which excluded horizontal wells. Therefore, the inclusion of the eight horizontal wells in the perched groundwater decreases predicted RDX mass flux by 303 kg over the 300-year period of simulation, or an approximate 83% reduction relative to the existing pump and treat system.

The cumulative and instantaneous flux of water and RDX across each of the reaches is depicted graphically in Figure A-28. The cumulative water flux (Figure A-28, lower left) is similar to other horizontal well runs present earlier. The cumulative RDX mass (Figure A-28, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-28, upper right) decreases from about 23.5 kg/year to < 1 kg/year coincident with the operation of the pump and treat system and horizontal wells. Following shut down of the system, the rate increases to nearly 1.5 kg/year between 50 and 75 years, then slowly declines to negligible rates (< 1 kg/y) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and a slight rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi-steady state rates between 150 to 200 years into the simulation.

During the 30-year period of operation, the groundwater pump and treat system with the eight horizontal wells removes 3,126 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and cannot migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 2.62 billion gallons relative to Runs #1 and #2 (an average reduction of 16.6 gpm) over the 300-year period of simulation.

A.4.3.2.2 Run #23 Summary

Run #23 incorporates the effects of the 30-years operation of the groundwater pump and treat system with no re-injection, eight horizontal wells, and reactive transport (sorption and degradation). The volume of water exiting the perched groundwater flow system dropped by 5.0 billion gallons relative to the baseline simulation (Run #1) and totaled 23.6 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 480 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline reactive result of 2,773 kg. This is a reduction of 83% when compared to the cumulative RDX baseline results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.5 kg/year under Run #23. Therefore, operation of the groundwater pump and treat system for a period of 30-years with no re-injection, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by 83% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.3.3 Run #24: Reactive Transport with Extraction, No Injection, Eight Horizontal Wells, and Reduced Recharge

Reactive transport is simulated in conjunction with eight horizontal wells (Figure A-26), the existing groundwater pump and treat system (with no re-injection), and with reduced recharge at the ditches and playas in Run #24 (MSPerched_20051202c_TRB) in Table A-8. The only difference between Run #24 and Run #23 is the reduction of the recharge term in areas of the ditches and playas by a factor of 10. As shown in the water balance presented earlier (Table A-7), recharge provides the vast majority of water and driving head to the perched groundwater zone. Reduction of the major sources of that recharge is representative of potentially re-directing surface water runoff to locations off of Pantex Plant or otherwise away from perched groundwater recharge zones through alternative use or increased evaporation. The method of execution of a reduction of recharge is not developed here, but it is discussed in Section 9 of the main report text. This recharge reduction represents a significant impact to the overall water budget and mass balance of the perched groundwater. Table A-8 indicates that Run #24 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- No active injection system is in operation
- Reduces rates of recharge [10 times less recharge at ditches and playas that those rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006) for post-Pantex Plant operations].

A.4.3.3.1 Run #24 Results

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system with no re-injection of treated groundwater, was operational. Additionally, eight horizontal wells were allowed to receive water from the perched groundwater during the 30-year remediation life cycle. After 30-years, the pump and treat system was shut down, and only reactive transport (NA processes) were simulated for the remaining 270 years. Sorption and degradation are included. Reduced recharge rates were applied throughout the simulation.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-16). The volume of water leaving each reach of the model decreases relative to the baseline simulation (Run #1) with the total volume of water exiting the perched groundwater flow system calculated at 8.96 billion gallons, a reduction of 19.6 billion gallons relative to the baseline simulation.

Table A-16. Run #24 Reach Reports

Run #24 Model MSPerched_20051202c_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1052	109	84	52	64	1360
50	1423	182	120	66	76	1867
100	2196	562	263	138	108	3266
150	2897	954	412	212	139	4613
200	3616	1360	566	293	174	6008
250	4364	1783	724	380	213	7465
300	5132	2217	885	472	253	8958
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1	282	8	50	33	375
50	1	324	19	59	38	441
100	1	349	46	70	43	509
150	1	350	47	72	43	514
200	1	350	48	72	44	514
250	1	350	48	72	44	514
300	1	350	48	72	44	514

Table A-16 shows the greatest volume of perched groundwater (5.1 billion gallons) migrates across Reach Zero over the 300-year simulation time. In the southeast area, Reach 1 has the highest flux of water, totaling 2.2 billion gallons over the 300-year period of simulation. The flux of water for Reaches Two and Three are 890 million and 470 million gallons, respectively. 250 million gallons of perched groundwater is transmitted across Reach 4 over 300-years. The most significant decrease from Run #1 occurs across Reach Zero, which dropped by 12.7 billion gallons. Reach 1 showed a predicted drop of 3.6 billion gallons over the 300-year period of simulation. Reach 2 (870 million gallons), Reach 3 (1.3 billion gallons), and Reach 4 (1.2 billion gallons) exhibited lesser declines.

The decrease in water flux across the reaches translates into a reduction in the RDX mass flux across the reaches. The data in Table A-6 show differences between the baseline reactive simulation (Run #2) and Run #24. In Run #24, the total RDX mass exiting the perched ground drops from 1,482 kg (Run #2) in the baseline simulation to 514 kg (Run #24). The largest RDX flux improvement was demonstrated at Reach 1, with a 30 and 300-year cumulative RDX mass flux of 282 kg and 350 kg, respectively, compared to 1,405 kg and 1,737 kg in Run #2.

The operation of the groundwater pump and treat system, excluding re-injection, the addition of the eight horizontal wells and reduced recharge results in a reduction of 431 kg of RDX exiting the perched groundwater flow system relative to Run #8, which excluded horizontal wells. Therefore, the inclusion of the eight horizontal wells and the reduced recharge in the perched groundwater decreases the predicted RDX mass flux by 431 kg over the 300-year period of simulation, or 43% reduction, relative to the operation of the existing pump and treat system with no re-injection.

The cumulative and instantaneous flux of water and RDX across each of the reaches is depicted graphically in Figure A-29. The cumulative water flux (Figure A-29, lower left) is significantly different

from all other models. The reduced recharge effectively lessens the slope of the cumulative water flux curve. The cumulative RDX mass (Figure A-29, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-29, upper right) decreases from about 23.5 kg/year to <1 kg/year coincident with the operation of the pump and treat system and horizontal wells. Following shut down of the system, the rate increases to nearly 2.5 kg/year between 50 and 75 years, then slowly declines to negligible rates (< 1 kg/y) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and exhibit almost no rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi-steady state rates between 100 to 150 years into the simulation. The reduction in recharge significantly alters the quasi-steady state instantaneous water flux out of the model because of the new water balance created with much less recharge.

During the 30-year period of operation, the groundwater pump and treat system with the eight horizontal wells removes 3,338 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and cannot migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 6.9 billion gallons relative to Runs #2 (an average reduction of 43.8 gpm) over the 300-year period of simulation.

A.4.3.3.2 *Run #24 Summary*

Run #24 incorporates the effects of the 30-years of operation of the groundwater pump and treat system with no re-injection, eight horizontal wells and reactive transport (sorption and degradation), and reduced recharge at the ditches and playas. The volume of water exiting the perched groundwater flow system dropped by 19.6 billion gallons relative to the baseline simulation (Run #2) and totaled 8.96 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 514 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline reactive result of 2,773 kg. This is a reduction of 81% when compared to the cumulative RDX baseline reactive results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.5 kg/year under Run #24. Therefore, operation of the groundwater pump and treat system for a period of 30-years with no re-injection, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by 81% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.3.4 Run #25: Reactive Transport with Extraction, No Injection, and 10 Horizontal Wells

Reactive transport is simulated in conjunction with 10 horizontal wells (Figure A-26), and the existing groundwater pump and treat system (with no re-injection) in Run #25 (MSPerched_20051202b_TRB) from Table A-8. The addition of 10 horizontal wells in areas selected based on a combination of higher saturated thickness and/or high concentration of RDX in groundwater further serves to reduce the driving head to the edges of the perched groundwater, thus reducing mass of RDX and volumetric water flux out of the perched zone. Table A-8 indicates that Run #25 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation

- 10 horizontal wells
- No active injection system is in operation
- Normal rates of recharge (same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006).

A.4.3.4.1 *Run #25 Results*

RDX reactive transport was simulated for a period of 300-years. During the first 30-years, the existing groundwater pump and treat system with no re-injection of treated groundwater, was operational. Additionally, 10 horizontal wells extracted water from the perched groundwater during the first 30-years. After 30-years, the pump and treat system and the horizontal wells were shut down, and only reactive transport (NA processes) was simulated for the remaining 270 years. Sorption and degradation are included.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-17). The volume of water leaving each reach of the model decreases relative to the baseline simulation (Run #2) with the total volume of water exiting the perched groundwater flow system calculated at 20.8 billion gallons, a reduction of 7.8 billion gallons relative to the baseline simulation.

Table A-17 shows the greatest volume of perched groundwater (12.96 billion gallons) migrates across Reach Zero over the 300-year simulation time. The addition of horizontal wells in areas in the upgradient in the flow path to Reach Zero served to reduce this number by 4.9 billion gallons from Run #2. The most significant decrease from Run #1 occurs across Reach Zero, which dropped by 4.9 billion gallons. Reach 1 showed a predicted drop of 1.5 billion gallons over the 300-year period of simulation. Reach 2 (370 million gallons), Reach 3 (510 million gallons), and Reach 4 (470 million gallons) exhibited lesser declines.

Table A-17. Run #25 Reach Reports

Run #25 Model MSPerched_20051202b_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	921	114	88	59	76	1259
50	1041	138	118	65	84	1445
100	1990	640	270	166	145	3212
150	4342	1472	524	395	310	7043
200	7152	2404	806	664	517	11542
250	10049	3358	1094	943	733	16176
300	12961	4316	1384	1222	950	20834
Cumulative Mass Across GHB Reaches (kg)						
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1	276	7	52	38	375
50	1	287	14	57	41	400
100	1	318	36	67	46	469
150	1	325	41	75	49	492
200	1	327	42	76	50	497
250	1	327	43	76	50	497
300	1	327	43	76	50	497

The decrease in water flux across the reaches translates into a reduction in the RDX mass flux across the reaches. The data in Table A-17 show significant differences between the baseline simulation (Run #2) and Run #25. In Run #25, the total RDX mass exiting the perched ground drops from 1,482 kg (Run #2) in the baseline simulation to 497 kg (Run #25), which is an improvement of 82%. The largest RDX flux improvement was demonstrated at Reach 1, with a 30 and 300-year cumulative RDX mass flux of 276 kg and 327 kg, respectively, compared to 1,405 kg and 1,737 kg in Run #2.

The operation of the groundwater pump and treat system, excluding re-injection, and the addition of the 10 horizontal wells results in a reduction of 398 kg of RDX exiting the perched groundwater flow system relative to Run #8, which excluded horizontal wells. Therefore, the inclusion of the horizontal wells decreases predicted RDX mass flux by 398 kg over the 300-year period of simulation, or an approximate improvement of 40% relative to the existing pump and treat system.

The cumulative and instantaneous flux of water and RDX across each of the reaches is depicted graphically in Figure A-30. The cumulative RDX mass (Figure A-30, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-30, upper right) decreases from about 23.8 kg/year to <1 kg/year coincident with the operation of the pump and treat system and horizontal wells. Following shut down of the system, the rate increases to nearly 1 kg/year between 50 and 75 years, then slowly declines to negligible rates (< 1 kg/yr) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and a slight rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi-steady state rates between 150 to 200 years into the simulation.

During the 30-year period of operation, the groundwater pump and treat system with the 10 horizontal wells removes 3,157 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and can not migrate to the underlying Ogallala Aquifer. In addition to the mass removed, the operation of the pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 2.87 billion gallons relative to Runs #1 and #2 (an average reduction of 18.2 gpm) over the 300-year period of simulation.

A.4.3.4.2 Run #25 Summary

Run #25 incorporates the effects of the 30-years operation of the groundwater pump and treat system with no re-injection, 10 horizontal wells, and reactive transport (sorption and degradation). Run #25 is identical to Run #8 with the only exception being the inclusion of 10 horizontal wells. The volume of water exiting the perched groundwater flow system dropped by 7.7 billion gallons relative to the baseline simulation (Run #1) and totaled 20.8 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 497 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline reactive result of 2,773 kg. This is a reduction of 82% when compared to the cumulative RDX baseline results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.8 kg/year under Run #25. Therefore, operation of the groundwater pump and treat system for a period of 30-years with no re-injection, coupled with naturally-occurring processes (reactive transport) is predicted to decrease by 82% cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.4 Vertical Extraction Well Scenarios

These runs comprise simulations in which the placement of lines of vertical wells in key areas of the model domain are supplemental to the operation of the existing extraction system over the 30-year life span of an expected remediation system. All runs in this category were conducted with the historical average pumping rate applied at existing wells. The other various components evaluated in this set of simulations included the application and exclusion of injection of water in the existing injection wells, reduced recharge at ditches and playas, and the extension of the period of operation to 60 years.

Runs #27 through #35 (Table A-8) evaluated the placement of up to eight lines of additional extraction wells installed perpendicular to groundwater flow and RDX migration. Runs #27 to #34 provided an evaluation of the stepwise addition of lines of new extraction wells and included the current groundwater pump and treat system (with re-injection of treated groundwater). Of the nine simulations in this series, Run #35, which did not include re-injection, had the best predicted performance in terms of minimizing the cumulative mass flux of RDX out of the perched groundwater flow system, thus it is the only scenario presented in detail here.

A.4.4.1 Run #35: 87 Vertical Wells with Reactive Transport with Extraction and No Injection

Lines of vertical extraction wells were located in areas to maximize RDX removal and avoid duplication of the current pump and treat system. The lines of wells ranged between 1880 feet to 2980 feet in length. Well spacing within a line was set to ensure cone of influence overlap with adjacent extraction wells. Spacing between each line was selected based upon RDX travel time over a 30-year period such that adjacent lines of wells would capture the RDX upgradient of each line of wells. The existing groundwater pump and treat system operation and reactive transport were included in Run #35.

Of the nine simulations in this series, Run #35 had the best predicted performance in terms of minimizing the cumulative mass flux of RDX out of the perched groundwater flow system. Run #35 consisted of the predicted performance of 87 extraction wells installed in eight lines as shown in Figure A-31. The existing groundwater pump and treat system operation was also included in the simulation. Re-injection of treated groundwater was not included in Run #35 to reduce to the extent possible, the volume of perched groundwater in the flow system. Table A-8 indicates that Run #35 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- Active extraction system is in operation
- Eight lines of extraction wells, totaling 87 additional wells
- No active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.4.1.1 *Run #35 Results*

A total of eight lines of new extraction wells along with the existing groundwater pump and treat system (with no re-injection of treated groundwater), were operational. After 30-years, the combined extraction system was shut down, and only reactive transport (NA processes) were simulated for the remaining 270 years. Individual extraction rates for each well were assigned at 50 gpm at the start of the simulation. The wells induced a dewatered condition in the model within 5 years of the simulation, resulting in average extraction rate for the 87 wells of less than 1.5 gpm throughout the rest of the 30-year period of system operation.

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-18). The volume of water leaving each reach of the model decreases relative to the baseline simulation (Run #1) with the total volume of water exiting the perched groundwater flow system calculated at 26.0 billion gallons, a reduction of 2.6 billion gallons relative to the baseline simulation.

Table A-18 shows the greatest volume of perched groundwater (17.33 billion gallons) migrates across Reach Zero over the 300-year simulation time. In the southeast area, Reach 1 has the highest flux of water, totaling 4.82 billion gallons over the 300-year period of simulation. Relative to the baseline simulation (Run #2), the most significant decrease occurs across Reach 1, which dropped by just over 1 billion gallons.

The decrease in water flux across the reaches translates into a reduction in the RDX mass flux across the reaches. The data in Table A-18 show differences between the baseline reactive simulation (Run #2) and Run #35. In Run #35, the total RDX mass exiting the perched ground drops from 2,773 kg (Run #2) in the baseline simulation to 161 kg (Run #35), which is an improvement of 94%. The largest RDX flux improvement was demonstrated at Reach 1, with a 30 and 300-year cumulative RDX mass flux of 76 kg and 199 kg, respectively, compared to 1,405 kg and 1,737 kg in Run #2.

Table A-18. Run #35 Reach Reports

Run #35 Model MSPerched120105a						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1870	70	45	15	32	2031
50	2936	179	66	19	38	3239
100	5712	997	299	230	199	7438
150	8592	1944	585	505	412	12038
200	11502	2901	875	784	629	16690
250	14416	3860	1165	1064	847	21352
300	17332	4819	1455	1344	1065	26015
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1	76	0	10	17	104
50	1	81	1	11	18	111
100	1	92	11	19	24	146
150	1	98	13	21	26	159
200	1	99	13	22	26	161
250	1	99	13	22	26	161
300	1	99	13	22	26	161

The addition of 87 extraction wells to the existing pump and treat system (excluding re-injection), results in a reduction of 161 kg of RDX exiting the perched groundwater flow system relative to Run #8, which consisted only of the existing pump and treat system (and excluded re-injection). Therefore, the inclusion of the 87 vertical wells in the perched groundwater decreases predicted RDX mass flux by 834 kg over the 300-year period of simulation, or an approximate 84% improvement relative to the existing pump and treat system.

The cumulative and instantaneous flux of water and RDX across each of the Reaches is depicted graphically in Figure A-32. The cumulative water flux (Figure A-32, lower left) is similar to results presented for previous simulations, but close examination reveals the decrease in cumulative water flux for each Reach. The cumulative RDX mass (Figure A-32, upper left) reflects the significant decrease in RDX mass exiting the perched groundwater flow system, especially when compared to the baseline simulation (Figure A-22). For Reach 1, the instantaneous RDX mass flux (Figure A-32, upper right) decreases from about 23.5 kg/year to < 1 kg/year coincident with the operation of the pump and treat system. Following shut down of the system, the rate increases to over 0.5 kg/year between 50 and 75 years, then slowly declines to negligible rates (<< 1 kg/y) after 75 years. Reaches Three and Four exhibit similar trends in the first 30-years of simulation time and a slight rebound after system shut down. The instantaneous water flux drops across all reaches during the first 30-years, then rebounds to quasi steady state rates between 100 to 150 years into the simulation.

During the 30-year period of operation, the combined groundwater pump and treat system removes 4,308 kg of RDX from the perched groundwater flow system. This mass is permanently removed from the perched groundwater flow system and cannot migrate to the underlying Ogallala Aquifer. The operation of the combined pump and treat system with no re-injection alters the perched groundwater flow field, reducing lateral flow gradients toward the perched groundwater extent. Travel times to the boundaries are

increased, allowing more time for degradation, and the volume of perched groundwater leaving the southeast area is reduced by 2.1 billion gallons (an average reduction of 13.1 gpm) over the 300-year period of simulation.

A.4.4.1.2 Run #35 Summary

Run #35 comprises eight lines of extraction wells and the groundwater pump and treat system and the 87 additional vertical wells (with no re-injection) extracting perched groundwater for a 30-year period under reactive transport conditions. The volume of water exiting the perched groundwater flow system dropped by 2.6 billion gallons relative to the baseline simulation (Run #2) and totaled 26.0 billion gallons over the 300-year period of simulation. In this same 300-year period, a total of 161 kg of RDX is predicted to exit the perched groundwater flow system in the absence of any remedial actions compared to a baseline reactive result of 2,773 kg. This is a reduction of 94% when compared to the cumulative RDX baseline results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.5 kg/year under Run #35. Therefore, the combined operation of eight lines of vertical extraction wells in conjunction with the groundwater pump and treat system for a period of 30-years (with no re-injection), coupled with naturally-occurring processes (reactive transport) is predicted to decrease by 94% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.5 Enhanced decay Scenarios

These runs comprise simulations in which the placement of zones with high rates of decay spaced approximately at locations of 10-year travel times throughout the RDX plume from the source areas to the boundary of the model (Figure A-33). Run #37 included the effects of the existing pump and treat system. Because Run #36 did not include the pump and treat system, it allows for evaluation of the addition of biological or chemical decay amendments alone. Therefore, only Run #36 of these two is discussed here.

Run #38 takes a similar approach to Run #36, but the enhanced decay zones are focused just upgradient of the Reach 1 area and the southeast portion of the perched groundwater (Figure A-33). Run #38 is also discussed in detail in this section.

A.4.5.1 Run #36: Reactive Transport with Enhanced decay Zones

Run #36 simulated zones of enhanced decay of RDX throughout the RDX plume area through application of location-specific short half-lives. No injection or extraction, even with the biodecay zones, was applied during the active remediation period of these simulations. The zones of enhanced decay were placed along the general perched flow path within the perched groundwater at locations of 10-year advective travel times. The acting low half-life in these zones was applied only during the 30-years of expected implementation of any active system that would be required operate to emplace enhance the geochemistry of the area. Normal, reactive transport conditions were applied after the 30-years of enhanced decay zones. Table A-8 indicates that Run #36 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included),
- No active extraction system is in operation,
- Enhanced decay zones active during the 30-years of active remediation (half-life = 10 days),

- No active injection system is in operation,
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.5.1.1 Run #36 Results

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-19). The volume of water leaving each reach of the model is essentially identical to baseline Runs #1 and #2 (28.4 billion gallons), as would be expected in the absence of active extraction or injections.

Table A-19. Run #36 Reach Reports

Run #36 Model MSPerched_20061221b_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1803	583	169	182	189	2926
50	3000	980	283	305	319	4886
100	5992	1975	586	607	569	9728
150	8902	2940	875	890	793	14400
200	11894	3905	1167	1174	1010	19150
250	14811	4862	1459	1451	1227	23810
300	17654	5820	1750	1735	1451	28411
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	3	224	27	101	47	403
50	5	227	43	104	58	436
100	5	240	49	105	71	470
150	5	247	50	108	76	485
200	5	247	51	109	76	488
250	5	247	51	109	76	489
300	5	247	51	109	76	489

The inclusion of reactive zones representing shorter degradation times and a faster half-lives results in differences between the baseline reactive simulation (Run #2) and Run #36. In Run #36, the total RDX mass exiting the perched groundwater drops from 2,773 kg (Run #2) in the baseline simulation to 489 kg (Run #36). Reach 1 exhibited differences in cumulative mass flux at 30-years (1,450 kg to 224 kg) and 300-years (1,737 kg to 247 kg). The differences in RDX mass flux can be attributed to RDX degradation as the plume migrates through the zones of short half-life.

This same information is shown graphically in four charts shown in Figure A-34. The cumulative water volume over time (Figure A-34, lower left) and instantaneous water flux (Figure A-33, lower right) are the same as shown in Figure A-22 for Run #2. The cumulative mass (Figure A-34, upper left) shows a steady increase over the first 50 to 75 years then gradually flattens indicating that nearly all mass has migrated out of the perched groundwater flow system within this 75 to 100 year period of time.

The instantaneous mass flux (Figure A-34, upper right) depicts the mass flux in kg/year migrating across each reach. The peak instantaneous mass flux has dropped to 26.7 kg/yr in comparison to Run #2. The instantaneous mass flux shows a sharp increase in the first 10 years followed by gradual decrease through 75 to 100 years into the simulation.

A.4.5.1.2 *Run #36 Summary*

Run #36 comprises zones of increased biodecay throughout the RDX plume area during the 30-years of active treatment. No extraction or injection is occurring during this remedial time frame. The volume of water exiting the perched groundwater flow system is essentially the same as the baseline scenarios conducted in Runs #1 and #2. In this same 300-year period, a total of 489 kg of RDX is predicted to exit the perched groundwater flow system compared to a baseline result of 2,773 kg. This is a reduction of 82% when compared to the cumulative RDX baseline reactive results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 26.7 kg/year under Run #36. Therefore, the emplacement of enhanced decay zones through the RDX plume for a period of 30, coupled with naturally-occurring processes (reactive transport) elsewhere is predicted to decrease by 82% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.4.5.2 Run #38: Reactive Transport with Focused Enhanced decay Zones

Run #38 simulated zones of enhanced decay of RDX in focuses areas of the RDX plume area through application of location-specific short half-lives. No injection or extraction, even with the biodecay zones, was applied during the active remediation period of these simulations. The zones of enhanced decay were placed in areas protecting of Reach 1 and the southeast area of the perched groundwater. The acting low half-life in these zones was applied only during the 30-years of expected implementation of any active injection system that would be required to enhance the geochemistry of the area. Normal, reactive transport conditions were applied after the 30-years of enhanced decay zones. Table A-8 indicates that Run #38 is specified as simulation of:

- Reactive contaminant transport (the effects of sorption [K_d equal to 0.171 L/kg] and degradation [7.57E-05 1/days] are included)
- No active extraction system is in operation
- Enhanced decay zones active during the 30-years of active remediation (half-life = 10 days)
- No active injection system is in operation
- Normal rates of recharge [same "post-Pantex Plant" recharge rates used in the calibrated flow model documented in the *Subsurface Modeling Report* (BWXT Pantex/SAIC, 2004) and in Appendix N of the Baseline HHRA (BWXT Pantex/SAIC, 2006)].

A.4.5.2.1 *Run #38 Results*

The volume of water and mass of RDX migrating across each reach are tabulated (Table A-20). The volume of water leaving each reach of the model is essentially identical to baseline Runs #1 and #2 (28.3 billion gallons), as would be expected in the absence of active extraction or injections.

Table A-20. Run #38 Reach Reports

Run #38 Model MSPerched_20061221b_TRB						
Cumulative Water Across GHB Reaches (millions of gallons)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	1803	583	169	182	189	2926
50	3037	950	262	271	289	4808
100	6112	1870	494	492	538	9506
150	9201	2790	728	714	785	14219
200	12268	3703	958	935	1040	18903
250	15335	4623	1197	1159	1287	23601
300	18402	5543	1429	1376	1534	28284
Cumulative Mass Across GHB Reaches (kg)						
Model Year	**Reach 0**	**Reach 1**	**Reach 2**	**Reach 3**	**Reach 4**	**Total**
30	3	41	19	38	182	284
50	4	70	23	87	262	446
100	5	126	45	137	311	624
150	5	134	47	141	317	644
200	5	135	48	142	317	646
250	5	135	48	142	317	646
300	5	135	48	142	317	646

The inclusion of reactive zones representing shorter degradation times and a faster half-lives results in differences between the baseline reactive simulation (Run #2) and Run #38. In Run #38, the total RDX mass exiting the perched groundwater drops from 2,773 kg (Run #2) in the baseline simulation to 646 kg (Run #38). Reach One exhibited differences in cumulative mass flux at 30-years (1,450 kg to 41 kg) and 300-years (1.737 kg to 135 kg). The differences in RDX mass flux can be attributed to RDX degradation as the plume migrates through the zones of short half-life.

This same information is shown graphically in four charts shown in Figure A-35. The cumulative water volume over time (Figure A-35, lower left) and instantaneous water flux (Figure A-35, lower right) are the same as shown in Figure A-22 for Run #2. The cumulative mass (Figure A-35, upper left) shows a steady increase over the first 50 to 75 years then gradually flattens indicating that nearly all mass has migrated out of the perched groundwater flow system within this 150 to 200 year period of time.

The instantaneous mass flux (Figure A-35, upper right) depicts the mass flux in kg/year migrating across each reach. The peak instantaneous mass flux has dropped to 23.5 kg/year in comparison to Run #2. The instantaneous mass flux shows a sharp increase in the first 10 years followed by gradual decrease through 200 to 250 years into the simulation.

A.4.5.2.2 *Run #38 Summary*

Run #38 comprises zones of increased biodecay in focused areas of the RDX plume area during the 30-years of active treatment. No extraction or injection is occurring during this remedial time frame. The volume of water exiting the perched groundwater flow system is essentially the same as the baseline scenarios conducted in Runs #1 and #2. In this same 300-year period, a total of 646 kg of RDX is predicted to exit the perched groundwater flow system compared to a baseline result of 2,773 kg. This is

a reduction of 30% when compared to the cumulative RDX baseline reactive results. The peak instantaneous RDX mass flux out of the perched groundwater flow system drops from 68.7 kg/year in the baseline simulation to 23.5 kg/year under Run #38. Therefore, the emplacement of enhanced decay zones through the RDX plume for a period of 30, coupled with naturally-occurring processes (reactive transport) elsewhere is predicted to decrease by 76% the cumulative RDX mass flux exiting the perched groundwater flow system (assuming the parameters for sorption, degradation, and pump and treat flow rates are representative for the period of simulation).

A.5 Summary of Results

The Baseline HHRA identified COCs in groundwater under current and future conditions, in the absence of active remediation. This appendix provides a fate and transport evaluation for comparison of potential remedial alternatives that may be protective of underlying Ogallala Aquifer. This appendix does not provide an evaluation of the cost, implementability, or other considerations pertaining to the execution of any alternative evaluated.

To complete this evaluation, a single-layer screening level model was constructed and calibrated to permit rapid evaluation of remedial alternatives. The screening model parameters were copied from the site wide model and the FTM models model using same parameters from Baseline Human Health Risk Assessment. The screening model focuses on flow and transport within the perched groundwater flow system only. The lateral water and RDX mass flux out of specified areas of the model boundaries (GHB reaches) are used as a proxy for the vertical water and RDX mass flux to the FGZ and underlying Ogallala Aquifer. The primary metric for alternative evaluation is Primary metric for evaluation of alternatives is the reduction of RDX mass flux out of the perched groundwater flow system through the GHB reaches. As a secondary metric, average concentrations in groundwater exiting each reach were calculated by dividing the instantaneous RDX mass flux into the instantaneous water flux for each reach. For comparison purposes, the average concentrations over time were tabulated (Attachment 1A) for each run presented in Table A-21.

A total of 37 runs representing a baseline condition, NA conditions, and various remedial alternatives were completed for evaluation as shown in Table A-8, with detailed results presented in Attachments 1A and 2A. The 37 models were generally grouped into categories representing the existing pump and treat system, potential horizontal well placement, additional vertical extraction well placement, and enhanced decay simulations. Attachment 1A provides a detailed ranking among each of these scenarios summarized in Table A-8 for both RDX and water mass flux out of the GHB cells and summary graphs of flux out the GHB cells. Attachment 2A presents the water table, saturated thickness, and RDX concentration in groundwater for key time steps in each of the screening alternatives at 5 years into active remediation; at the end of active remediation at 30-years; and at 150 years, which corresponds roughly with the return of most models to a quasi-steady state water mass balance.

The most important of these scenarios are described in detail here in Appendix A. Table A-21 summarizes the primary and secondary evaluation metrics for each of the key screening alternatives. Specifically, the key observations from these scenarios summarized in Table A-21 are:

- Site data historically indicate that NA is occurring to an extent in perched groundwater at Pantex Plant. The rate of NA is uncertain, but all modeling calculations accounting for NA have employed a rate at the low end of literature values. NA could potentially play a significant role in remedial design, as Table A-21 shows that NA alone, Run #2, has the potential to remove on the order of 6,300 kg of RDX from the system in 300-years.

- Adding the existing pump and treat system to the NA occurring at the site results in only a small relative improvement in RDX mass flux out of the GHB cells. Table A-21 shows that Run #5 exhibits only a 27% reduction in total RDX mass flux leaving the perched groundwater at the GHB cells over a 300-year period (2,015 kg in Run #5, and 2,773 kg in Run #2).

- Run #8 shows that removing the re-injection from the operation of the pump and treat system results in a significant 64% reduction (Table A-21) in total RDX mass flux leaving the perched groundwater at the GHB cells over a 300-year period. Removing injection from the pump and treat system improves the performance of the remedial design relative to just NA (995 kg in Run #8, and 2,773 kg in Run #2).

- Each of the key horizontal well scenarios presented here show improvements to the overall RDX flux out of the GHB cells when compared with all other alternatives. This is partly because the horizontal wells are additional remediation components to the pump and treat systems, and do not act alone in these models. The best of these, Run #24 also included a reduction in recharge through the ditches and playas. Run #24 indicates that limiting recharge in conjunction with an active remediation scheme results in a 81% reduction (Table A-21) in total RDX mass flux leaving the perched groundwater at the GHB cells over a 300-year period relative to just NA (514 kg in Run #24, and 2,773 kg in Run #2). Maintaining the same recharge conditions as all other models, Run #25 indicates that the addition of 10 horizontal wells to the pump and treat results in a 82% reduction (Table A-21) in total RDX mass flux leaving the perched groundwater at the GHB cells over a 300-year period relative to just NA (497 kg in Run #25, and 2,773 kg in Run #2).

- Table A-21 shows that that the addition of 87 new extraction wells (Run #35) to the pump and treat system without re-injection results in the most RDX mass removed for treatment (4,308 kg) compared to any of the key simulations. The addition of the 87 extraction wells throughout the RDX plume does not show a significant improvement in performance of the existing pump and treat system without re-injection when evaluated against the metric of total RDX flux out of the GHB cells (161 kg in Run #35, 995 kg in Run #8).

- The biodecay runs indicated that enhanced degradation zones can reduce the mass of RDX exiting the perched groundwater. Run #36 showed a total of 489 kg of RDX is predicted to exit the perched groundwater flow system compared to a baseline result of 2,773 kg (Run #2). This is a reduction of 82% when compared to the cumulative RDX baseline reactive results. The major effect of the biodecay amendment application is the elimination of the higher RDX instantaneous mass flux terms leaving the model in early time. A focused application of the amendment served to reduce the early time impacts. The application of any biodecay amendments to groundwater would require significant injection efforts, which could potentially result in an increase of volume of water and RDX mobilization to the edges of the perched groundwater.

Overall, the key feature in each of the best screening alternatives is the reduction in the driving hydraulic gradient in the perched groundwater to the model boundary, which is set at the location the perched groundwater is 0.5 ft in thickness. The reduction in the gradient slows down the groundwater velocity, the contaminant velocity, and results in more time for the action of NA processes on the contaminant. Installation of new horizontal wells and/or vertical wells for extraction can be effective at reducing hydraulic gradients, but the technical difficulty of placement and the cost of design/construction/operation may be prohibitive.. The existing pump and treat system without re-injection can act an agent for dewatering the perched groundwater, thus reducing the driving hydraulic gradients to the perched margin, and achieving much of the desired goals of limiting the RDX flux through the FGZ. The existing pump

and treat system is well-placed in areas of high RDX concentrations for significant mass removal for treatment. A better understanding of the NA rates actually at work at Pantex Plant could indicate that use of the existing system without re-injection, in combination with a higher (likely engineered) RDX degradation rate, could effectively reduce RDX impacts to the Ogallala Aquifer.

The results reported herein are the result use of a simplified screening level model for ranking remediation alternative. The results are not intended for use beyond it's intended purpose. Information is provided on RDX concentrations with time, with the understanding that the SLM solves for only a part of the flow system, the most mobile part. While discussions are included in the text that documents the limitations of the approach, the value is the rapid screening and aggregation of the cause and effect of various remediation approaches for the RDX in the perched groundwater is realized. Translating the model results to an actionable plan is discussed in Section 7. These include such items as the engineered feasibility / difficultly of installing a robust vertical or horizontal well system in thin aquifer zones where the flow is controlled by the uncertain topography of the FGZ.

The information from the SERDP, ESTCP, ITRC, Pantex Plant and this 2D-SLM model is then used to evaluate how the preferred alternative would perform on a site-wide scale. The effective performance within the treatment zones is upscaled in this analysis, based in part on the above work. The fully 3D coupled flow and transport is computed fully transient from initial conditions through 250 years in the future. During this time, the Ogallala Aquifer is modeled as declining for the next 100 years, and then is held steady at that condition. The perched groundwater responds as it would under natural forces. The extended site-wide is under development. It comprises of 20-slices from land surface to the bottom of the Ogallala Aquifer and has an extent of 17-square miles as shown in the *Subsurface Modeling Report*. This simulation will provide the quantified insight into the expected effectiveness of the preferred alternative on the water quality in the perched groundwater and Ogallala Aquifer, as an integrated system. This model includes all the RDX mass in the complete system; the draining vadose zone and the FGZ, in three-dimensions.

Table A-21. Summary of Selected Modeling Results for Alternatives Evaluated

Run #	Description	Cumulative Water Out (millions of gallons)	Cumulative Mass Out (kg)		Cumulative Mass Extracted – Active Remediation (kg)	Cumulative Mass Decayed in Soil and Water (kg)
			Reach 1	Entire Perched		
1	Baseline simulation	28,596	1313	2343	--	--
2	Baseline reactive (NA)	28,596	1737	2773	--	6301
3	Baseline reactive, reduced recharge beneath playas and ditches	12,522	1622	2449	--	5823
5	Pump and treat, existing system with re-injection	28,484	1302	2015	2561	4947
8	Pump and treat, existing system, no re-injection	26,772	675	995	2798	4122
22	Pump and treat, existing system, no re-injection, plus six horizontal wells	24,419	328	518	3126	3338
23	Pump and treat, existing system, no re-injection, plus eight horizontal wells	23,599	317	480	3158	3166
24	Pump and treat, existing system, no re-injection, plus eight horizontal wells and reduced recharge beneath ditches and playas	8,958	350	514	3338	2963
25	Pump and treat, existing system, no re-injection, plus 10 horizontal wells	20,834	328	497	3157	3160
35	Pump and treat, existing system, no re-injection, plus eight lines of vertical extraction wells	26,015	99	161	4308	2189
36	Biodecay Amendment, no pump and treat system	28,411	248	489	--	8340
38	Focused Biodecay Amendment, no pump and treat system	28,284	135	646	--	8114

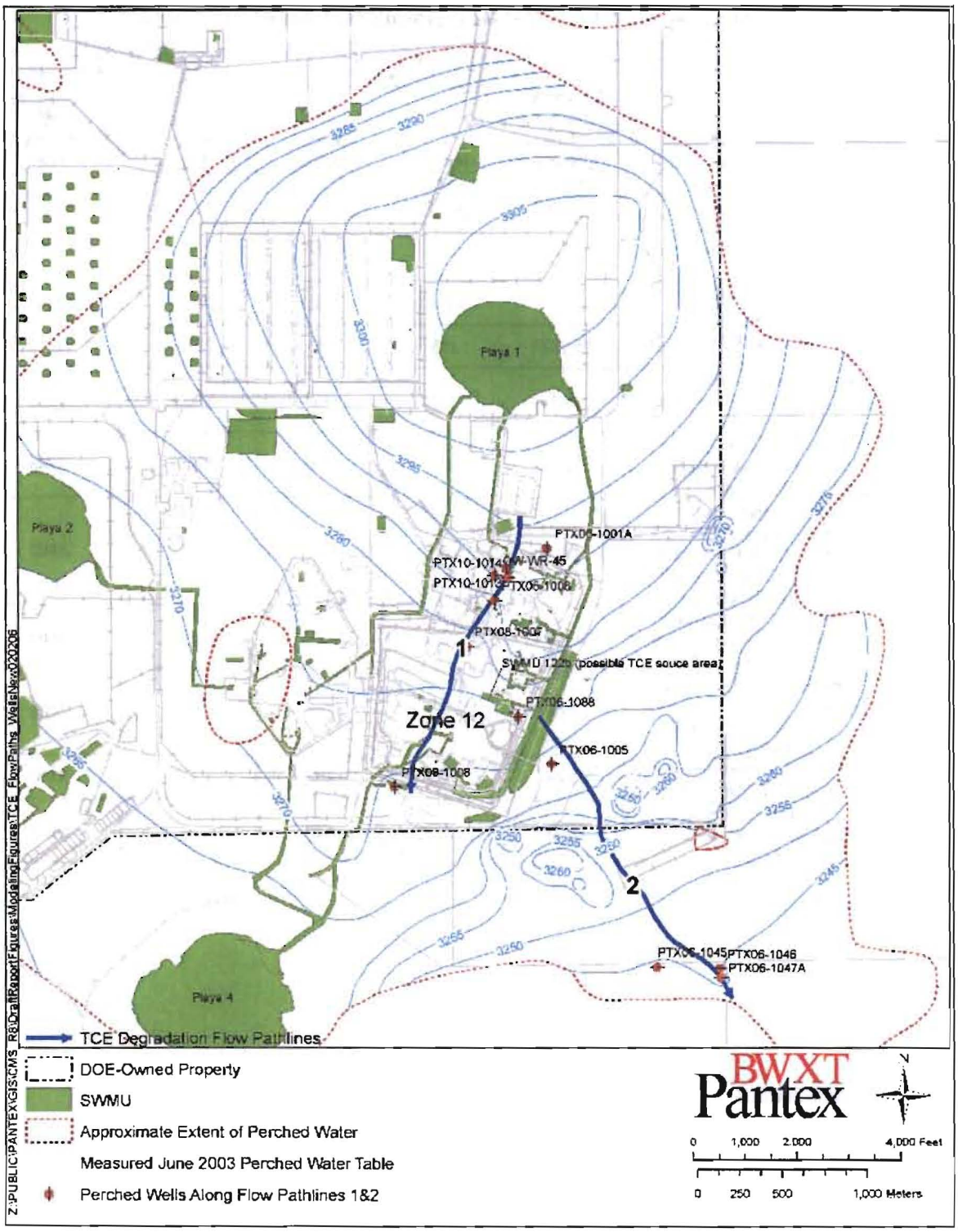


Figure A-1. Flow Paths Selected for Site-Specific Biodegradation Calculations

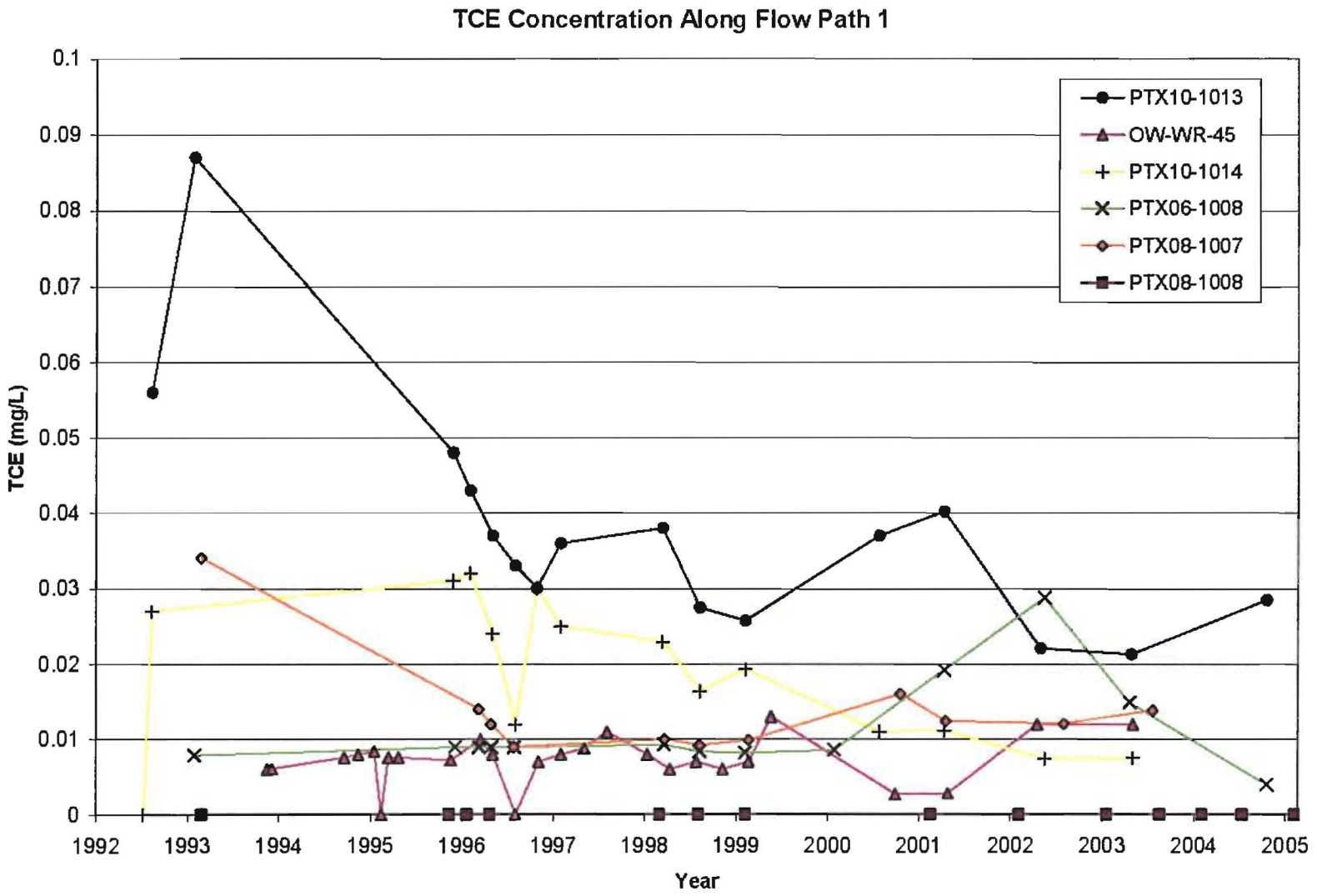


Figure A-2. TCE Trendplot for Flowpath #1

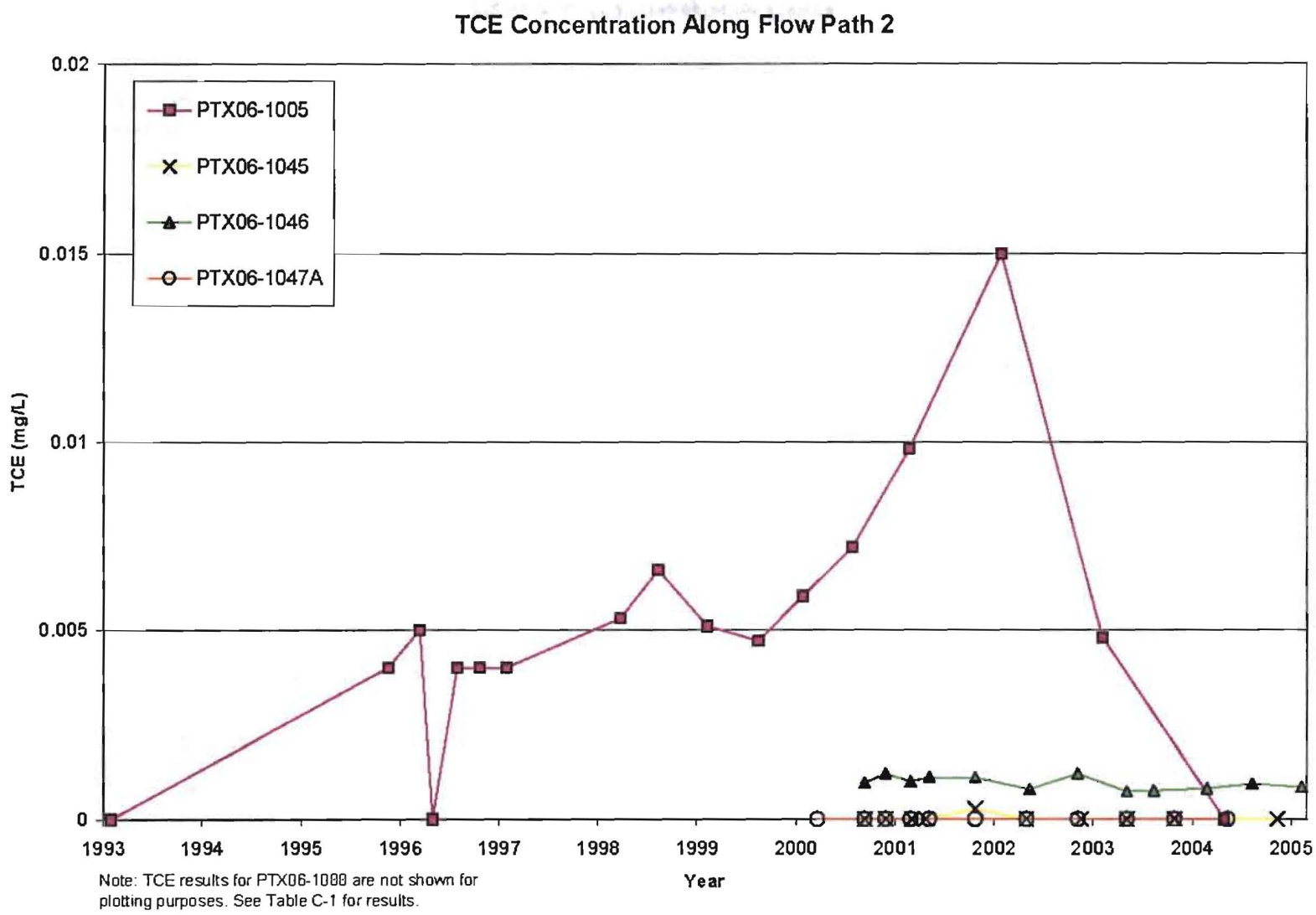


Figure A-3. TCE Trendplot for Flowpath #2

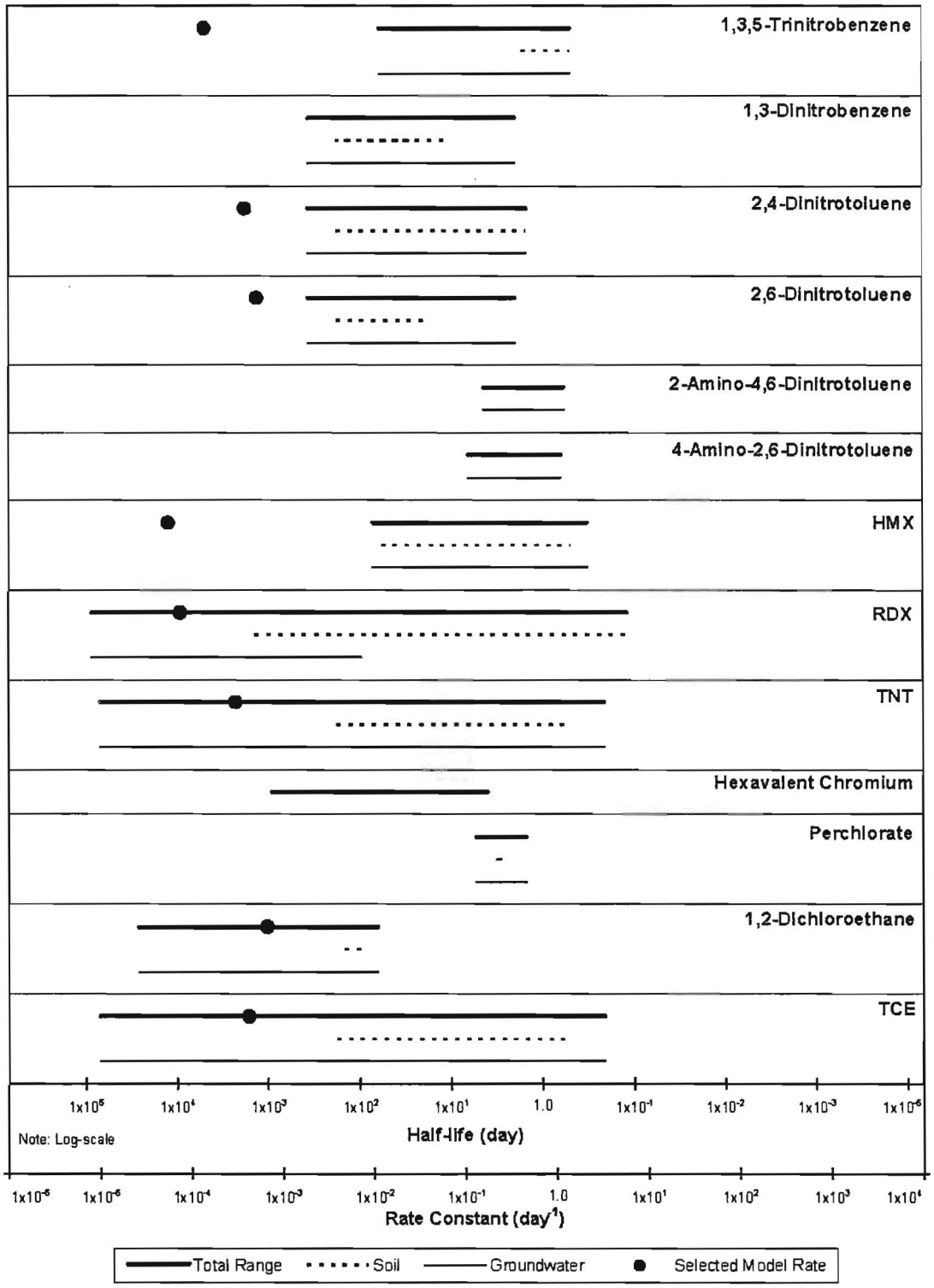


Figure A-4. Site-Specific Degradation Rates and Range of Reported Literature Rates

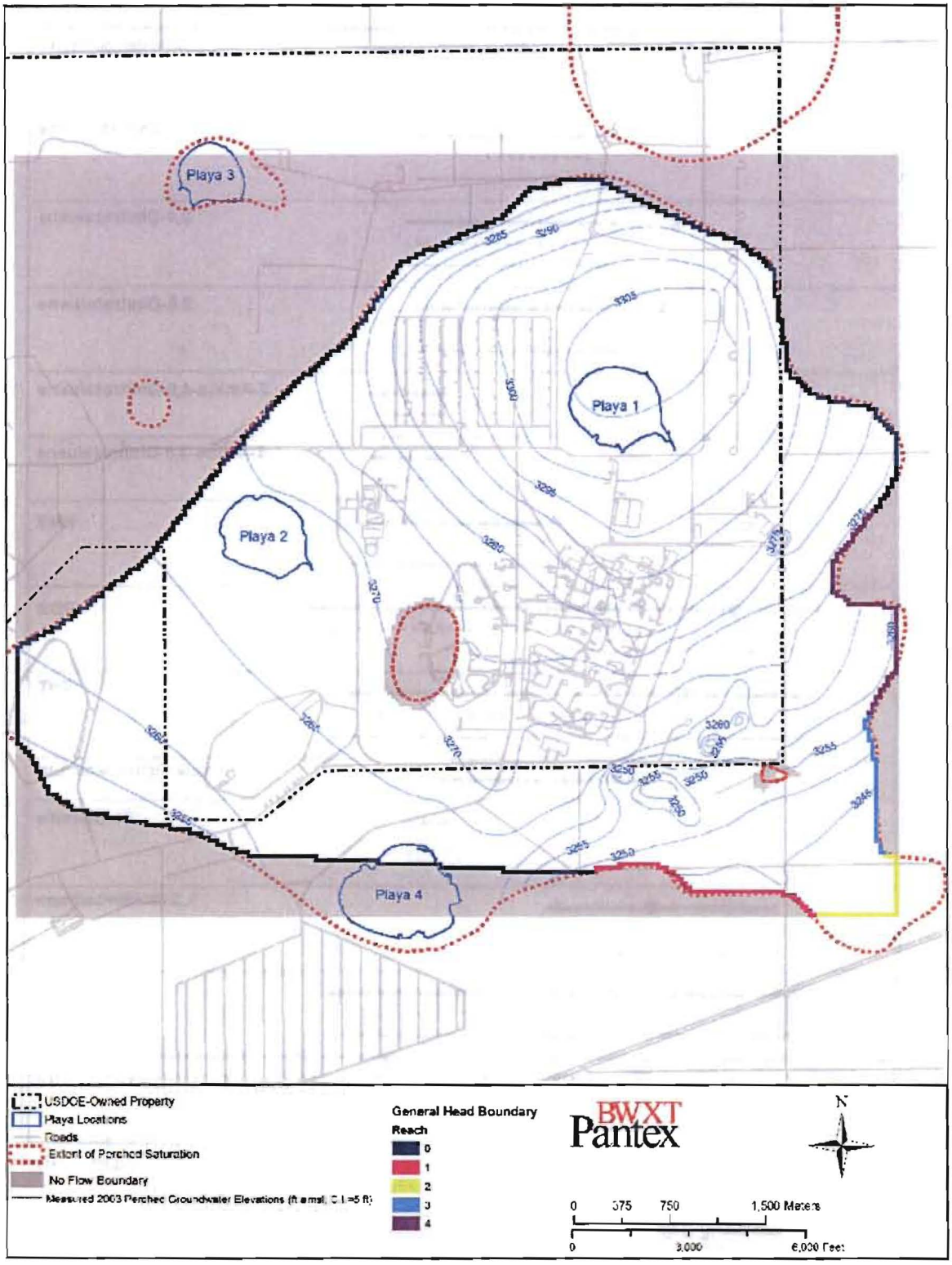


Figure A-5. June 2003 Perched Groundwater Potentiometric Surface

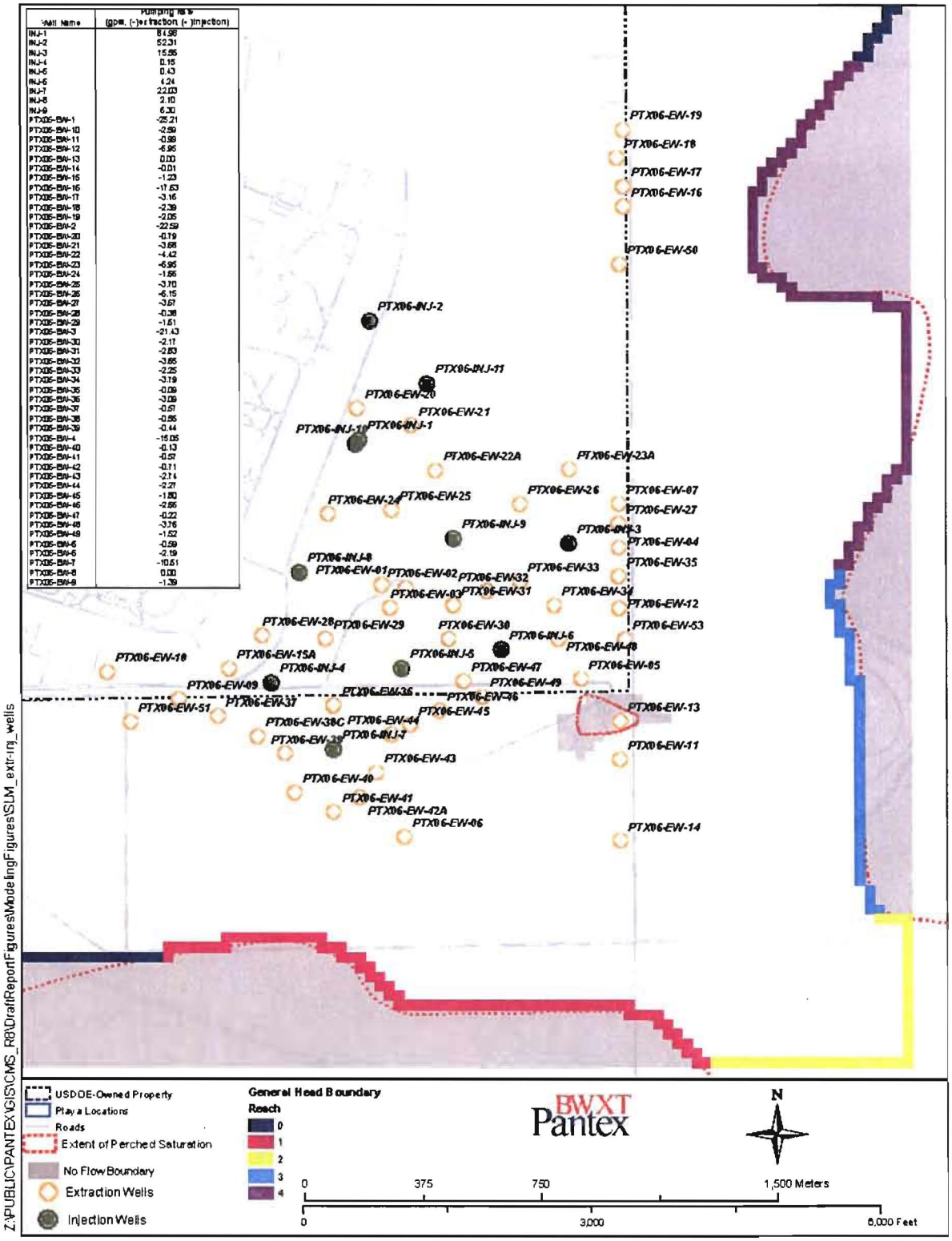


Figure A-6. Groundwater Pump and Treat System

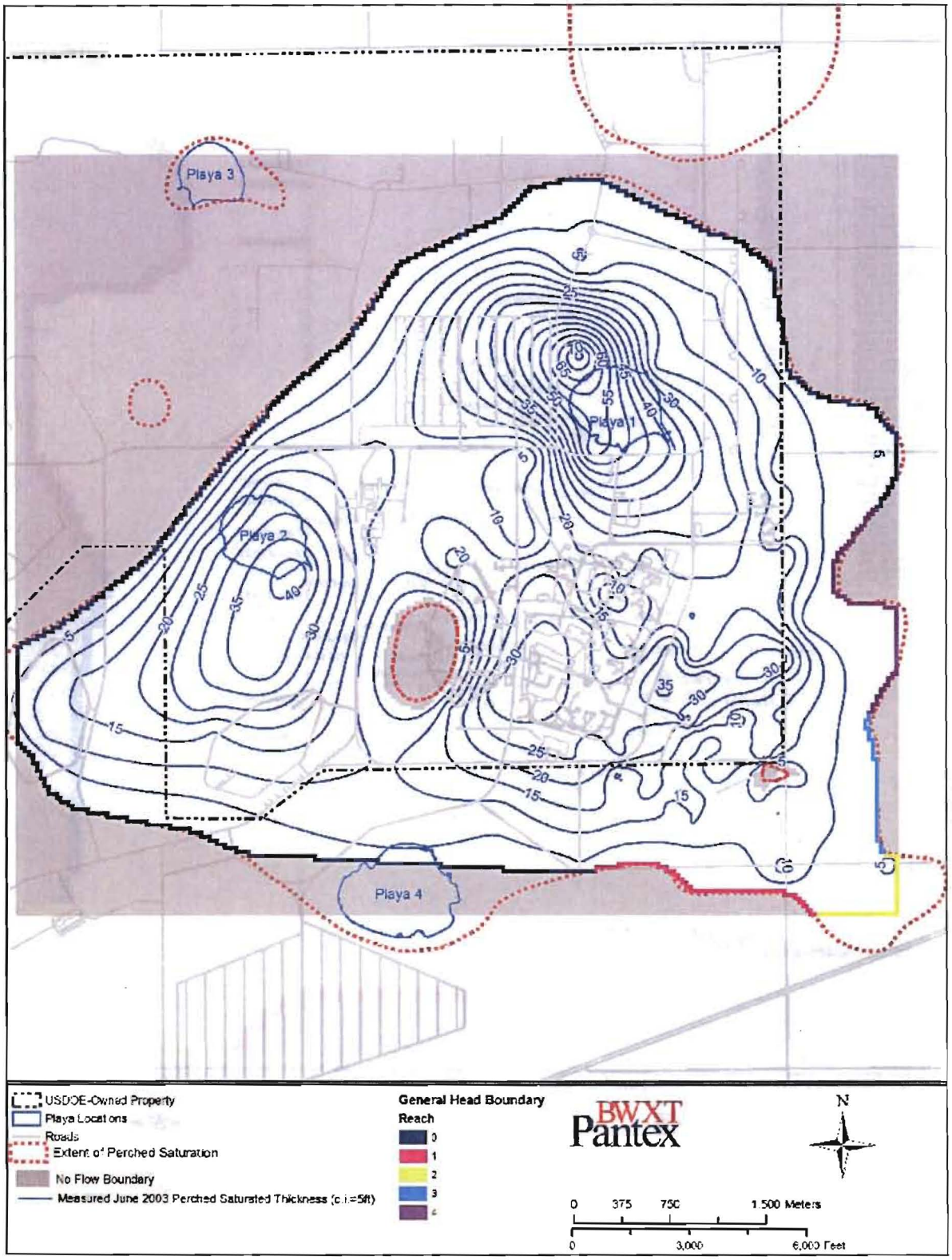


Figure A-7. June 2003 Perched Groundwater Saturated Thickness

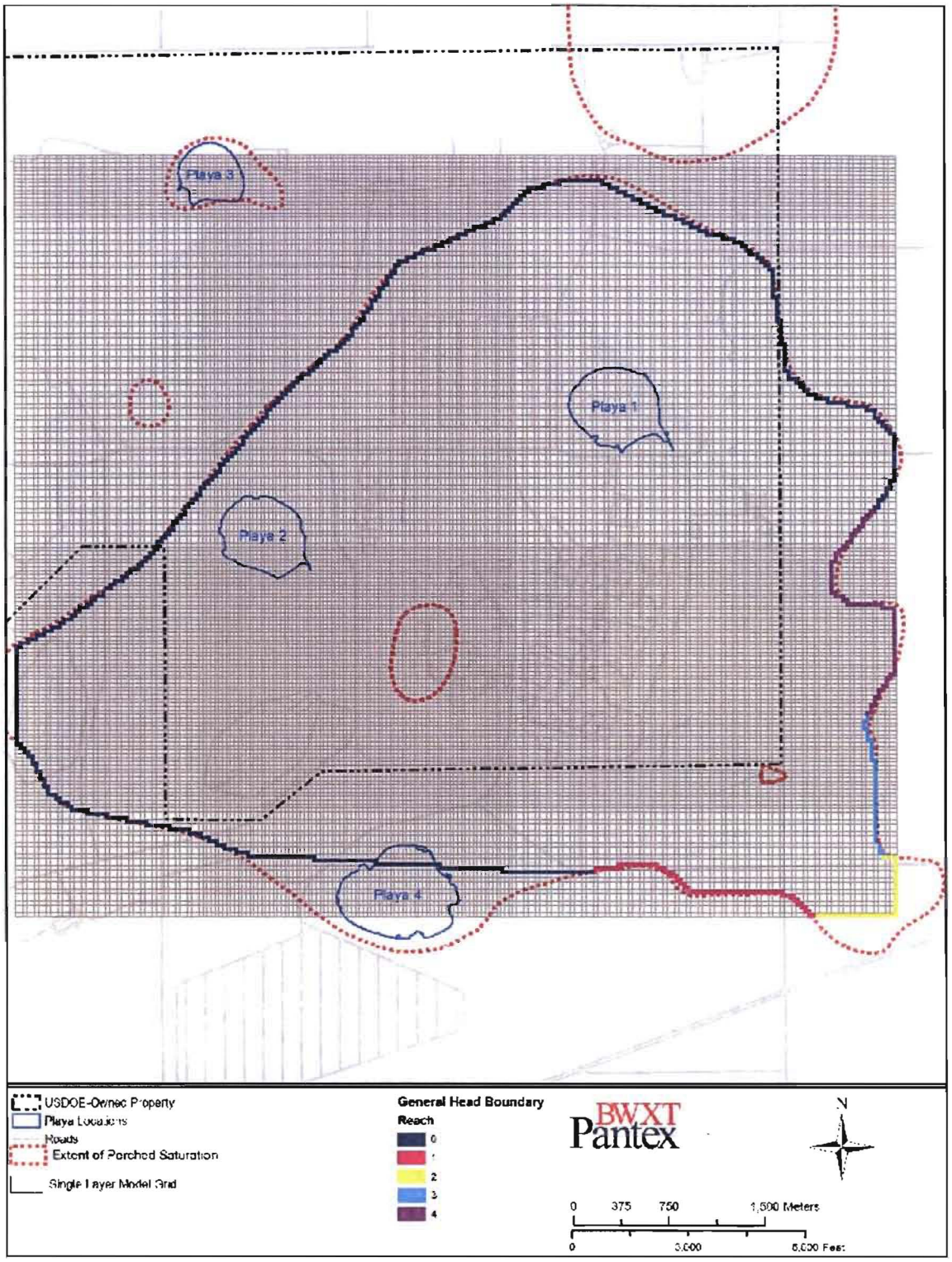


Figure A-8. Screening Model Finite-Difference Grid

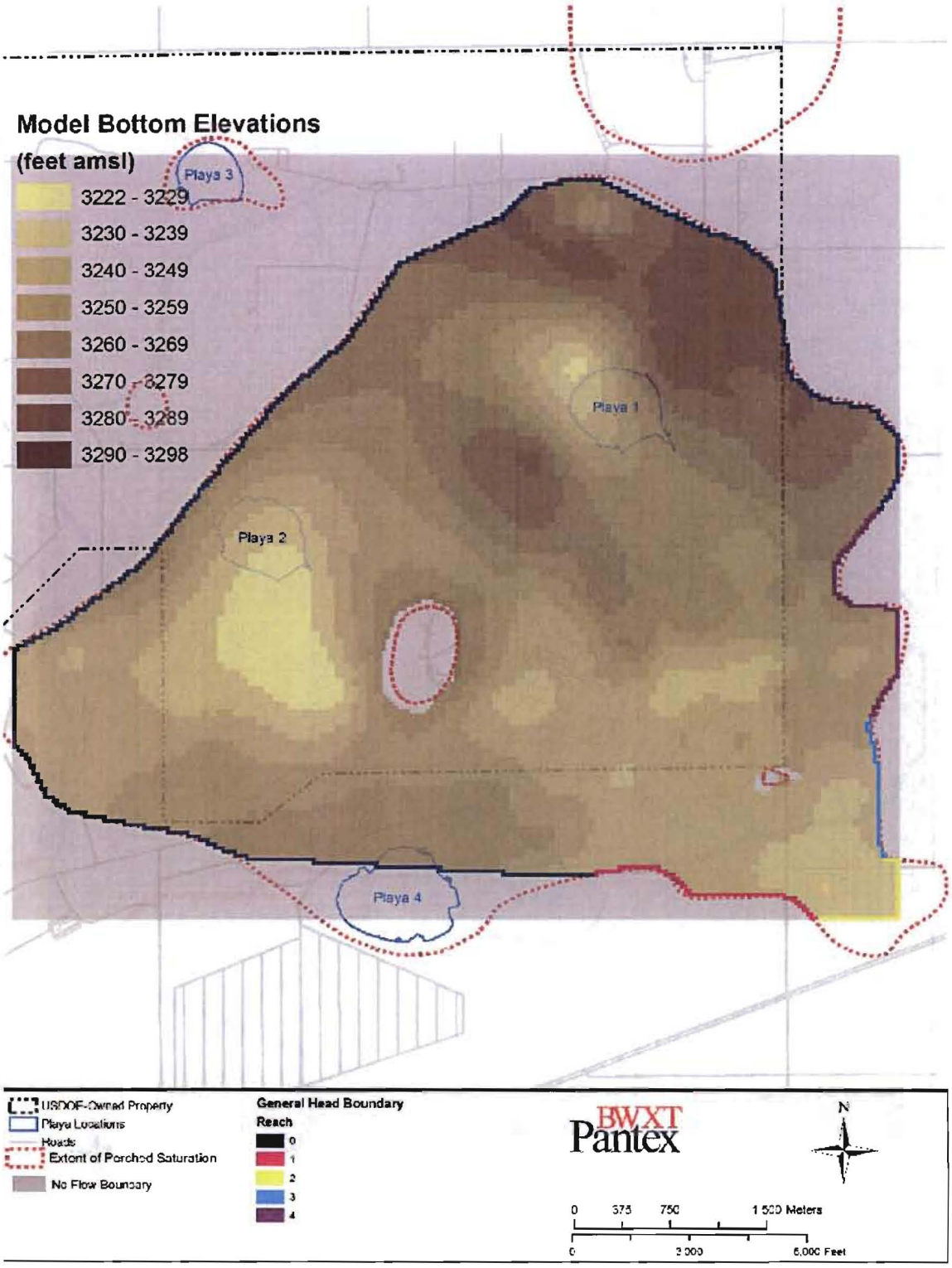


Figure A-9. Screening Model Bottom Elevation

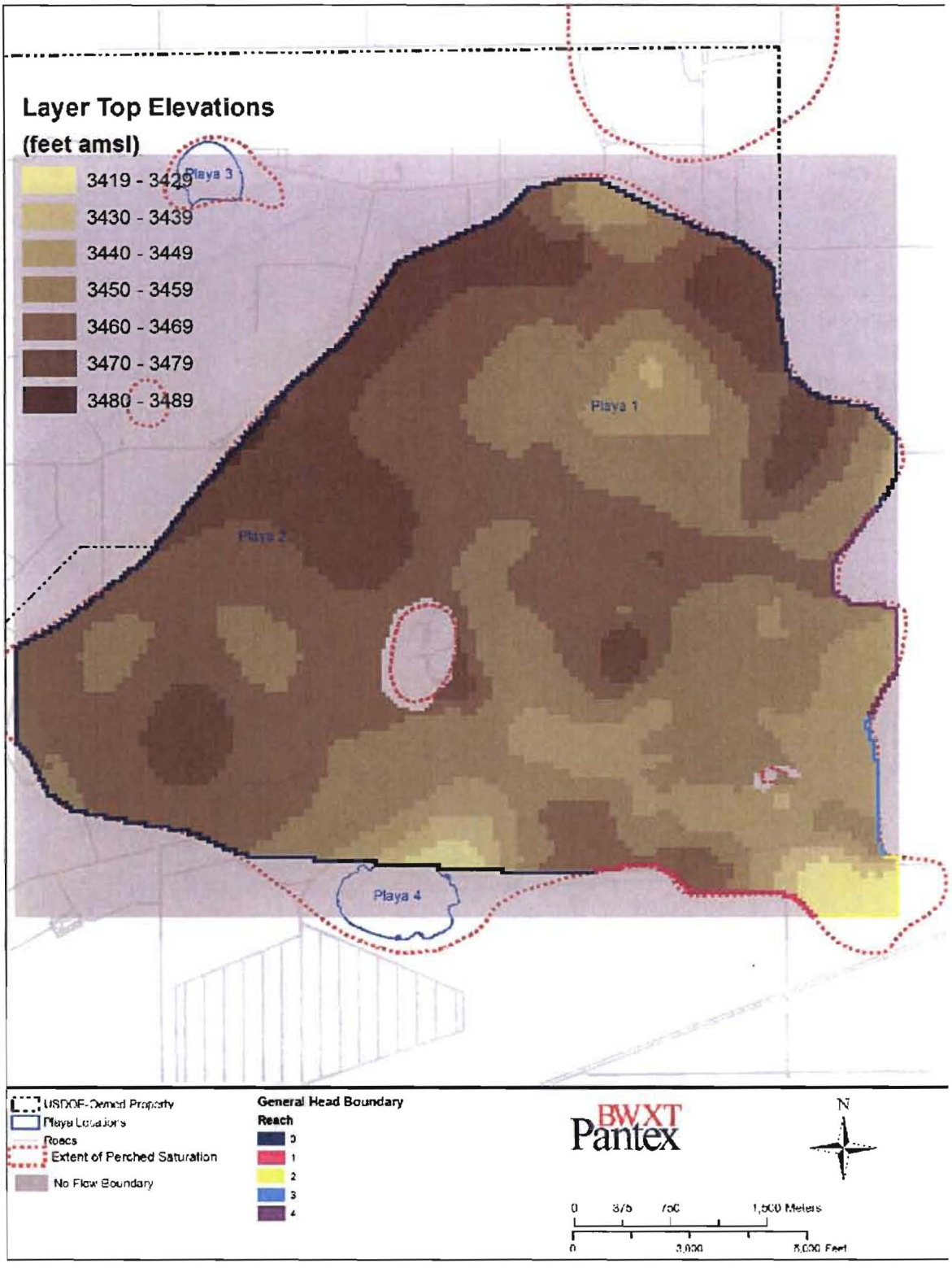


Figure A-10. Screening Model Top Elevation

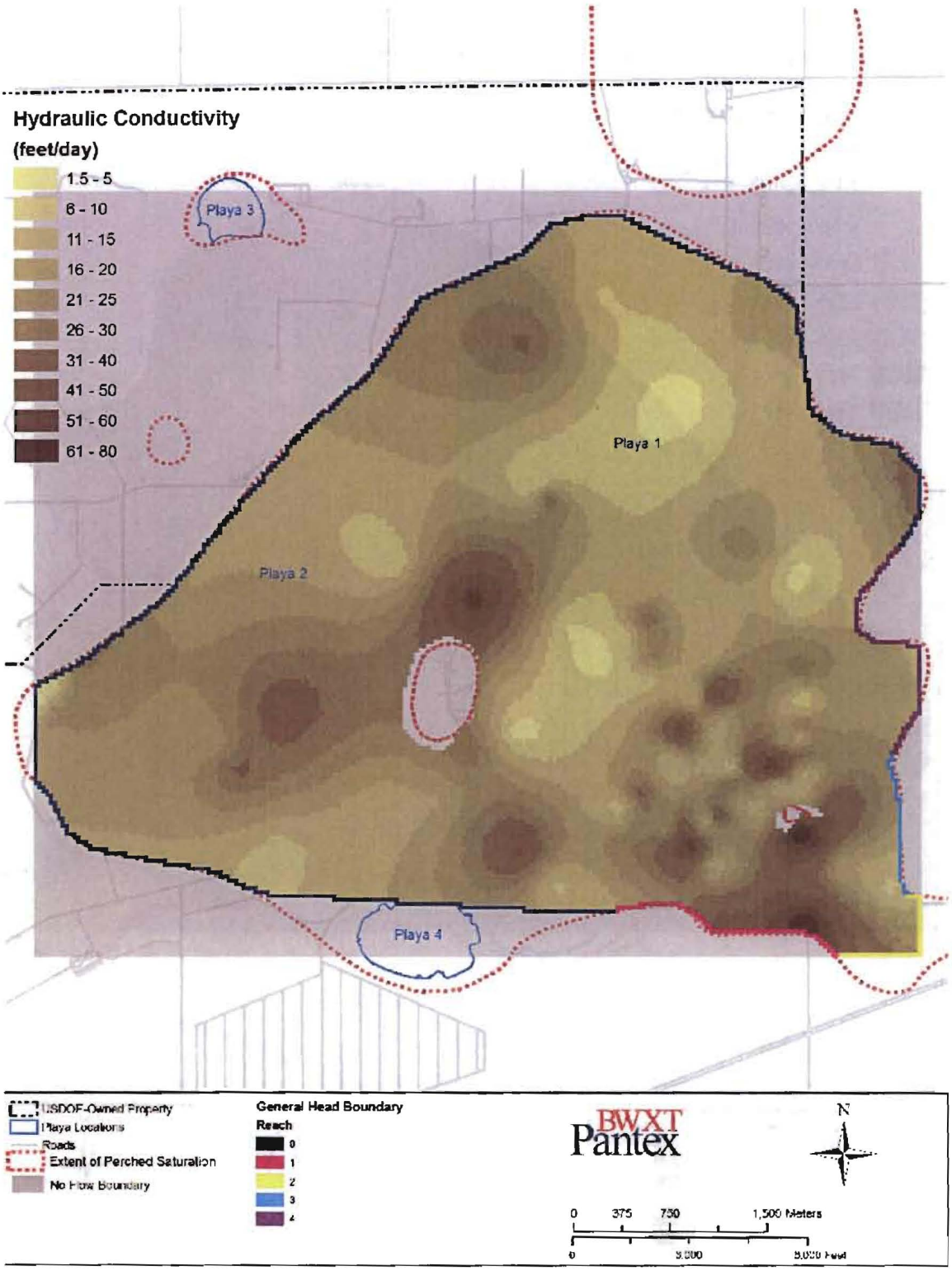


Figure A-11. Screening Model Hydraulic Conductivity Field

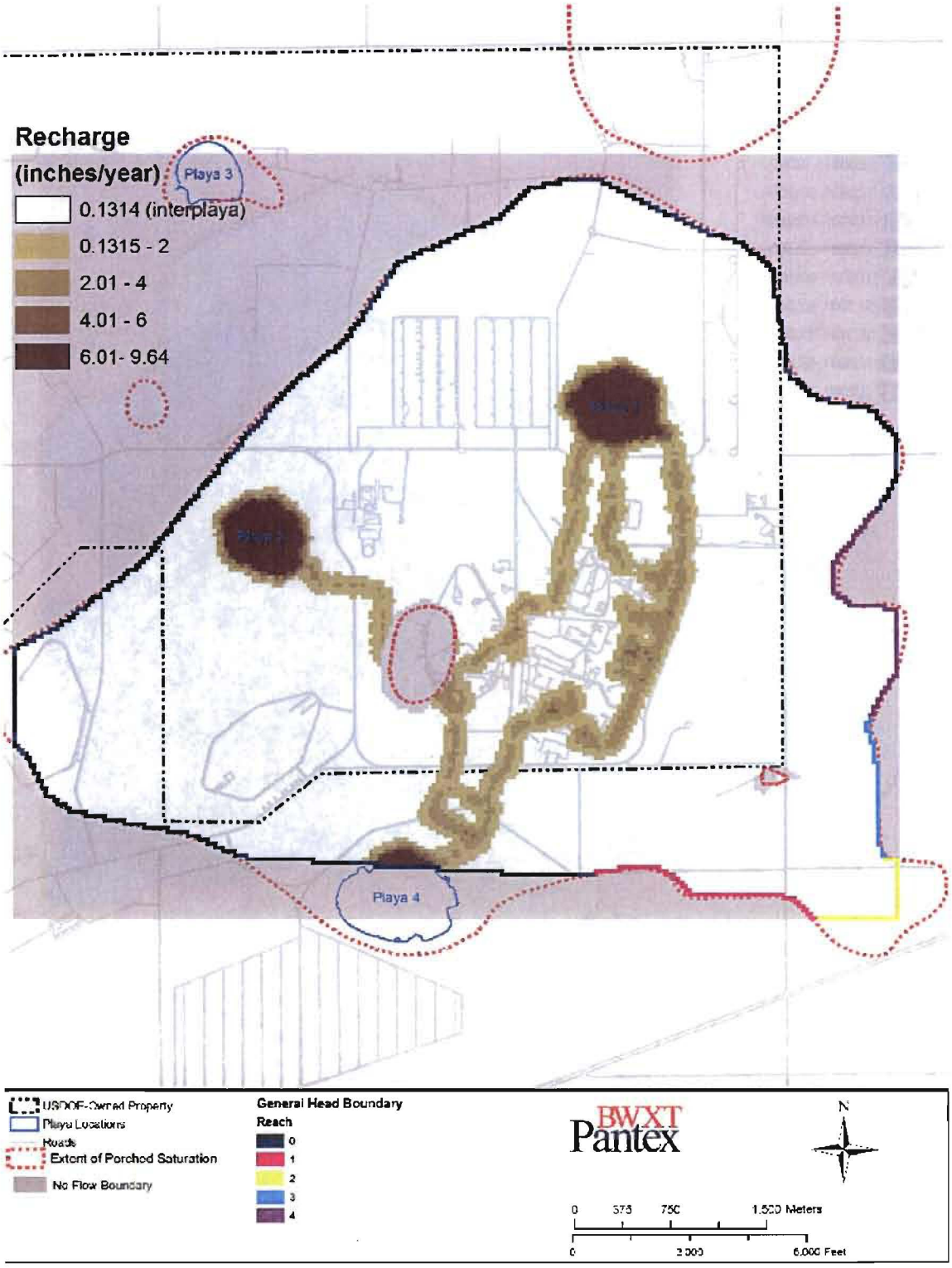


Figure A-12. Screening Model Recharge Field

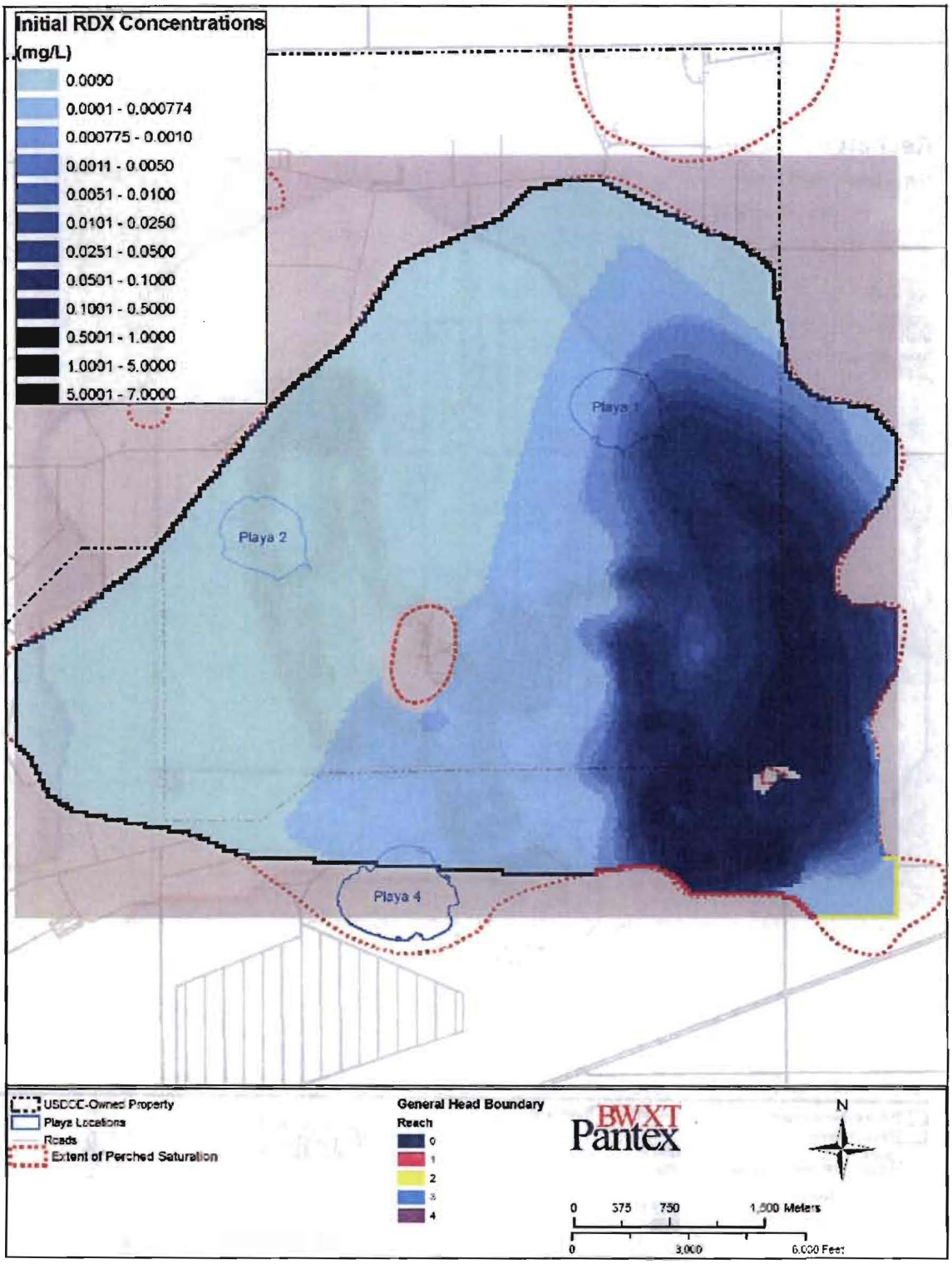


Figure A-13. Screening Model RDX Initial Concentrations in Groundwater

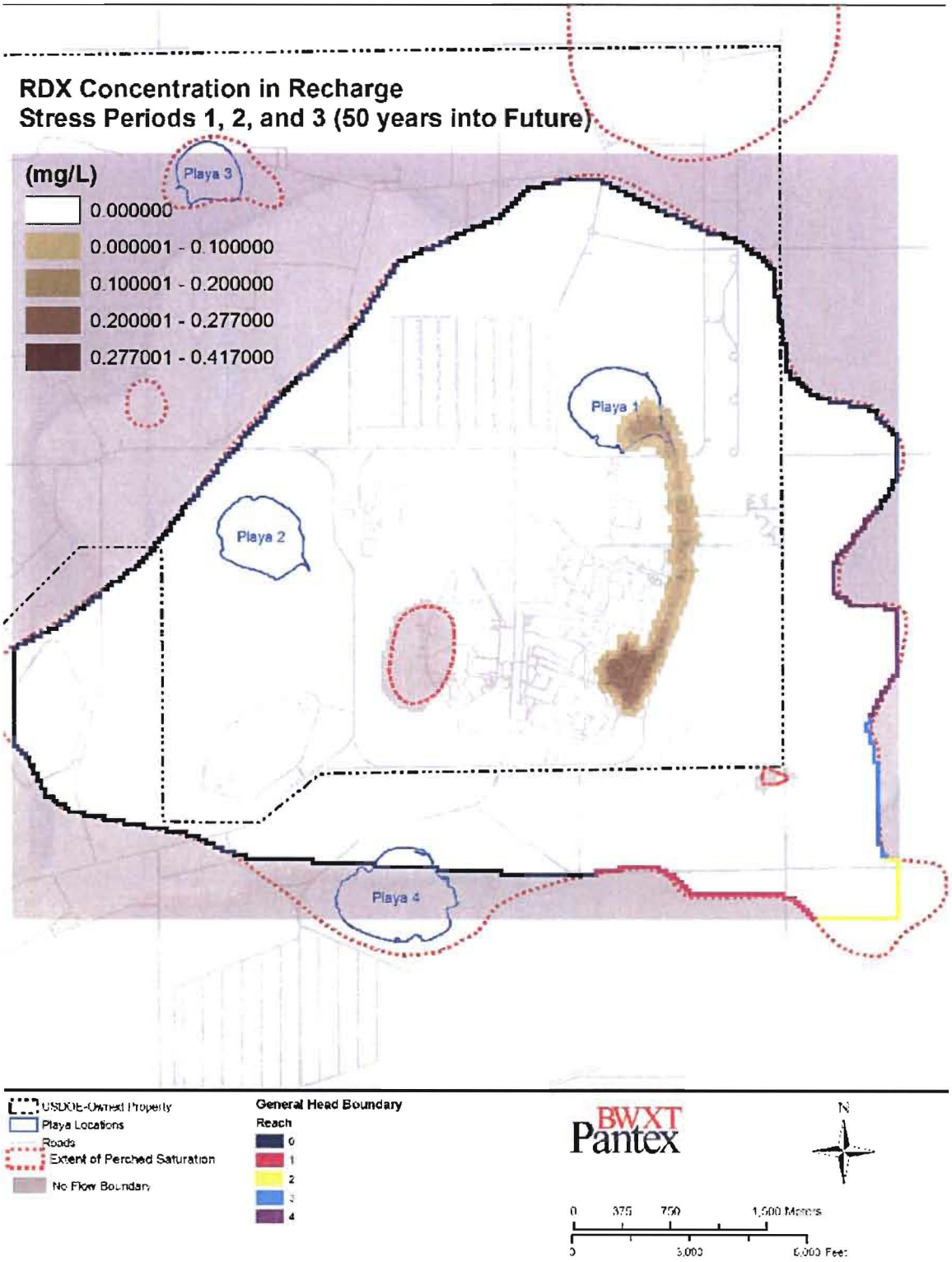


Figure A-14. Screening Model RDX Source Area Application

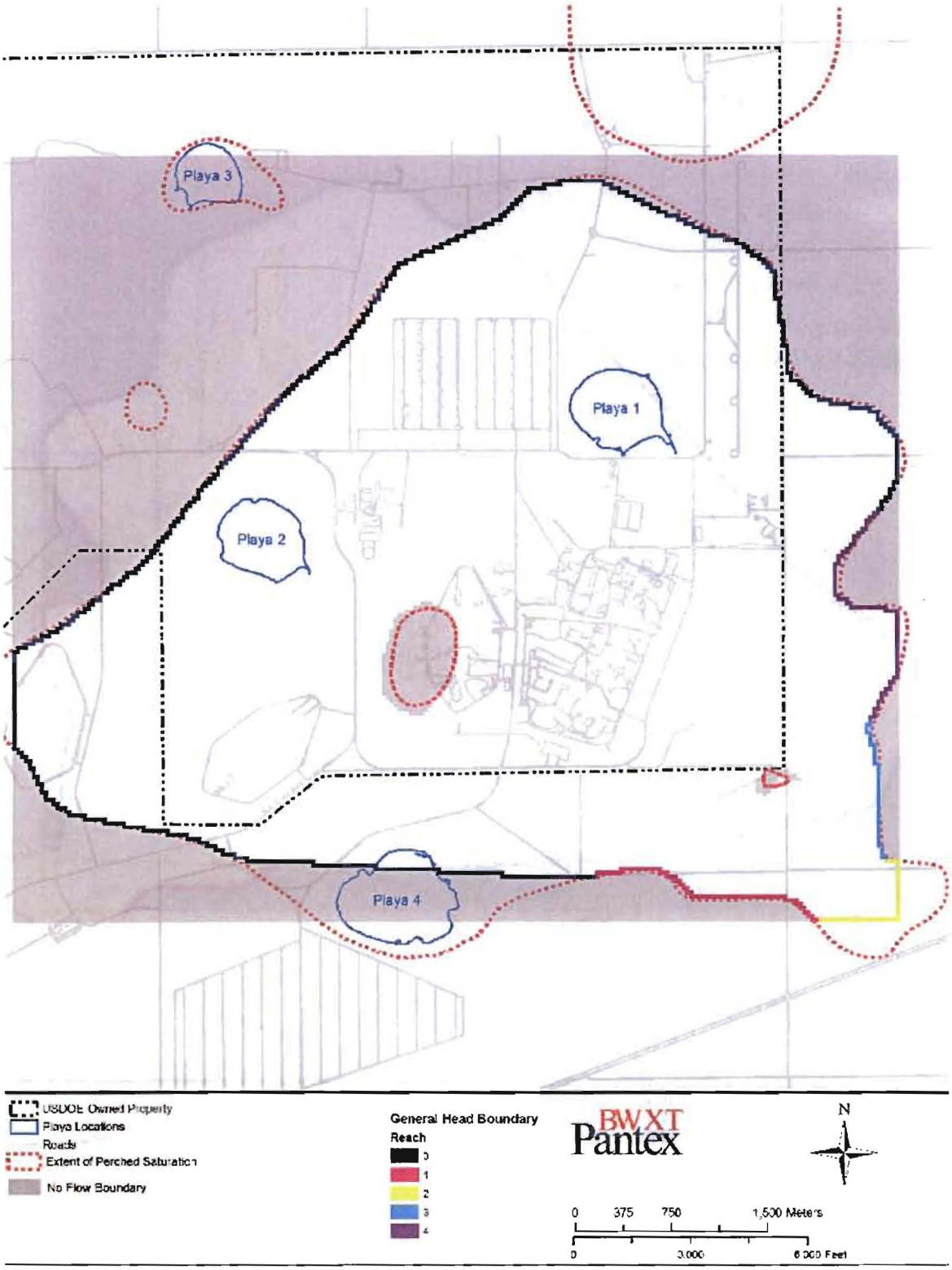


Figure A-15. Screening Model Boundary Conditions

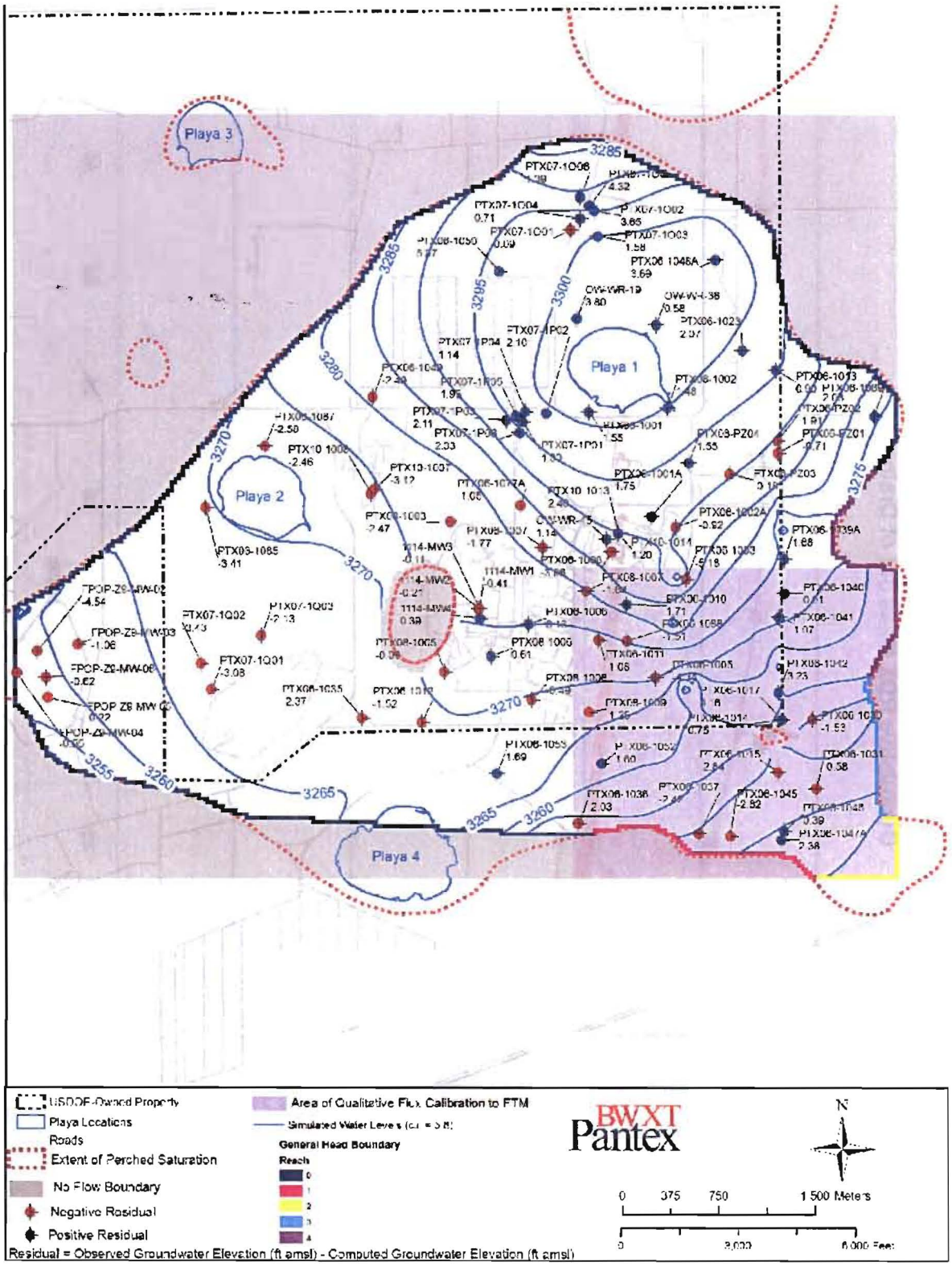


Figure A-16. Calibration Targets and Residuals

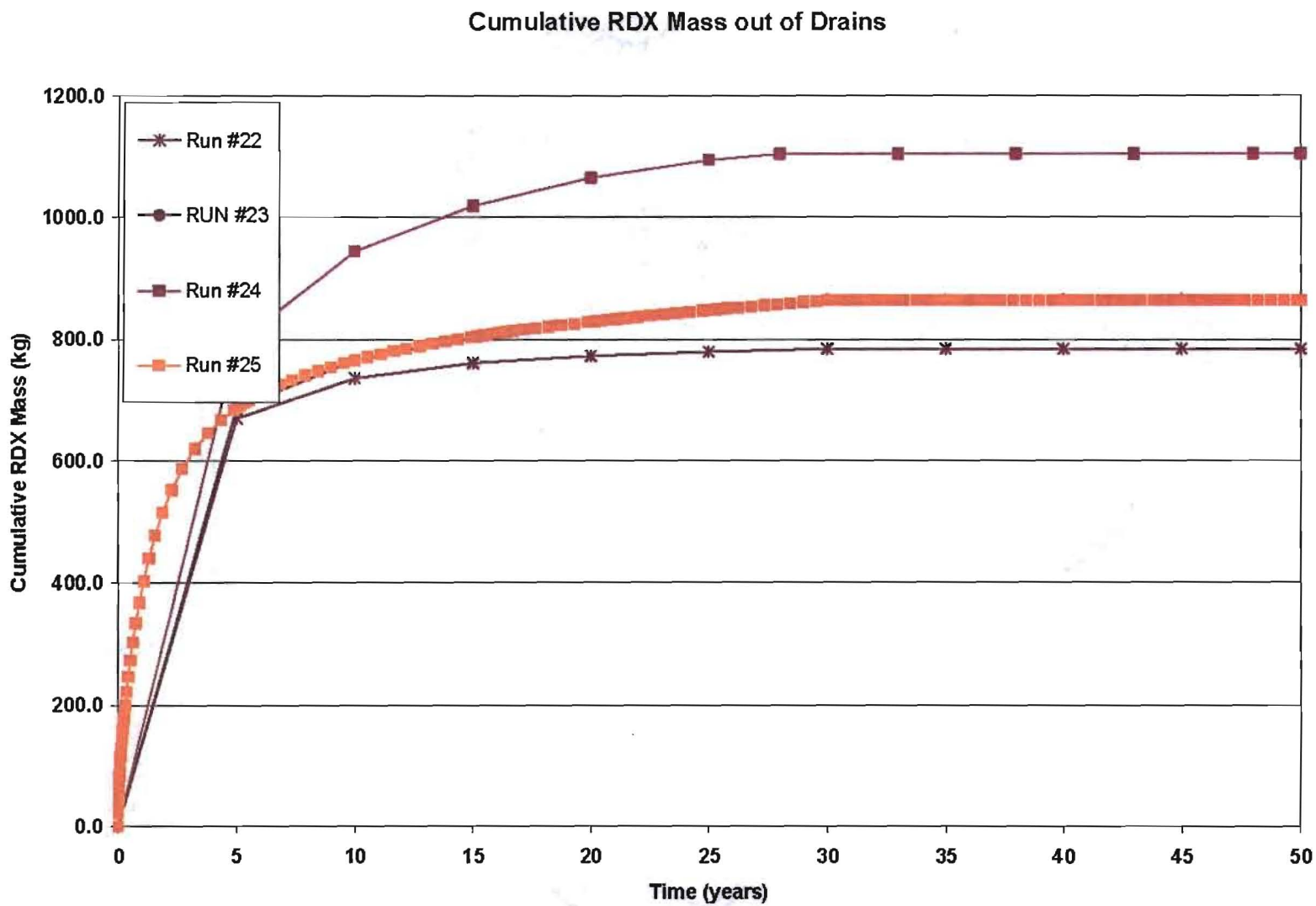


Figure A-17. RDX Mass Flux from Horizontal Wells for Selected Models

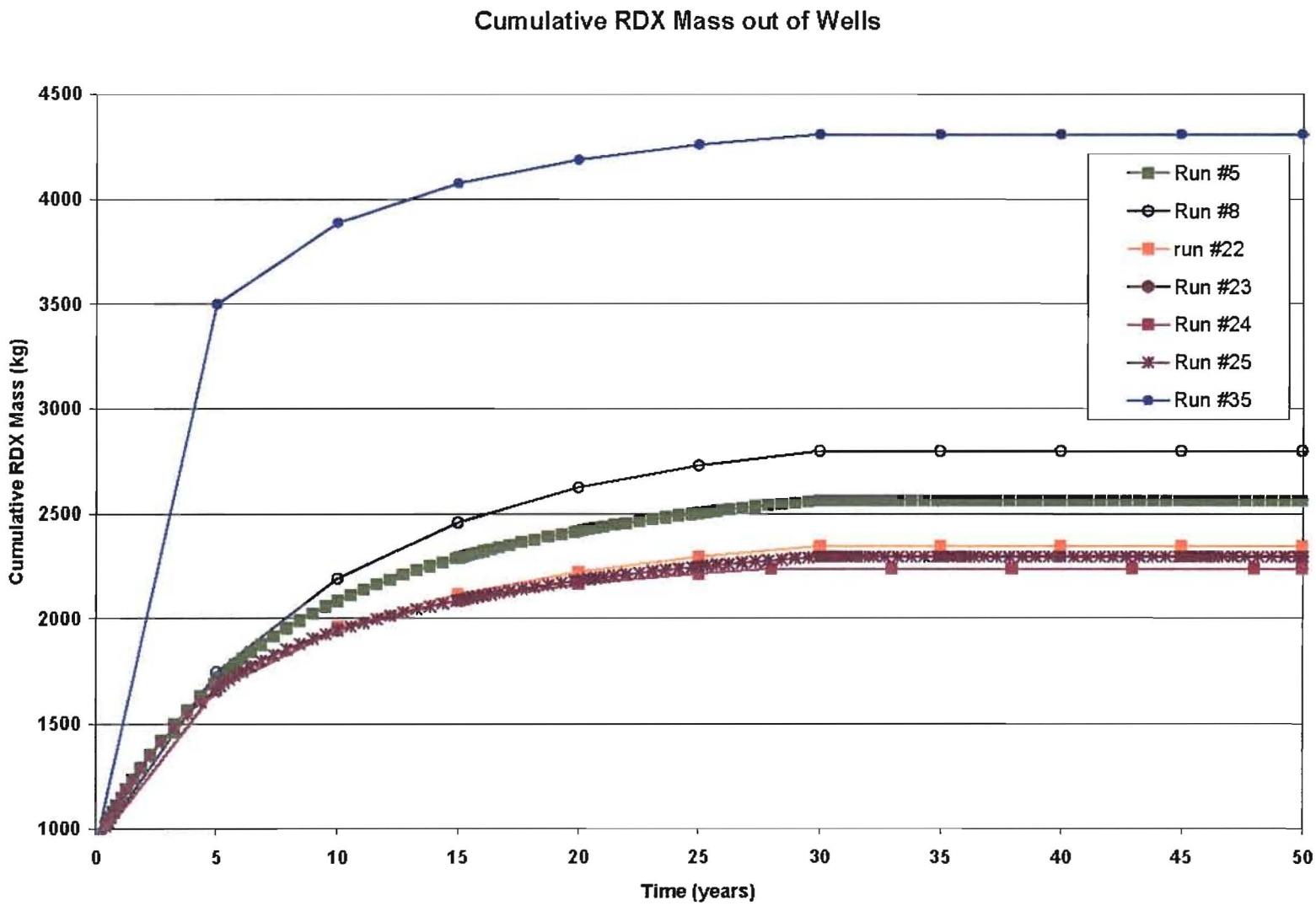


Figure A-18. RDX Mass Flux from Vertical Wells for Selected Models

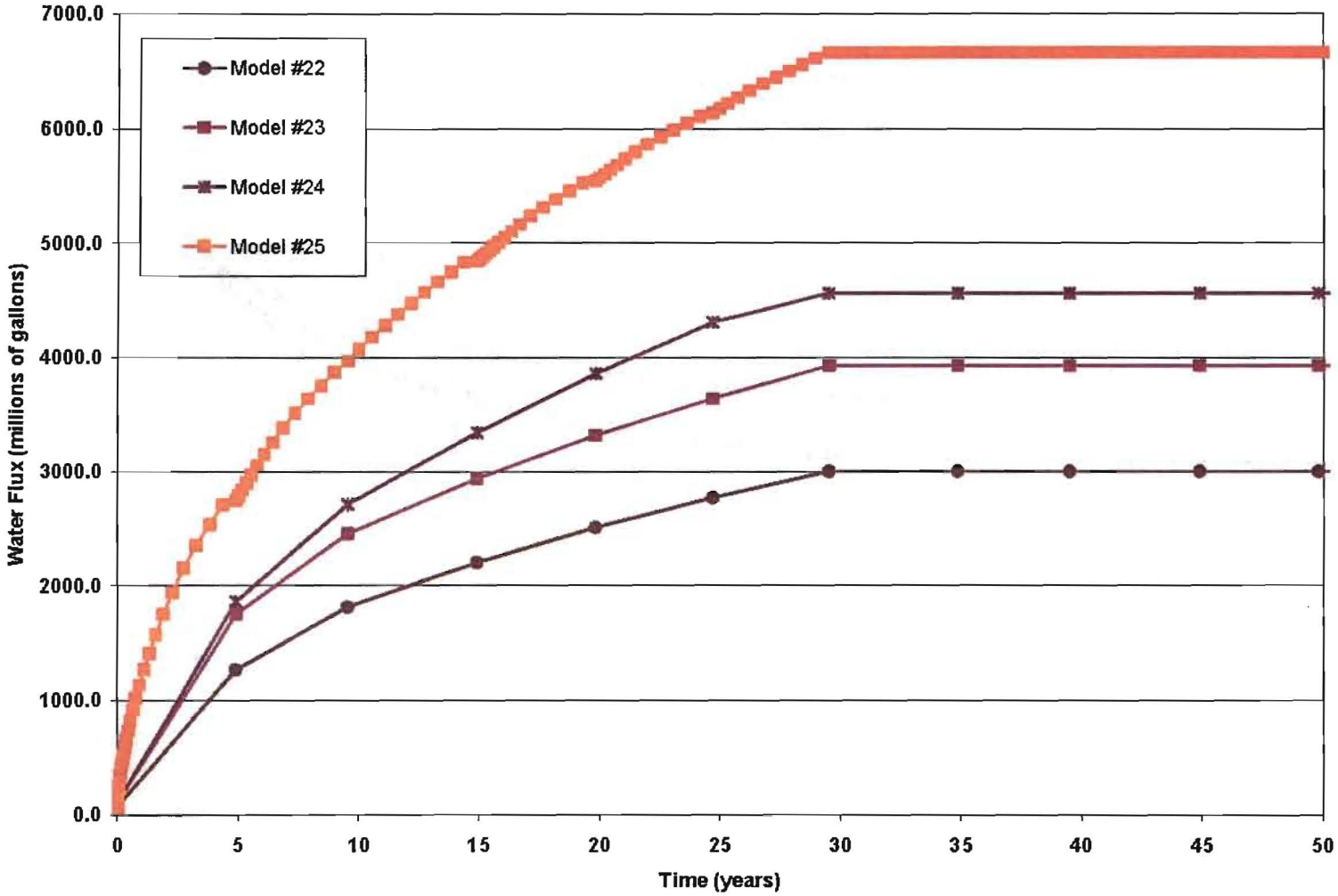
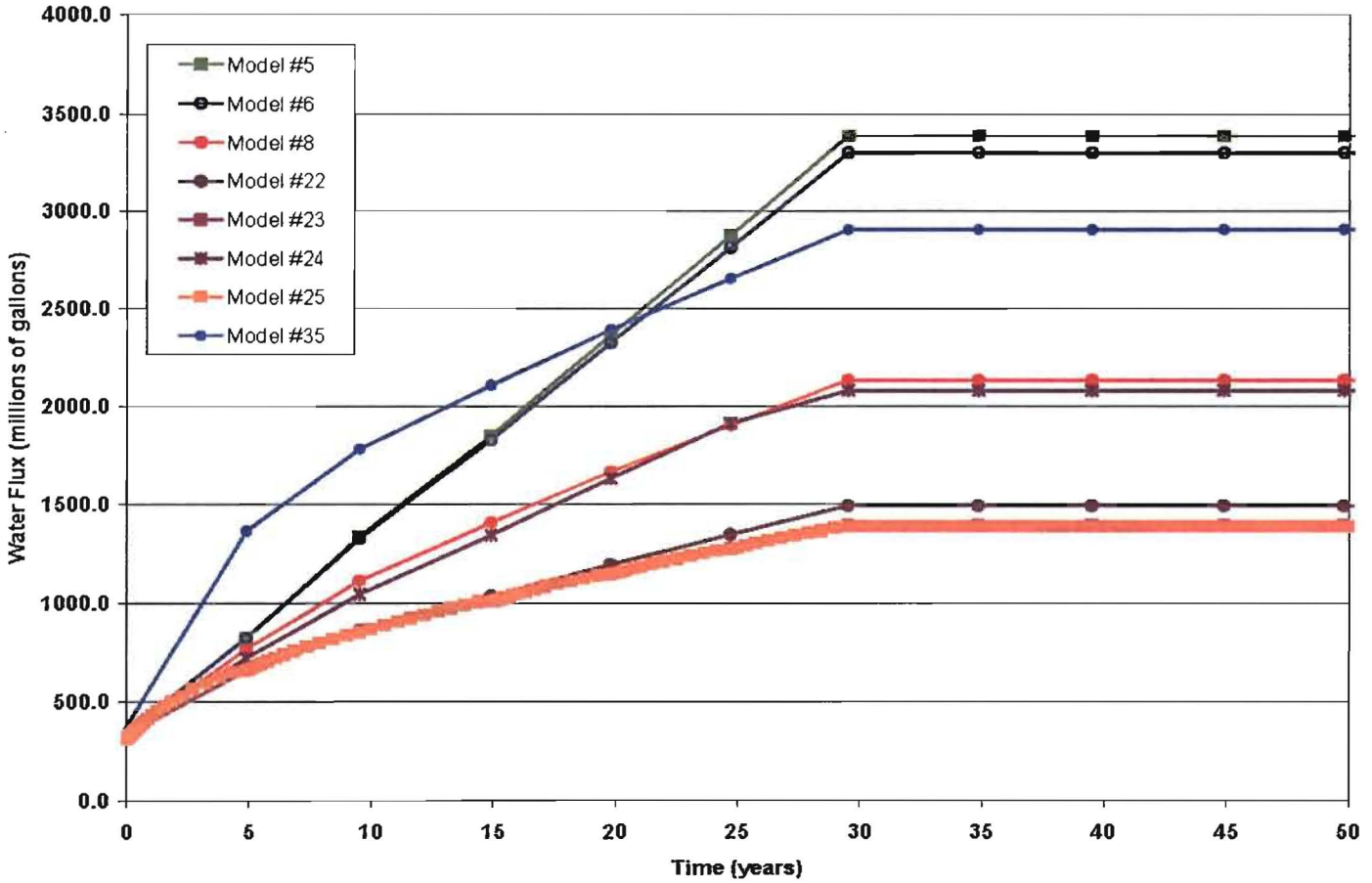


Figure A-19. Water Flux from Horizontal Wells for Selected Models



All SLM modeling scenarios included an initial 3-year transient calibration period in which water was were removed via the existing pump and treat system, and this water volume is included in the total volume extracted numbers reported here for Runs 5, 8, 22, 23, 24, 25 and 35.

Figure A-20. Water Flux from Vertical Wells for Selected Models

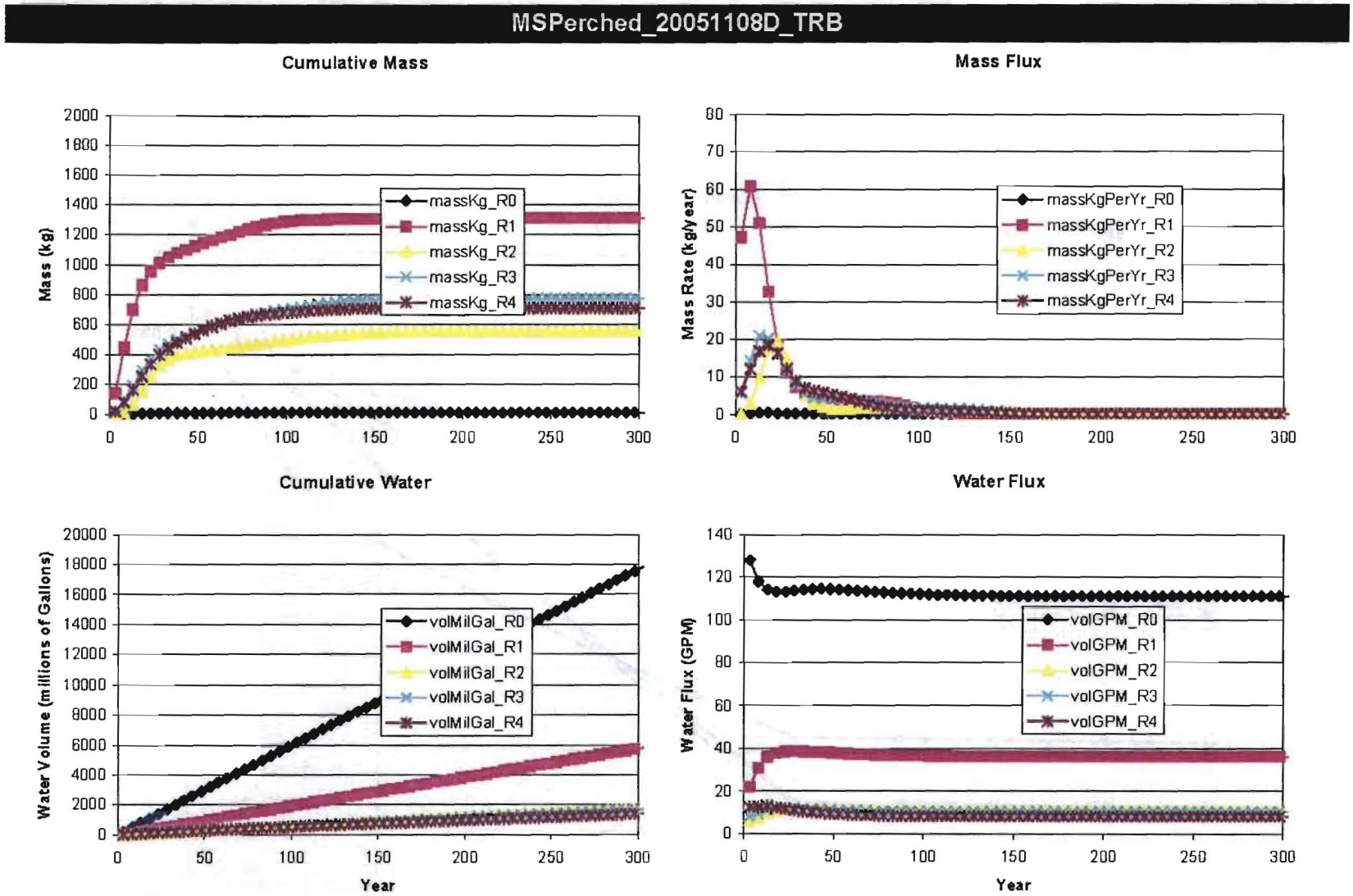


Figure A-21. Run #1 GHB Reach RDX and Water Flux Over Time

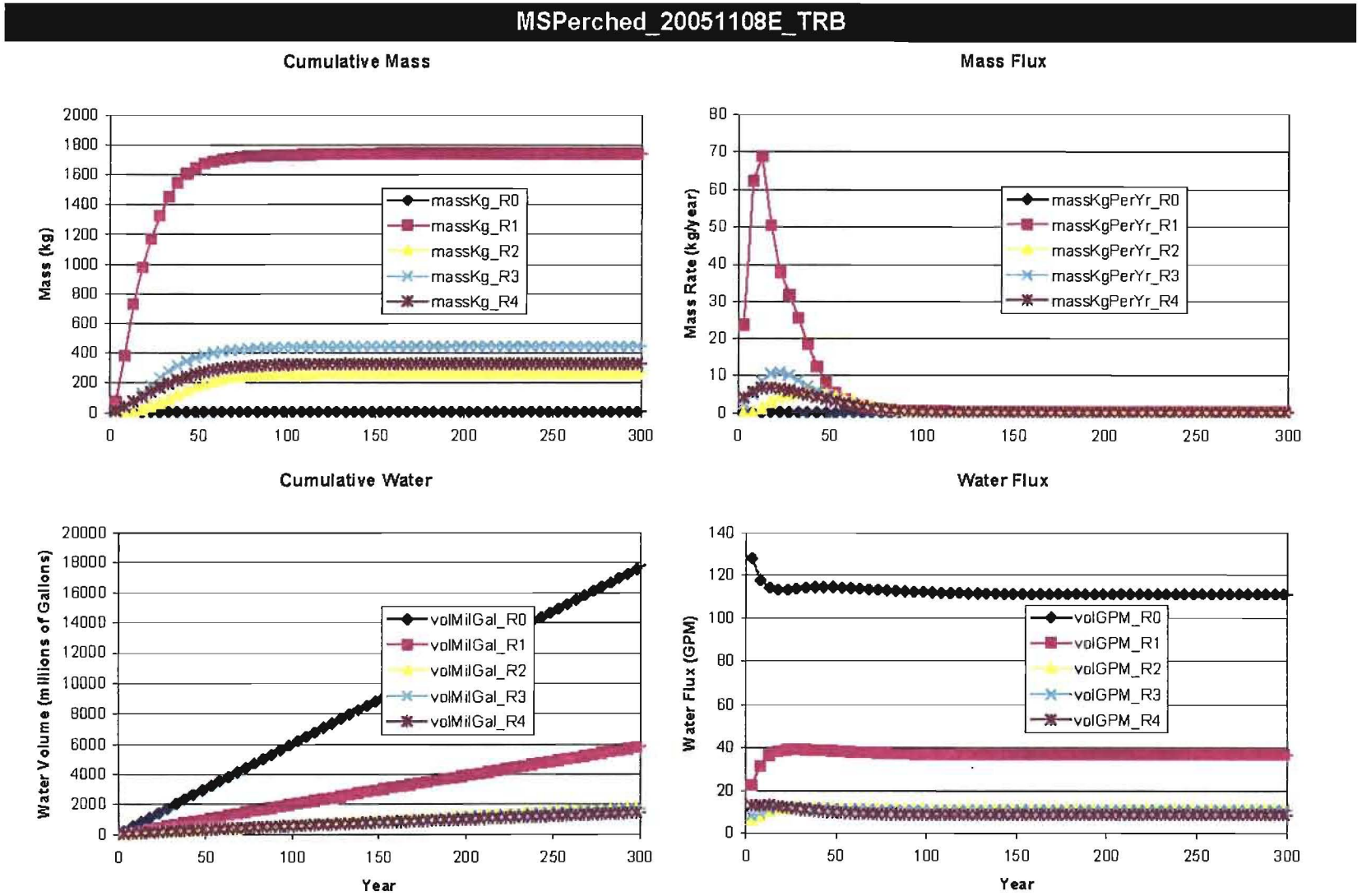


Figure A-22. Run #2 GHB Reach RDX and Water Flux Over Time

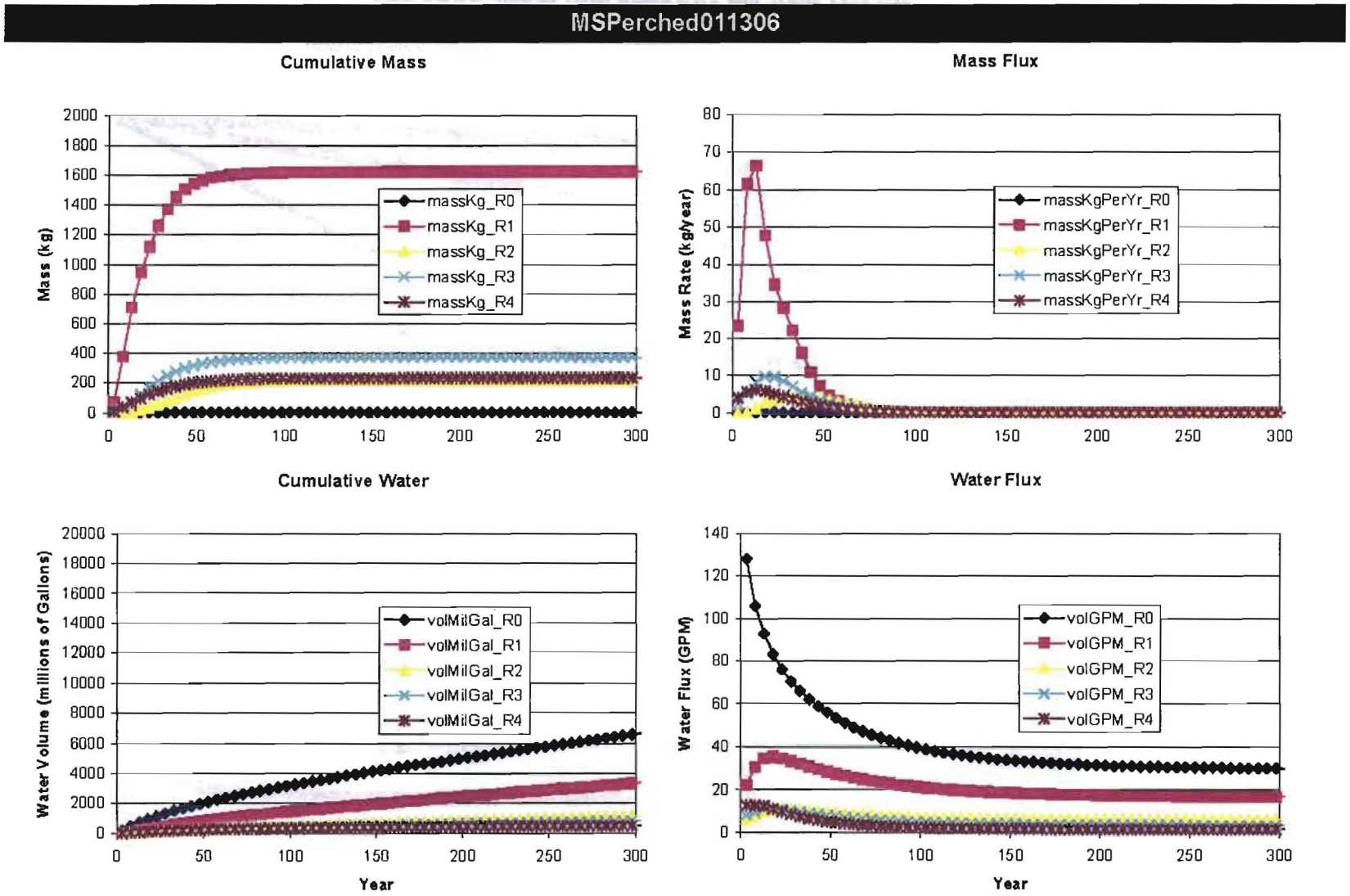


Figure A-23. Run #3 GHB Reach RDX and Water Flux Over Time

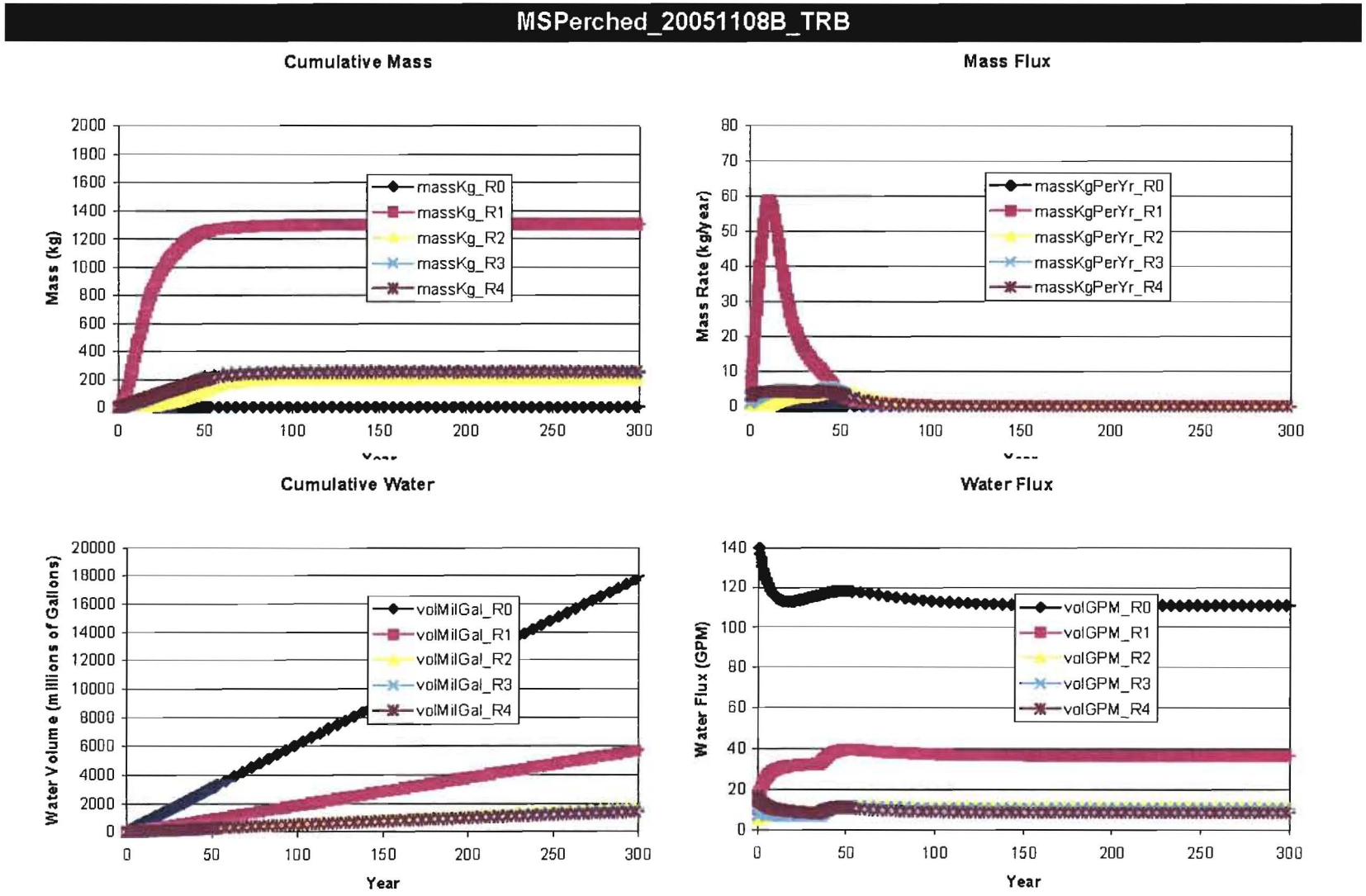


Figure A-24. Run #5 GHB Reach RDX and Water Flux Over Time

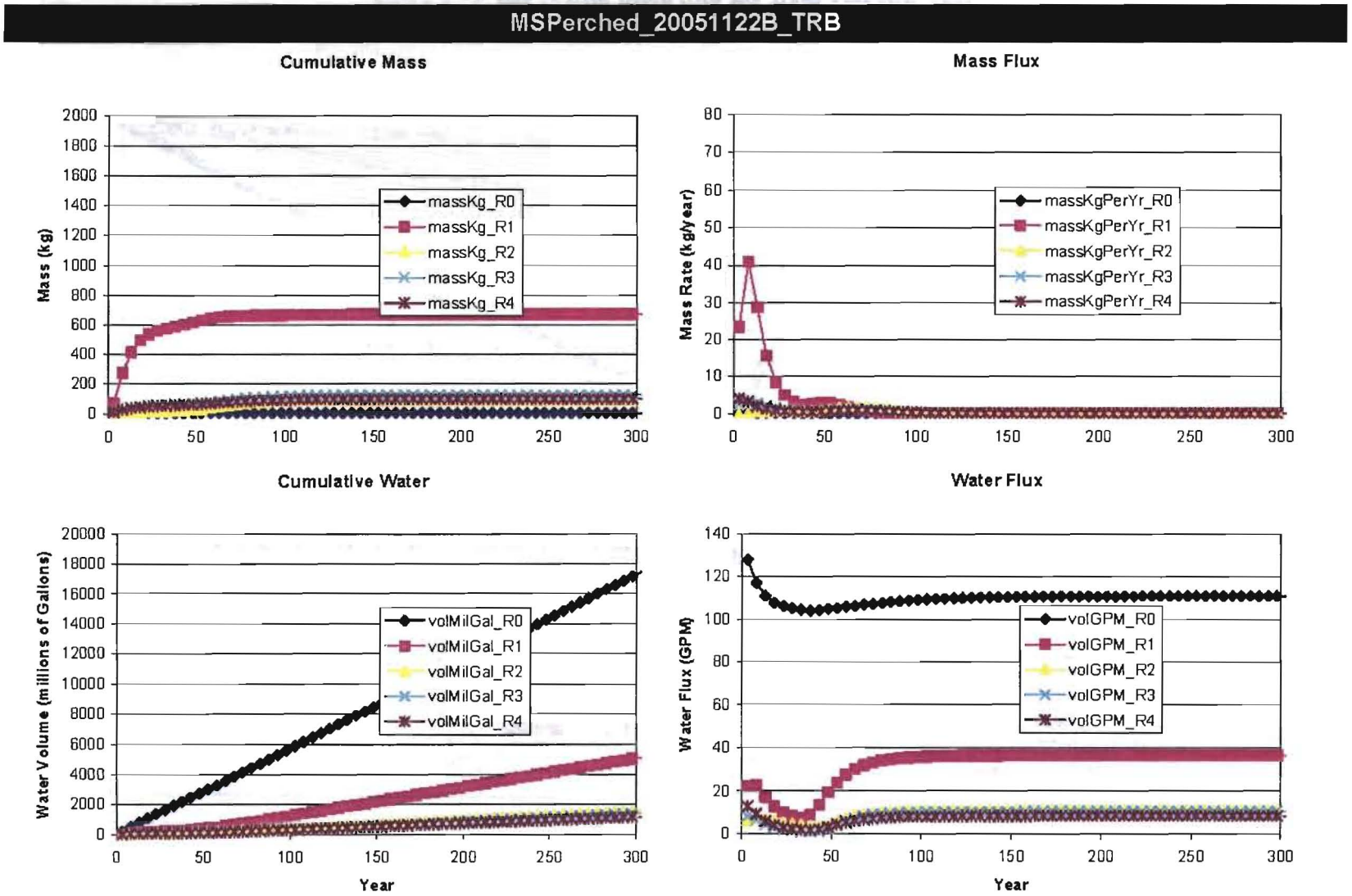


Figure A-25. Run #8 GHB Reach RDX and Water Over Time

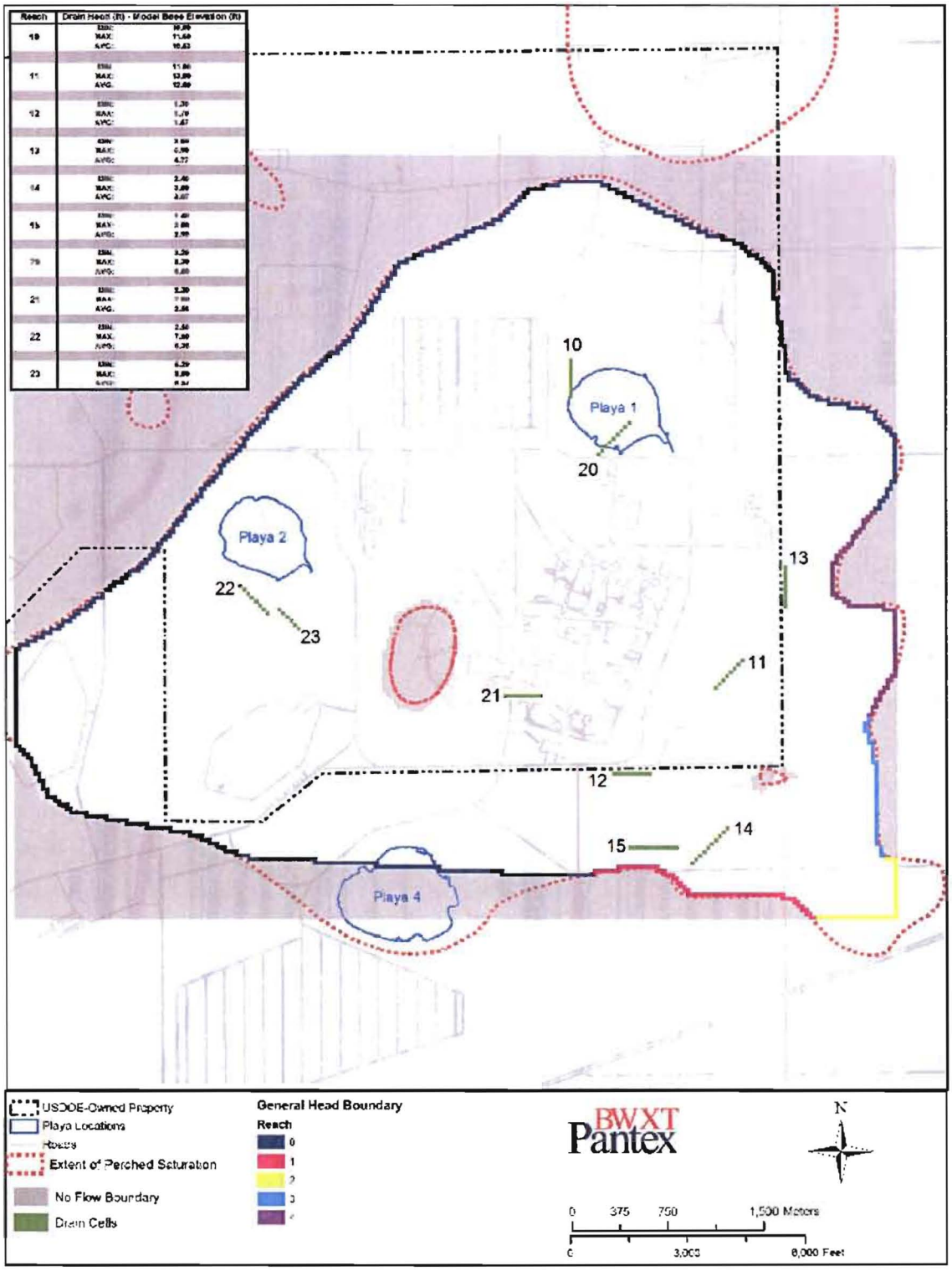


Figure A-26. Drain Reaches Representing Horizontal Well Placement

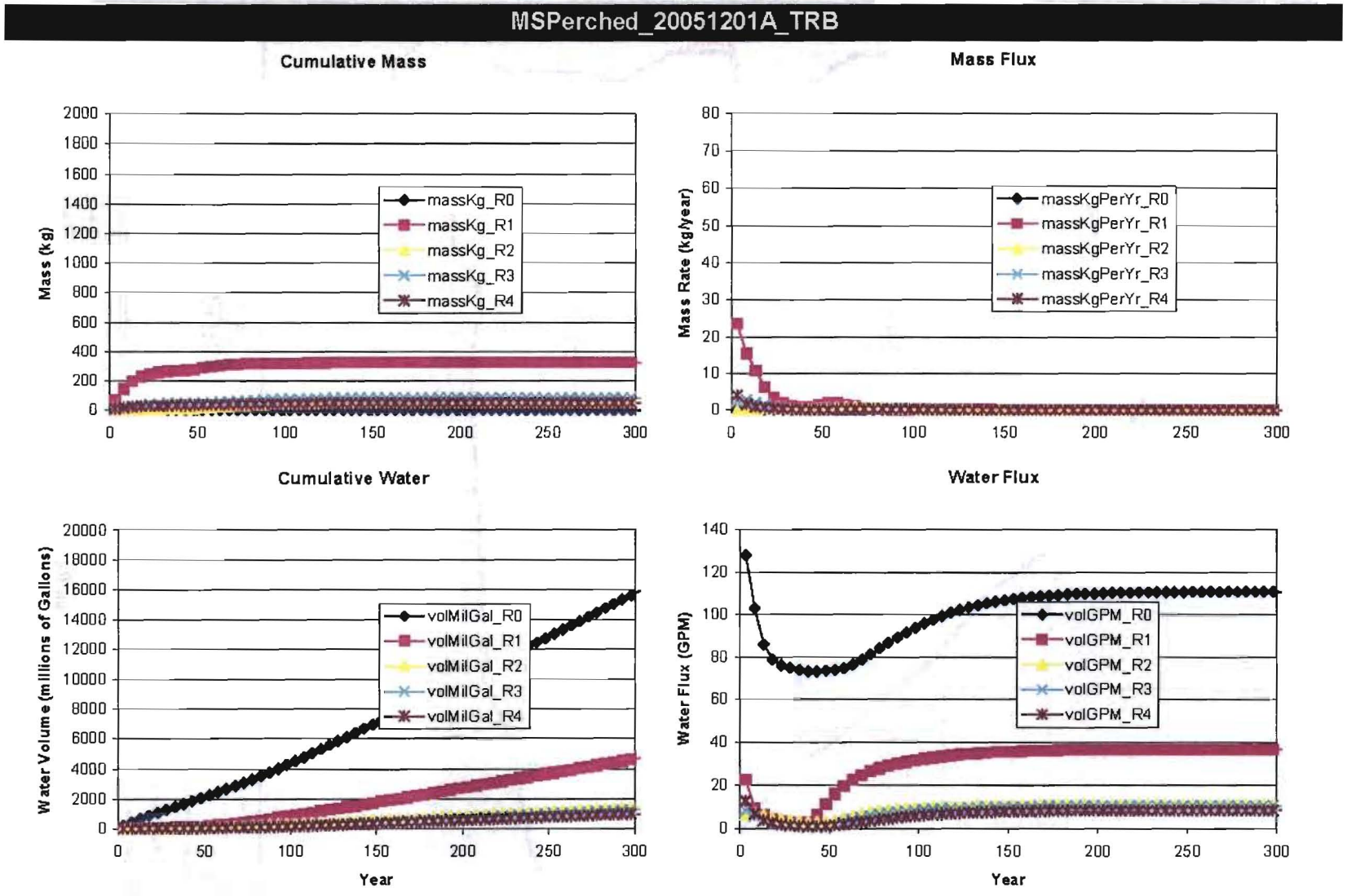


Figure A-27. Run #22 GHB Reach RDX and Water Flux Over Time

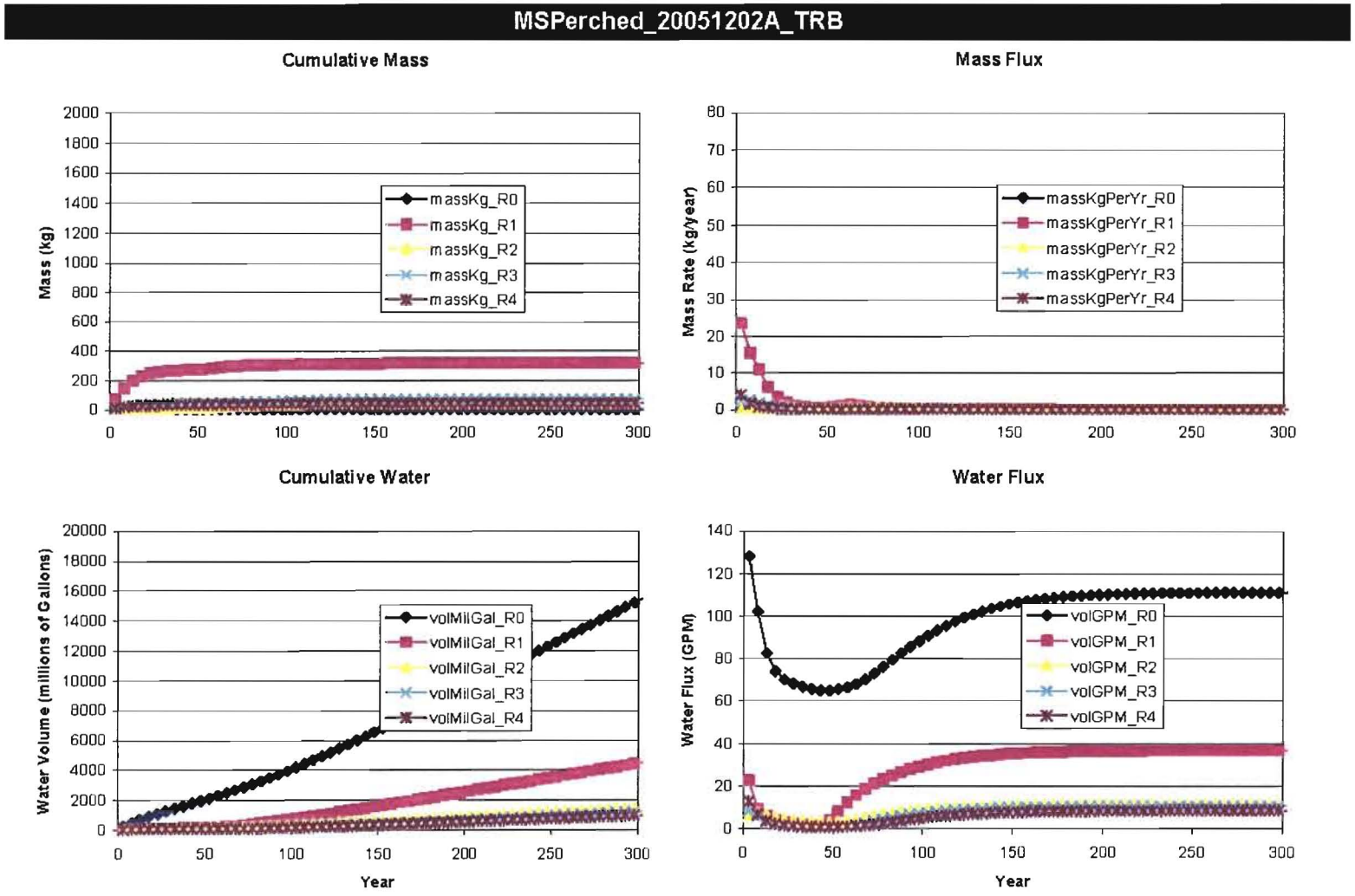


Figure A-28. Run #23 GHB Reach RDX and Water Flux Over Time

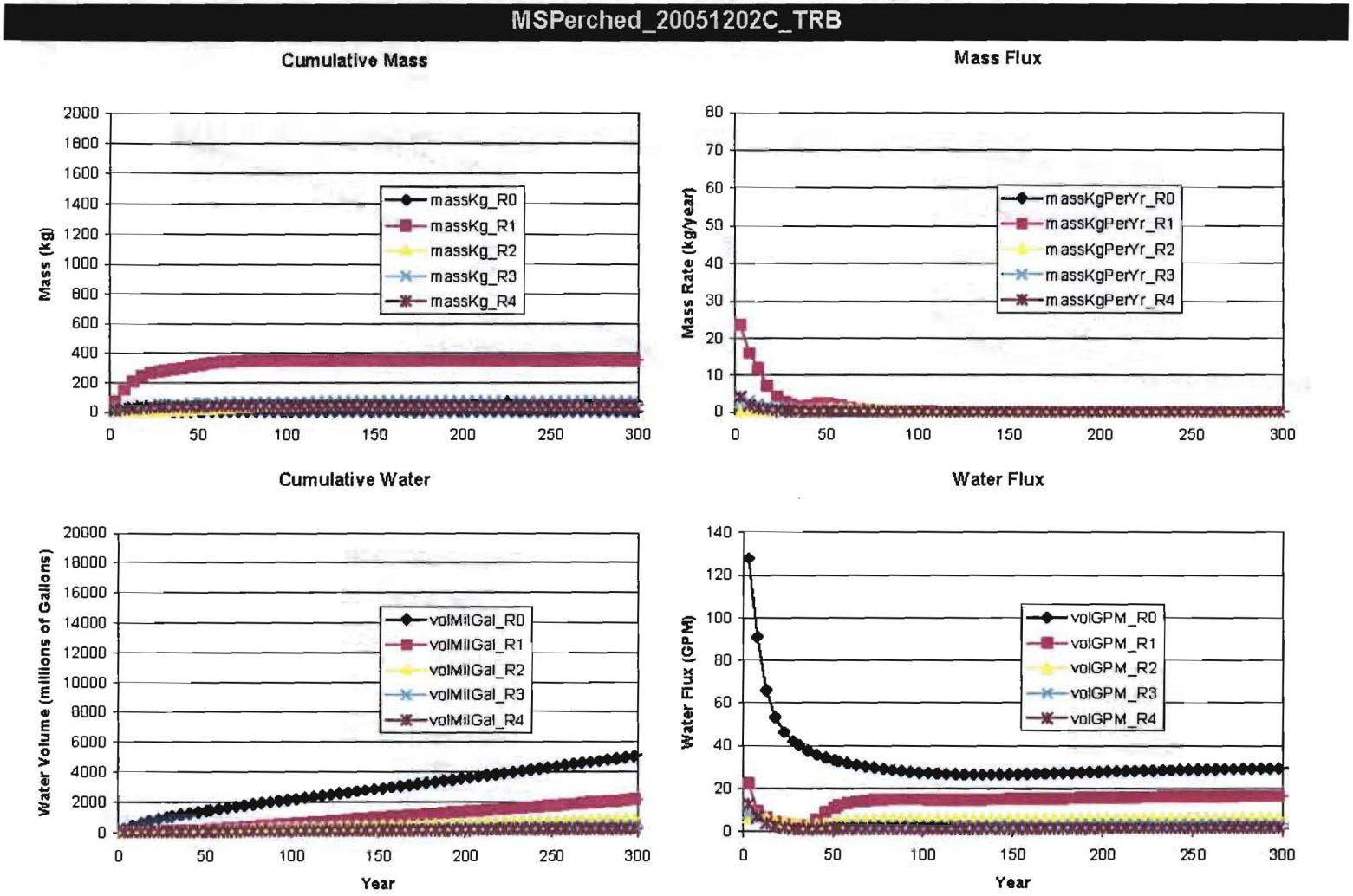


Figure A-29. Run #24 GHB Reach RDX and Water Flux Over Time

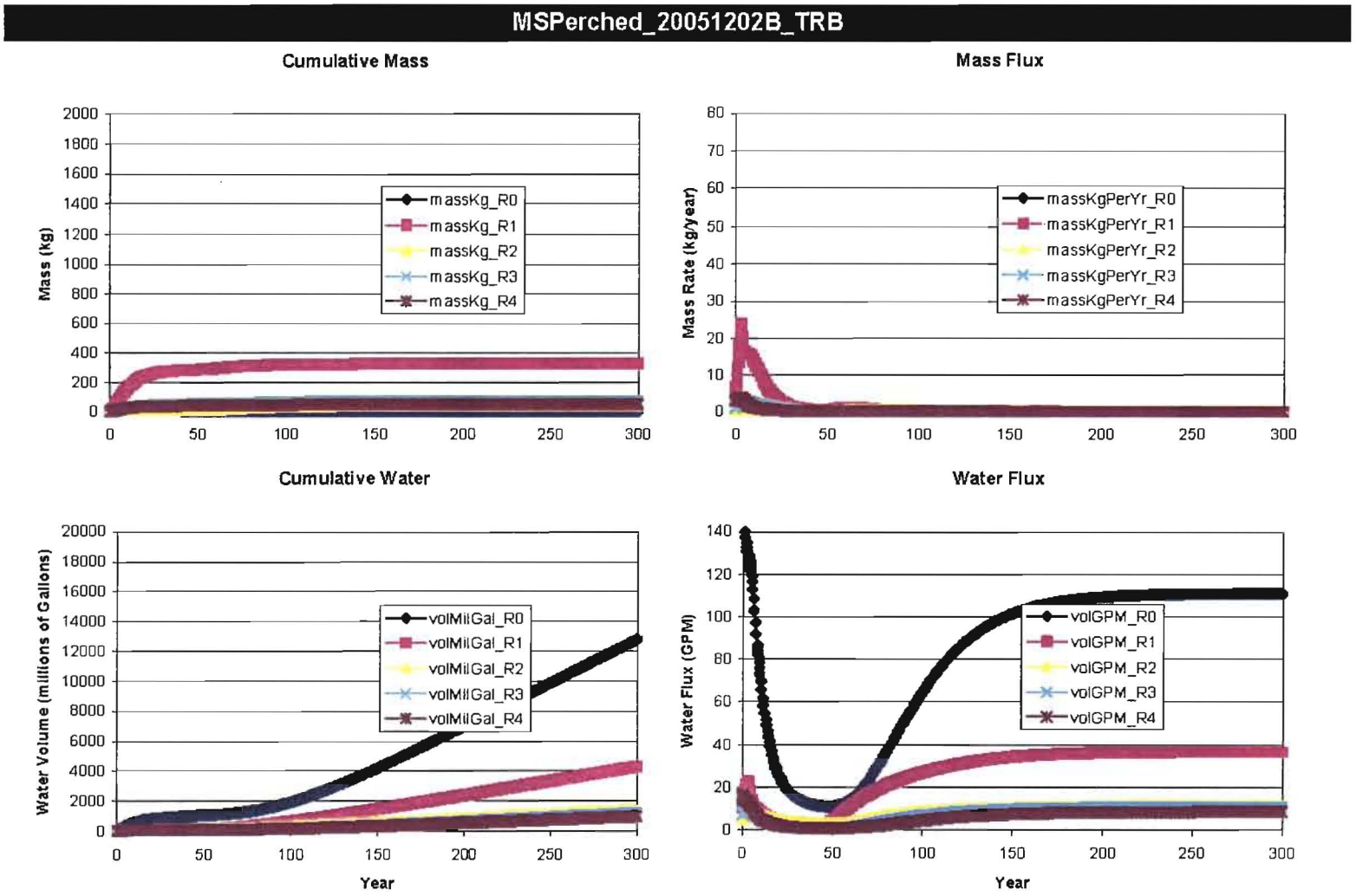


Figure A-30. Run #25 GHB Reach RDX and Water Flux Over Time

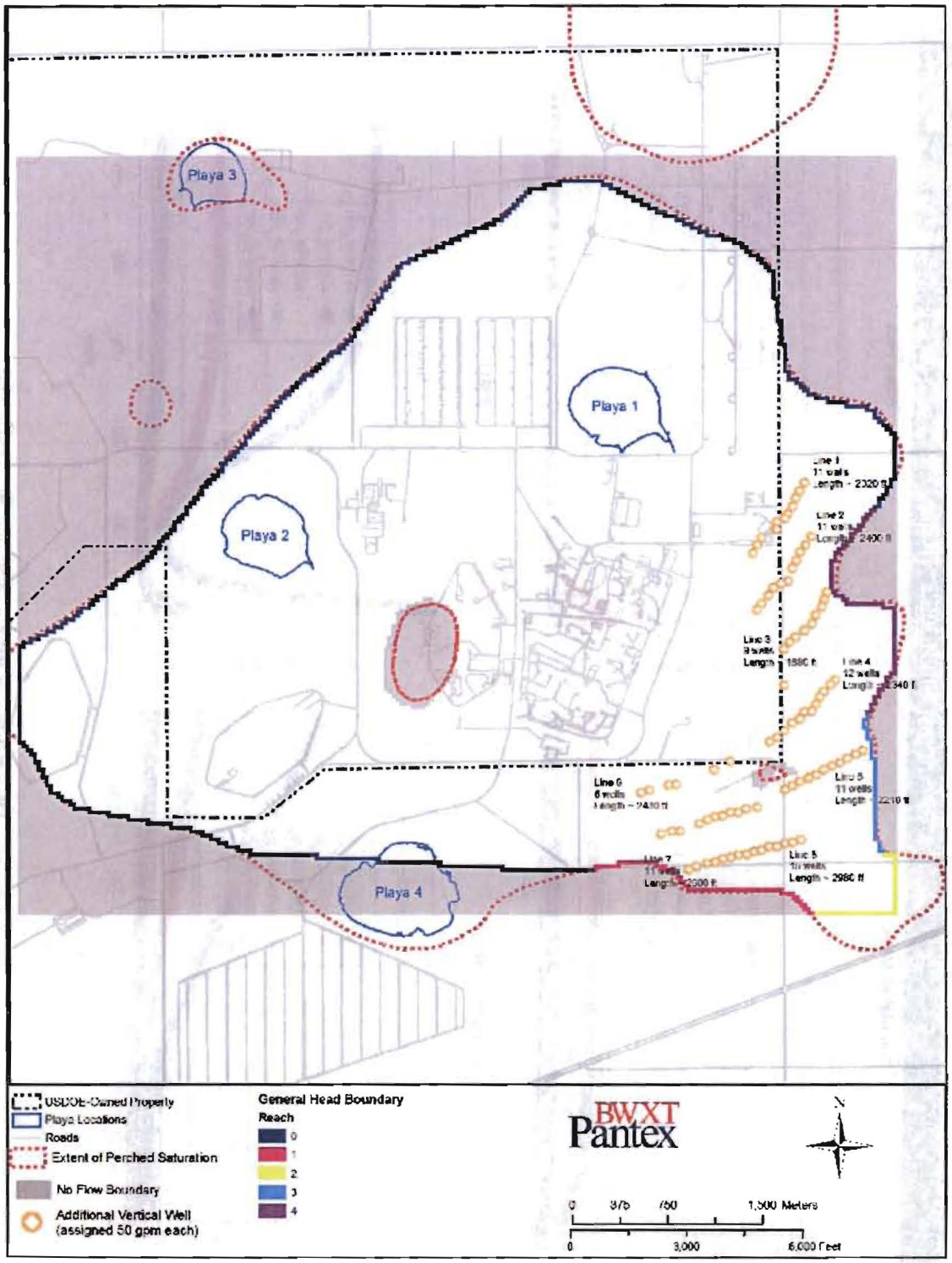


Figure A-31. Additional Vertical Wells

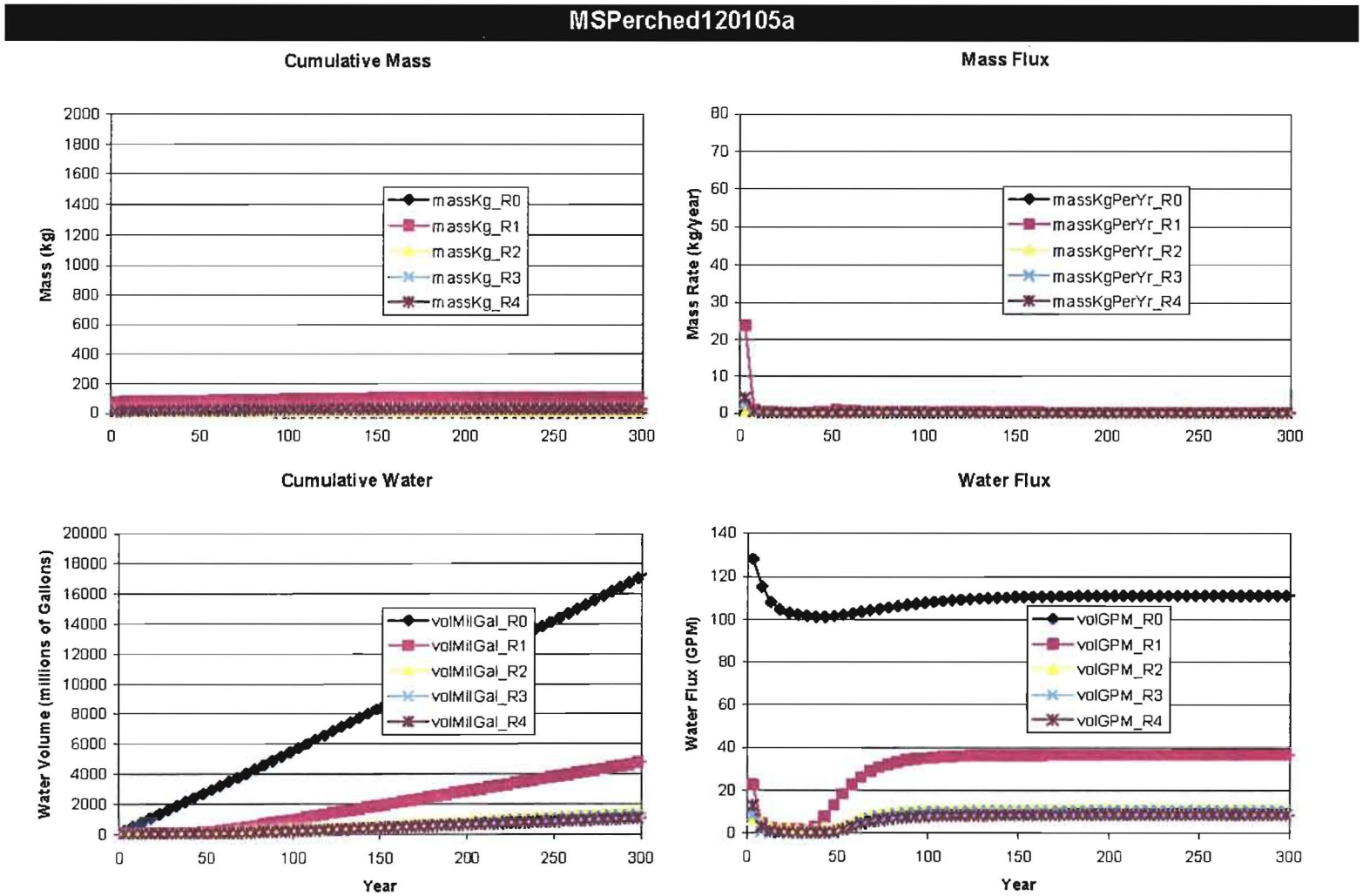


Figure A-32. Run #35 GHB Reach RDX and Water Flux Over Time

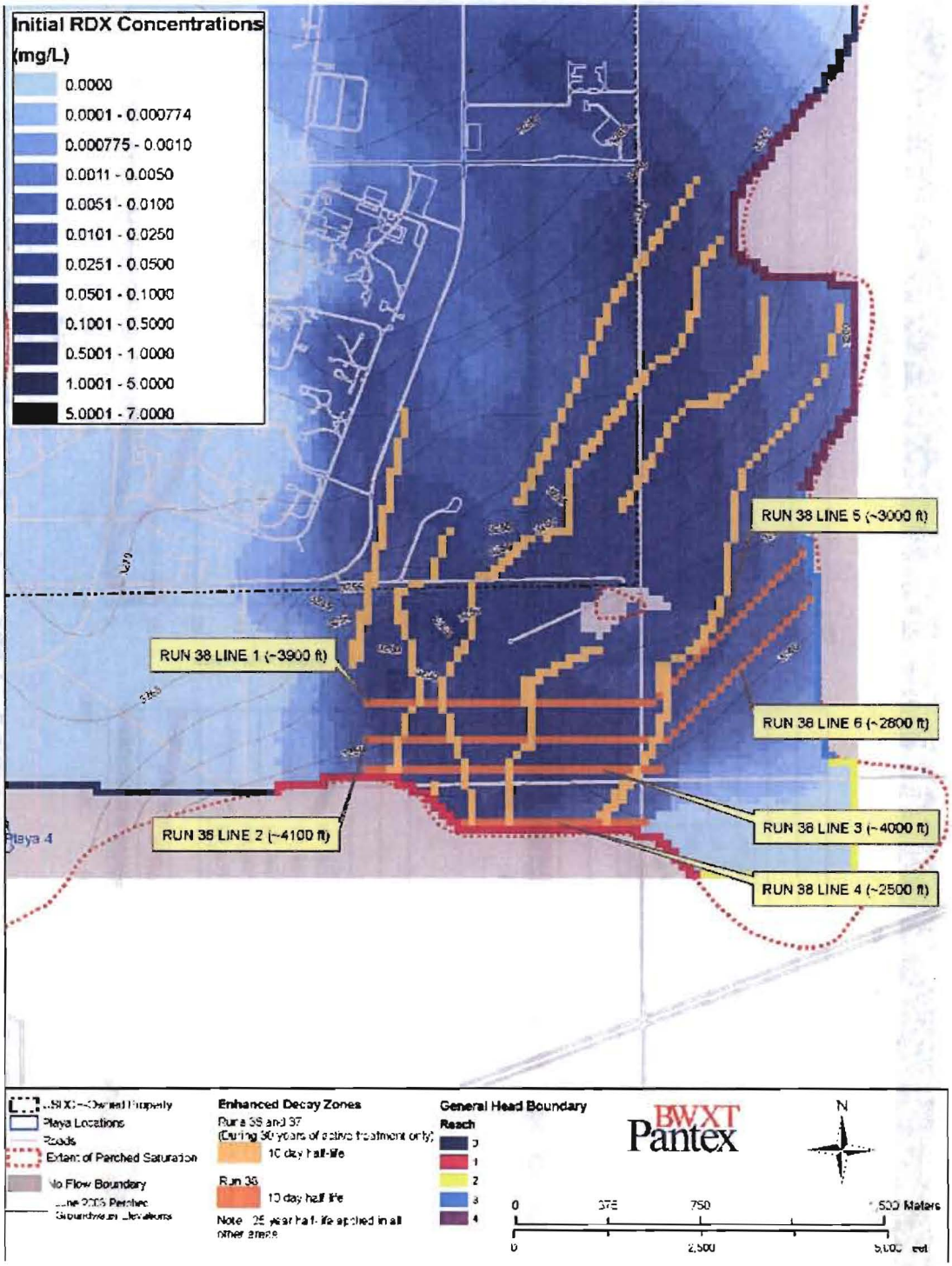


Figure A-33. Areas of Enhanced Biodecay Zones

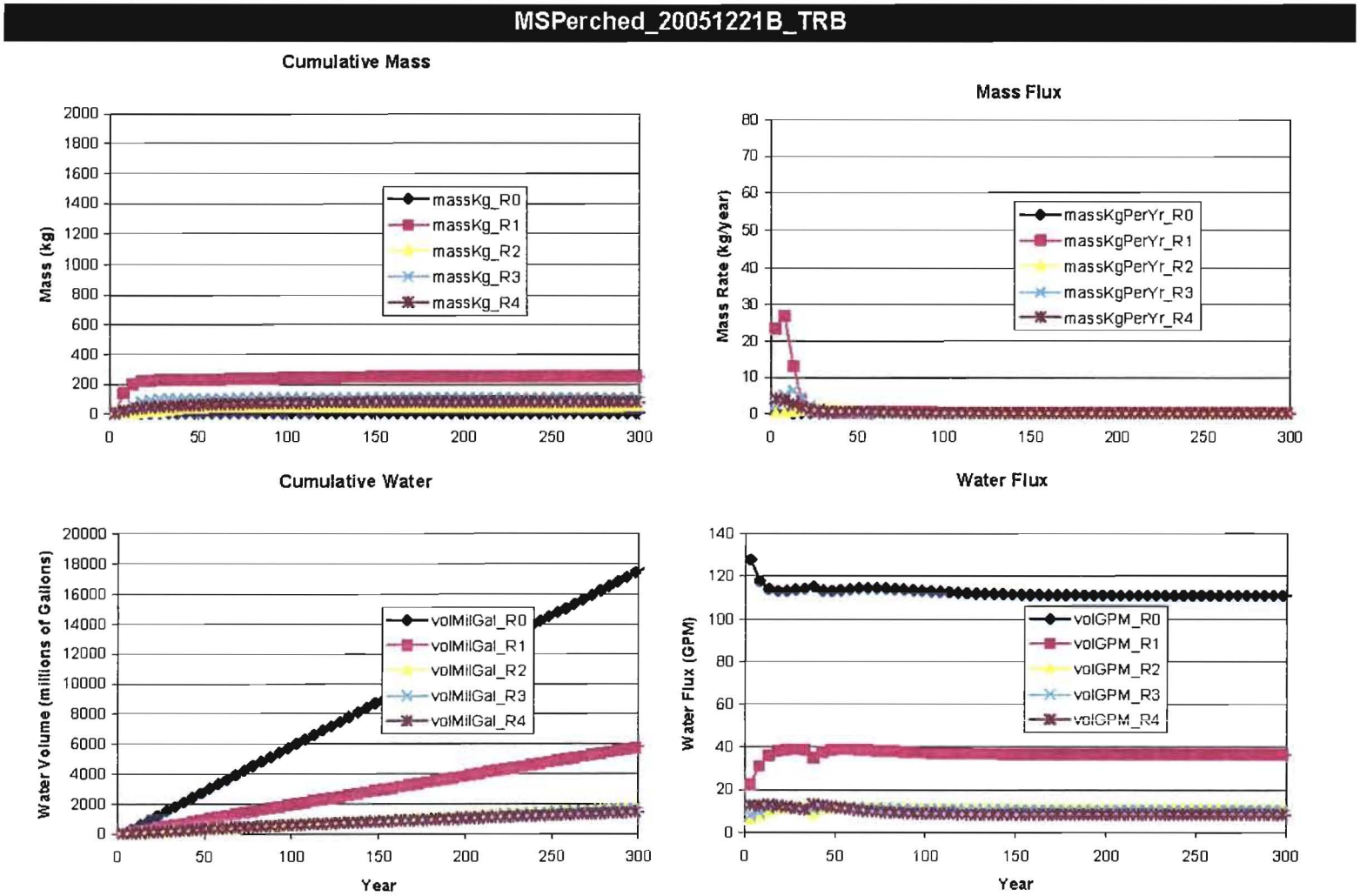


Figure A-34. Run #36 GHB Reach RDX and Water Flux Over Time

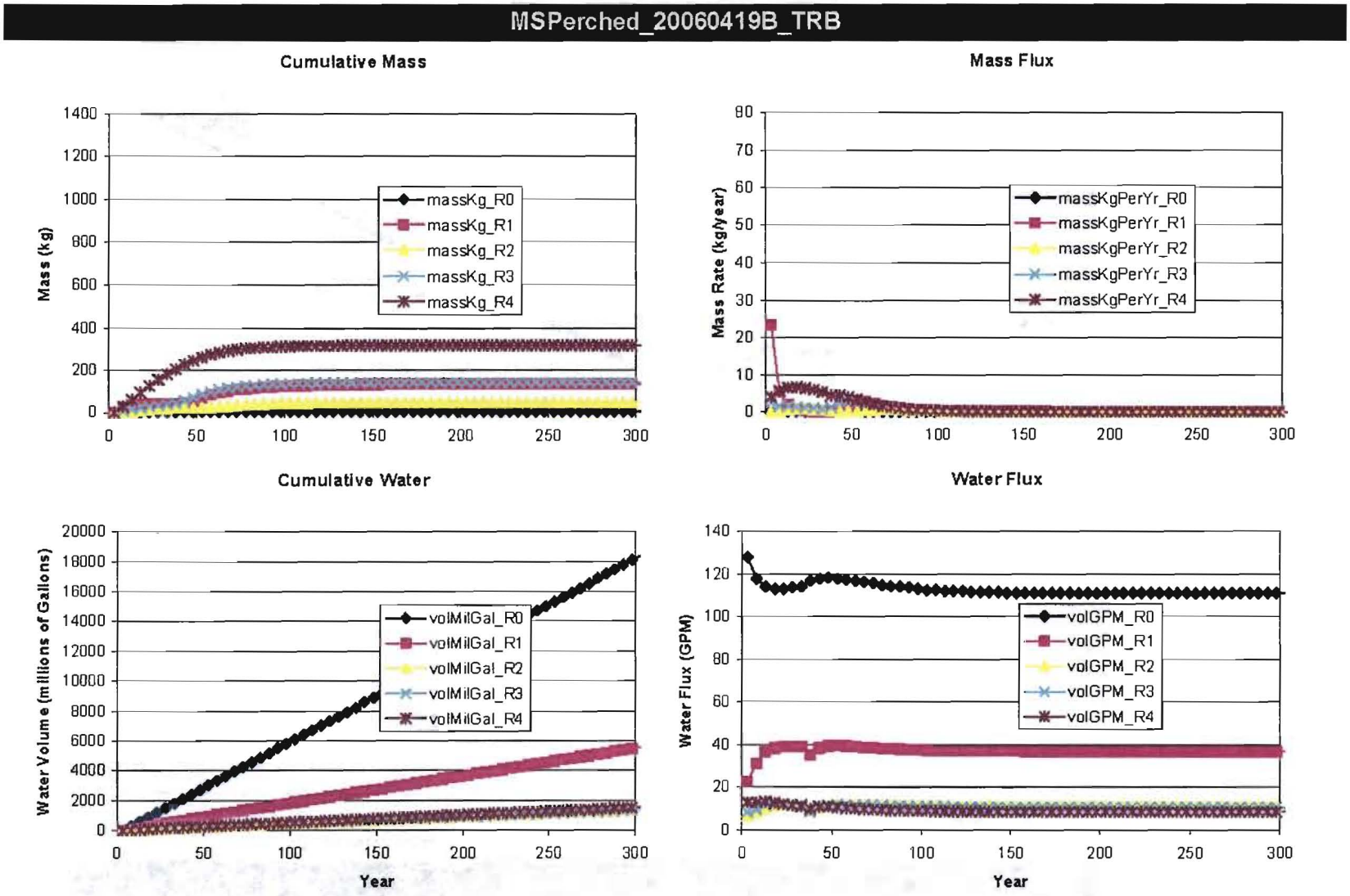


Figure A-35. Run #38 GHB Reach RDX and Water Flux Over Time

ATTACHMENTS 1A AND 2A
MODELING SIMULATIONS RANKING DETAILS
AND SUMMARY GRAPHS
CORRECTIVE MEASURE STUDY/FEASIBILITY STUDY
FOR THE USDOE/NNSA PANTEX PLANT
AMARILLO, TEXAS

Refer to Files on Attachment 1A CD

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Summary of Alternatives

Remedial Alternatives		Non Discounted Cost[a]				
		Capital Cost	Duration (yr)	O&M Cost	Duration (yr)	Total Cost
1	No Action	$0	0	$0	0	$0
2	Monitored Natural Attenuation (MNA)	$2,289,000	<1	$12,212,000	30	$14,501,000
3	Existing Pump and Treat	$3,193,000	1	$39,517,000	30	$42,710,000
4a	Enhanced Pump and Treat using Horizontal Wells	$15,629,000	1	$89,693,000	30	$105,322,000
4b	Enhanced Pump and Treat using Vertical Wells	$11,286,000	2	$63,326,000	30	$74,612,000
5	MNA with Targeted Treatment	$45,267,000	2	$616,504,000	30	$661,771,000
5.1	Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite	$108,070,000	2	$100,937,000	30	$209,007,000
5.2	Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide	$22,240,000	2	$52,321,000	30	$74,561,000
5.3	Modification No. 3 - Chemical Oxidation using Potassium Permanganate	$45,267,000	2	$136,475,000	30	$181,742,000
R1	Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells	$8,262,000	2	$88,939,000	30	$97,201,000

Remedial Alternatives		Discounted Cost[b] (Nominal Rate = 3.1%)				
		Capital Cost	Duration (yr)	O&M Cost	Duration (yr)	Total Cost
1	No Action	$0	0	$0	0	$0
2	Monitored Natural Attenuation (MNA)	$2,289,000	<1	$6,850,849	30	$9,139,849
3	Existing Pump and Treat	$3,193,000	1	$24,462,000	30	$27,655,000
4a	Enhanced Pump and Treat using Horizontal Wells	$15,629,000	1	$56,475,000	30	$72,104,000
4b	Enhanced Pump and Treat using Vertical Wells	$11,286,000	2	$38,745,000	30	$50,031,000
5	MNA with Targeted Treatment	$45,267,000	2	$442,150,000	30	$487,417,000
5.1	Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite	$108,070,000	2	$74,514,000	30	$182,584,000
5.2	Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide	$22,240,000	2	$37,345,000	30	$59,585,000
5.3	Modification No. 3 - Chemical Oxidation using Potassium Permanganate	$45,267,000	2	$107,763,000	30	$153,030,000
R1	Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells	$8,262,000	2	$56,173,000	30	$64,435,000

a. The guidance document used to develop these cost estimates is The Guide to Developing and Documenting Cost Estimates During the Feasibility Study prepared by the United States Environmental Protection Agency. July 2000. EPA 540-R-00-002.

b. The base year of comparison and cost data will be CY2005. The "real" discounted rates used to calculate present values are based on OMB Circular No. A-94 memorandum dated January 31, 2005.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 2 - Monitored Natural Attenuation (MNA)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	4.0	Survey for deed restrictions and monitoring wells. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	60	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500 Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Plans and Reports			
Corrective Action Completion Report	hrs	400	Includes reviewing construction QC data and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 2 - Monitored Natural Attenuation (MNA)
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			
Annual Sampling	years	30	Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect wells, signs, and complete checklist for annual report.
Field Labor	$/hr	60	
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 127 wells. Includes, mob, grout, backhoe, and truck. Existing wells that are not part of this alternative are not included.
Abandon Wells	$/lot	2,661,370	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 2 - Monitored Natural Attenuation (MNA)
Cost Estimate

CAPITAL COST $2,288,690

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	4	$875.00	$3,500
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	60	$50.00	$3,000
Install Signs on Post (ea)	20	$136 50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Plans and Reports			
Corrective Action Completion Report (hrs)	400	$85.00	$34,000
Subtotal			$1,344,390
Design		8%	$107,551
Office Overhead		5%	$67,220
Field Overhead		15%	$201,659
Subtotal			$1,720,819
Profit		8%	$137,666
Contingency		25%	$430,205
Total			$2,288,690

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 2 - Monitored Natural Attenuation (MNA)
Cost Estimate

OPERATION AND MAINTENANCE $12,212,180

Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M Sampling & Analysis (Years 0-30)				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$2,661,370	$2,661,370	$1,064,989
Subtotal			$7,756,720	$4,351,403
Design		8%	$620,538	$348,112
Office Overhead		5%	$387,836	$217,570
Field Overhead		15%	$1,163,508	$652,710
Subtotal			$9,928,602	$5,569,796
Profit		8%	$794,288	$445,584
Contingency		15%	$1,489,290	$835,469
Total			$12,212,180	$6,850,849

TOTAL ALTERNATIVE CAPITAL AND O&M COST $14,500,870

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 3 - Existing Pump and Treat
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	4.0	Survey for deed restrictions and monitoring wells. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area. RSMeans 01107 700 0600.
Civil Survey Monuments	$/ea	108	
Survey Drawings	hours	60	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above RSMeans 028907000100 & 1500. Add 50% for custom letters
Install Signs on Posts	$/ea	136 50	
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Detention Pond and Sprinkler System			Includes detention pond to hold 30 days of extraction system flow. Based on existing systems flow of 160,000 GPD. Total for 30 days = 4.8 million gallons. Assume 200 x 250 ft x 15 ft deep. Assumed bermed storage pond with 6 ft cut and 9 ft berm RSMeans G10301153150.
Earthwork (Cut and Fill)	cy	11,100	
Earthwork (Cut and Fill)	$/cy	5.09	
Liner	sf	69,600	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to pond (1 ea. 4-in lines @ 2,500-ft) and from pond to irrigation plot (1 ea. 4-in lines @ 500-ft). Includes 1 pump plus a backup pump from treatment bldg. to pond with electrical hookup. Cost based on RACER parametric model.
	$/lot	135,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 3 - Existing Pump and Treat
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Irrigation System	lot $/lot	1 250,000	Assume new irrigation system is constructed to accommodate the 160,000 GPD. Includes irrigating 200 acres using two each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes replacement sprinkler. Includes pumps, piping, and freeze protection at the sprinkler.
Plans and Reports			
Corrective Action Completion Report	hrs	400	Includes reviewing construction QC data and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 3 - Existing Pump and Treat
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
New Irrigation System	years	30	O&M of the sprinkler will be $148/acre and includes power and maintenance Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
	$/year	43,600	
Pump and Treat O&M	Years	30	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. Cost based on PANTEX existing system cost.
	$/year	534,500	
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			
Annual Sampling	years	30	Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect wells, signs, and complete checklist for annual report.
Field Labor	$/hr	60	
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 127 wells. Includes, mob, grout, backhoe, and truck. Existing wells that are not part of this alternative are not included
Abandon Wells	$/lot	2,661,370	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 3 - Existing Pump and Treat
Cost Estimate

CAPITAL COST $3,193,146

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100 00	$24,000
Site Work			
Civil Survey (day)	4	$875.00	$3,500
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	60	$50.00	$3,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Detention Pond and Irrigation System			
Earthwork (Cut and Fill) (cy)	11,100	$5.09	$56,499
Liner (sf)	69,600	$1.29	$89,784
Pumps and Piping (lot)	1	$135,000.00	$135,000
Irrigation System (lot)	1	$250,000 00	$250,000
Plans and Reports			
Corrective Action Completion Report (hrs)	400	$85.00	$34,000
Subtotal			$1,875,673
Design		8%	$150,054
Office Overhead		5%	$93,784
Field Overhead		15%	$281,351
Subtotal			$2,400,861
Profit		8%	$192,069
Contingency		25%	$600,215
Total			$3,193,146

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 3 - Existing Pump and Treat
Cost Estimate

OPERATION AND MAINTENANCE **$39,516,999**

Activity (unit)	Quantity	Unit Cost	Total	Present Value
New Irrigation System				
New Irrigation System (years)	30	$43,600	$1,308,000	$843,638
Pump and Treat O&M				
Pump and Treat O&M (years)	30	$534,500	$16,035,000	$10,342,301
O&M Sampling & Analysis (Years 0-30)				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$2,661,370	$2,661,370	$1,064,989
Subtotal			$25,099,720	$15,537,342
Design		8%	$2,007,978	$1,242,987
Office Overhead		5%	$1,254,986	$776,867
Field Overhead		15%	$3,764,958	$2,330,601
Subtotal			$32,127,642	$19,887,798
Profit		8%	$2,570,211	$1,591,024
Contingency		15%	$4,819,146	$2,983,170
Total			$39,516,999	$24,461,992

TOTAL ALTERNATIVE CAPITAL AND O&M COST **$42,710,145**

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4a - Enhanced Pump and Treat using Horizontal Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	20.0	Survey for deed restrictions, monitoring wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad.
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Treatment System Upgrades	ea	1	Based on existing treatment capacities, it is anticipated that the existing system will be able to treat the increased flow except for the chromium contaminated water. It is assumed that the existing system capacity of 150 GPM will need to be tripled. Included is an additional 300 GPM ion exchange system with piping. Cost based on PANTEX existing system cost and includes cost for placement of initial ion exchange canisters plus allowances for new piping, controls, canister units, shipping, and setup. Assume no additional building area is required.
	$/ea	350,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4a - Enhanced Pump and Treat using Horizontal Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Detention Pond and Sprinkler System			
Earthwork (Cut and Fill)	cy	38,700	Includes two detention ponds to hold 30 days of extraction system flow. Based on existing and new systems flow of 590,000 GPD. Total for 30 days = 17.7 million gallons. For Pond No. 1, assume 200 x 250 ft x 15 ft deep. For Pond No. 2, assume 400 x 310 ft x 15 ft deep. Assumed bermed storage pond with 6 ft cut and 9 ft berm. RSMeans G10301153150.
Earthwork (Cut and Fill)	$/cy	5.09	
Liner	sf	223,600	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model.
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to both ponds (1 ea. 6-in lines @ 7,100-ft) and from ponds to irrigation plots (multiple 4-in lines @ 11,000-ft). Includes 1 pump plus a backup pump from treatment bldg. to ponds with electrical hookup. Cost based on RACER parametric model.
	$/lot	590,000	
Irrigation System	lot	1	Assume new irrigation system is constructed to accommodate the 590,000 GPD. Includes irrigating 700 acres using six each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes two replacement sprinklers. Includes pumps, piping, and freeze protection at the sprinkler.
	$/lot	700,000	
Exploratory Holes			
Exploratory Boreholes	ea	102	Assume TD 280' (2-inch) - Includes Air Rotary Casing. Added $500 for IDW handling and disposal (100% nonhazardous).
Exploratory Boreholes	$/ea	18,500	
Enhanced Pump and Treat			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Horizontal Well Installation	ea	6	Includes installation of 6-in stainless steel horizontal wells. Average screen length is 1,100 lf at a depth of 280-ft. Includes drilling well, well installation, pump w/controls, secondary piping, Geologist, and IDW handling (100% nonhazardous). Cost based on RACER parametric model.
Horizontal Well Installation	$/ea	480,000	
Primary Piping	$/lot	864,000	Includes 17,000 LF of 6-in avg steel extraction piping. Cost based on RACER parametric model.
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4a - Enhanced Pump and Treat using Horizontal Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
Pump and Treat O&M	Years	30	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. The flow will increase by 300 GPM over the existing 110 GPM flow. The cost for the new and current system was calculated based on unit rates of the current system.
	$/year	1,509,000	
New Irrigation System Zone No. 1	years	30	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
	$/year	101,200	
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	years	30	
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect wells, signs, and complete checklist for annual report.
Field Labor	$/hr	60	
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 127 vertical and 6 horizontal wells. Includes, mob, grout, backhoe, and truck. Existing wells that are not part of this alternative are not included.
Abandon Wells	$/lot	3,568,570	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4a - Enhanced Pump and Treat using Horizontal Wells
Cost Estimate

CAPITAL COST $15,629,423

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	20	$875.00	$17,500
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Treatment System Upgrades	1	$350,000.00	$350,000
Detention Pond and Irrigation System			
Earthwork (Cut and Fill) (cy)	38,700	$5.09	$196,983
Liner (sf)	223,600	$1.29	$288,444
Pumps and Piping (lot)	1	$590,000.00	$590,000
Irrigation System (lot)	1	$700,000.00	$700,000
Exploratory Holes			
Exploratory Boreholes	102	$18,500.00	$1,887,000
Enhanced Pump and Treat			
Mob/Site Preparation (lot)	1	$3,000	$3,000
Horizontal Well Installation (ea)	6	$480,000.00	$2,880,000
Primary Piping (lot)	1	$864,000.00	$864,000
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$9,180,817
Design		8%	$734,465
Office Overhead		5%	$459,041
Field Overhead		15%	$1,377,123
Subtotal			$11,751,446
Profit		8%	$940,116
Contingency		25%	$2,937,861
Total			$15,629,423

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4a - Enhanced Pump and Treat using Horizontal Wells
Cost Estimate

OPERATION AND MAINTENANCE				$89,693,442
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
Pump and Treat O&M				
Pump and Treat O&M (years)	30	$1,509,000	$45,270,000	$29,198,378
New Irrigation System				
New Irrigation System (years)	30	$101,200	$3,036,000	$1,958,168
O&M Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$3,568,570	$3,568,570	$1,428,020
Subtotal			$56,969,920	$35,870,980
Design		8%	$4,557,594	$2,869,678
Office Overhead		5%	$2,848,496	$1,793,549
Field Overhead		15%	$8,545,488	$5,380,647
Subtotal			$72,921,498	$45,914,854
Profit		8%	$5,833,720	$3,673,188
Contingency		15%	$10,938,225	$6,887,228
Total			$89,693,442	$56,475,270

TOTAL ALTERNATIVE CAPITAL AND O&M COST	$105,322,865

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4b - Enhanced Pump and Treat using Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	20.0	Survey for deed restrictions, monitoring wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad.
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Treat System Upgrades	ea	1	Based on existing treatment capacities, it is anticipated that the existing system will be able to treat the increased flow except for the chromium contaminated water. It is assumed that the existing system flow capacity of 150 GPM will need to be doubled. Included is an additional 150 GPM ion exchange system with piping. Cost based on PANTEX existing system cost.
	$/ea	175,000	
Detention Pond and Sprinkler System			Includes two detention ponds to hold 30 days of extraction system flow. Based on existing and new systems flow of 360,000 GPD. Total for 30 days = 17.7 million gallons. For Pond No. 1, assume 200 x 250 ft x 15 ft deep. For Pond No. 2, assume 200 x 290 ft x 15 ft deep Assumed bermed storage pond with 6 ft cut and 9 ft berm. RSMeans G10301153150.
Earthwork (Cut and Fill)	cy	24,000	
Earthwork (Cut and Fill)	$/cy	5.09	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4b - Enhanced Pump and Treat using Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Detention Pond and Sprinkler System			
Liner	sf	148,800	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model.
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to both ponds (1 ea. 6-in lines @ 2,500-ft) and from ponds to irrigation plots (multiple 4-in lines @ 12,500-ft). Includes 1 pump plus a backup pump from treatment bldg. to ponds with electrical hookup. Cost based on RACER parametric model.
	$/lot	425,000	
Irrigation System	lot	1	Assume new irrigation system is constructed to accommodate the 360,000 GPD. Includes irrigating 400 acres using four each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes two replacement sprinklers. Includes pumps, piping, and freeze protection at the sprinkler.
	$/lot	500,000	
Enhanced Pump and Treat			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Extraction Well Installation	ea	87	
Extraction Well Installation	$/ea	42,000	Includes installation of 6-in PVC extraction wells with 20-ft stainless steel screened interval. Includes mud drilling, well installation, and pump w/controls. Cost based on RACER parametric model. Added $1,000 for IDW handling and disposal (100% nonhazardous).
Extraction Well Piping (4-in)	lf	10,150	Includes excavating trench and installing 4-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (4-in)	$/lf	12.90	
Extraction Well Piping (1-in)	lf	1,015	Includes excavating trench and installing 1-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (1-in)	$/lf	5.73	
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4b - Enhanced Pump and Treat using Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
Pump and Treat O&M	Years	30	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. The flow will increase by 130 GPM over the existing 110 GPM flow. The cost for the new and current system was calculated based on unit rates of the current system.
	$/year	902,200	
New Irrigation System Zone No. 1	years	30	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
	$/year	87,200	
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			
Annual Sampling	years	30	Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect wells, signs, and complete checklist for annual report.
Field Labor	$/hr	60	
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 214 wells. Includes, mob, grout, backhoe, and truck. Existing wells that are not part of this alternative are not included.
Abandon Wells	$/lot	5,444,900	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4b - Enhanced Pump and Treat using Vertical Wells
Cost Estimate

CAPITAL COST			$11,285,640

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	20	$875.00	$17,500
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Treat System Upgrades (lot)	1	$175,000.00	$175,000
Detention Pond			
Earthwork (Cut and Fill) (cy)	24,000	$5.09	$122,160
Liner (sf)	148,800	$1.29	$191,952
Pumps and Piping (lot)	1	$425,000.00	$425,000
Irrigation System (lot)	1	$500,000.00	$500,000
Enhanced Pump and Treat			
Mob/Site Preparation	1	$3,000	$3,000
Extraction Well Installation	87	$42,000.00	$3,654,000
Extraction Well Piping (4-in)	10,150	$12.90	$130,935
Extraction Well Piping (1-in)	1,015	$5.73	$5,816
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$6,629,253
Design		8%	$530,340
Office Overhead		5%	$331,463
Field Overhead		15%	$994,388
Subtotal			$8,485,444
Profit		8%	$678,836
Contingency		25%	$2,121,361
Total			$11,285,640

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 4b - Enhanced Pump and Treat using Vertical Wells
Cost Estimate

OPERATION AND MAINTENANCE				$63,325,910
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
Pump and Treat O&M				
Pump and Treat O&M (years)	30	$902,200	$27,066,000	$17,457,108
New Irrigation System				
New Irrigation System (years)	30	$87,200	$2,616,000	$1,687,275
O&M Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (ea)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$5,444,900	$5,444,900	$2,178,863
Subtotal			$40,222,250	$24,609,661
Design		8%	$3,217,780	$1,968,773
Office Overhead		5%	$2,011,113	$1,230,483
Field Overhead		15%	$6,033,338	$3,691,449
Subtotal			$51,484,480	$31,500,365
Profit		8%	$4,118,758	$2,520,029
Contingency		15%	$7,722,672	$4,725,055
Total			$63,325,910	$38,745,450

TOTAL ALTERNATIVE CAPITAL AND O&M COST	$74,611,551

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	30.0	Survey for deed restrictions, monitoring wells, injection wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	ea	2	
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Detention Pond and Sprinkler System			Includes detention pond to hold 30 days of extraction system flow. Based on existing systems flow of 160,000 GPD. Total for 30 days = 4.8 million gallons. Assume 200 x 250 ft x 15 ft deep. Assumed bermed storage pond with 6 ft cut and 9 ft berm. RSMeans G10301153150.
Earthwork (Cut and Fill)	cy	11,100	
Earthwork (Cut and Fill)	$/cy	5.09	
Liner	sf	69,600	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model.
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to pond (1 ea. 4-in lines @ 2,500-ft) and from pond to irrigation plot (1 ea. 4-in lines @ 500-ft). Includes 1 pump plus a backup pump from treatment bldg. to pond with electrical hookup. Cost based on RACER parametric model.
	$/lot	135,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Detention Pond and Sprinkler System			
Irrigation System	lot $/lot	1 250,000	Assume new irrigation system is constructed to accommodate the 160,000 GPD. Includes irrigating 200 acres using two each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes replacement sprinkler. Includes pumps, piping, and freeze protection at the sprinkler.
Exploratory Holes			
Exploratory Boreholes Exploratory Boreholes	ea $/ea	766 18,500	Assume TD 280' (4-inch) - Includes Air Rotary Casing. Added $500 for IDW handling and disposal (100% nonhazardous).
Anaerobic In Situ Bioremediation			
Injection Capital Equipment Cost			
Storage Building Storage Building	ea $/ea	1 81,000	Includes insulated 60 ft x 40 ft x 12 ft pre-engineered storage building. Includes floor, electric, water, sewer, and HVAC.
Steel Tanks Steel Tanks	ea $/ea	2 14,000	10,000 gal steel tanks with mixer, pump, and connections. Includes delivery
Mobile Work Platforms Mobile Work Platforms	ea $/ea	6 500	OSHA rated mobile work platform to 500 lbs Grainger 2324T1
Hydrant with hose Hydrant with hose	ea $/ea	2 350	Anti-freeze hydrant installed with 100 ft hose
Injection System Controls Injection System Controls	lot $/lot	1 20000	Includes pump, chemical metering system, and controls with remote access and alarms.
Mob/Site Preparation	$/lot	3,000	Based on vendor quote
Injection Wells Injection Wells	ea $/ea	203 20,500	Assume TD 280' (4-inch PVC casing) - Includes mud drilling, well installation, and pump w/controls. Unit rate based on pilot study cost. Added $500 for IDW handling and disposal (100% nonhazardous)
Injection Well Piping (4-in) Injection Well Piping (4-in)	lf $/lf	20,400 117.00	Includes excavating trench and installing 4-in stainless steel pipe with fittings. Includes backfill and compaction.
Injection Well Piping (1-in) Injection Well Piping (1-in)	lf $/lf	6,790 27.00	Includes excavating trench and installing 1-in stainless steel pipe with fittings. Includes backfill and compaction.
New Pump and Treat Treatment System	ea $/ea	1 $0	Assume the existing treatment system is used to treat extracted water. The existing treatment capacities of 150 GPM will be able to treat the extracted water of up to 50,000 gal/well at 10 GPM from up to 15 wells.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Extraction Wells and Piping			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Extraction Well Installation	ea	178	
Extraction Well Installation	$/ea	42,000	Includes installation of 6-in PVC extraction wells with 20-ft stainless steel screened interval. Includes mud drilling, well installation, and pump w/controls. Cost based on RACER parametric model. Added $1,000 for IDW handling and disposal (100% nonhazardous)
Extraction Well Piping (4-in)	lf	20,300	Includes excavating trench and installing 4-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (4-in)	$/lf	12.90	
Extraction Well Piping (1-in)	lf	2,030	Includes excavating trench and installing 1-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (1-in)	$/lf	5.73	
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 10)			
New Irrigation System	years $/year	10 43,600	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
Pump and Treat O&M	Years $/year	10 427,600	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. Cost based on PANTEX existing system cost. Assume same labor and equipment required under this alternative, but reduce cost by 20% for less resin/carbon required.
Anaerobic In Situ Bioremediation	years	10	Includes semiannual injections for 10 years and 20 events. Includes injection of 203 injection wells with electron donor material. Assumes 10 GPM for a total of 30,000 gal per well over 2.1 days Assumes 1,800 gals of electron donor material per well.
In Situ Bioremediation	events	20	
In Situ Bioremediation	wells	203	
Labor, Equipment, and Supplies	$/well	8,000	Based on automated injection system and includes performance monitoring.
Electron Donor Materials	$/well	51,000	
Performance Sampling & Analysis	years	10	
Annual Sampling	wells	178	Includes sampling approximately 178 new extraction wells The wells will be sampled monthly for Years 0-2 and semi-annually for Years 3-10 in 49 days (4 wells/day) including 4 days for prep and cleanup There are 41 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redox, and dissolved oxygen). Assumes 2 sampling technicians at 10 hours/day
Annual Sampling	events	41	
	day/event	49	
	hr/event	980	
	$/hr	60	
	$/event	58,800	
Other Direct Sampling Costs	$/event	18,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	74,200	Includes laboratory cost to analyze samples for VOCs (250 @ $100), explosives (205 @ $140), and metals (205 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks
Data Management	$/event	21,360	Includes 2 hrs/well sampled for data management & validation.
O&M (Years 11 to 30)			
New Irrigation System	years $/year	20 28,800	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
Pump and Treat O&M	Years $/year	20 213,800	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. Cost based on PANTEX existing system cost. Assume same labor is required for Years 11-30 under this alternative, but reduce cost by an additional 50% for less resin/carbon and equipment.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Anaerobic In Situ Bioremediation	years	20	Includes semiannual injections for Years 11-20. Total events = 40 events. Includes injection of 69 injection wells with electron donor material. Assumes 10 GPM for a total of 30,000 gal per well over 2.1 days. Assumes 1,800 gals of electron donor material per well.
In Situ Bioremediation	events	40	
In Situ Bioremediation	wells	69	
Labor, Equipment, and Supplies	$/well	8,000	Based on automated injection system and includes performance monitoring.
Electron Donor Materials	$/well	51,000	
Performance Sampling & Analysis	years	20	
Annual Sampling	wells	69	Includes sampling approximately 69 new extraction wells. The wells will be sampled semi-annually for Years 3-10 in 22 days (4 wells/day) including 4 days for prep and cleanup. There are 40 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redox, and dissolved oxygen) Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	events	40	
	day/event	22	
	hr/event	440	
	$/hr	60	
	$/event	26,400	
Other Direct Sampling Costs	$/event	7,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	74,200	Includes laboratory cost to analyze samples for VOCs (250 @ $100), explosives (205 @ $140), and metals (205 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks.
Data Management	$/event	8,280	Includes 2 hrs/well sampled for data management & validation.
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	years	30	
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Performance Monitoring Report	$/year	40,000	Includes preparing a semiannual performance monitoring report. Assume $40K per report.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place Also
Field Labor	$/hr	60	inspect wells, signs, and complete checklist for annual report.
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 508 wells Includes, mob, grout, backhoe, and truck.
Abandon Wells	$/lot	9,727,700	Existing wells that are not part of this alternative are not included.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Cost Estimate

CAPITAL COST			$45,267,319
Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	30	$875.00	$26,250
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Detention Pond			
Earthwork (Cut and Fill) (cy)	11,100	$5.09	$56,499
Liner (sf)	69,600	$1.29	$89,784
Pumps and Piping (lot)	1	$135,000.00	$135,000
Irrigation System (lot)	1	$250,000.00	$250,000
Exploratory Holes			
Exploratory Boreholes	766	$18,500.00	$14,171,000
Anaerobic In Situ Bioremediation Injection Capital Equipment Cost			
Storage Building	1	$81,000	$81,000
Steel Tanks	2	$14,000.00	$28,000
Mobile Work Platforms	6	$500	$3,000
Hydrant with hose	2	$350	$700
Injection System Controls	1	$20,000	$20,000
Mob/Site Preparation	1	$3,000.00	$3,000
Injection Wells	203	$20,500.00	$4,161,500
Injection Well Piping (4-in)	20,400	$117.00	$2,386,800
Injection Well Piping (1-in)	6,790	$27.00	$183,330
Extraction Wells and Piping			
Mob/Site Preparation	1	$3,000	$3,000
Extraction Well Installation	178	$42,000	$7,476,000
Extraction Well Piping (4-in)	20,300	$12.90	$261,870
Extraction Well Piping (1-in)	2,030	$5.73	$11,632

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$30,752,255
Design		2%	$615,045
Office Overhead		3%	$922,568
Field Overhead		10%	$3,075,225
Subtotal			$35,365,093
Profit		8%	$2,829,207
Contingency		20%	$7,073,019
Total			$45,267,319

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Cost Estimate

OPERATION AND MAINTENANCE				$616,503,886
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
New Irrigation System (Years 0 to 10)				
New Irrigation System (years)	10	$43,600	$436,000	$370,026
Pump and Treat O&M (Years 0 to 10)				
Pump and Treat O&M (years)	10	$427,600	$4,276,000	$3,628,970
In Situ Bioremediation (Years 0 to 10)				
Labor, Equipment, and Supplies (years)	10	$3,248,000	$32,480,000	$27,565,239
Electron Donor Materials (years)	10	$20,706,000	$207,060,000	$175,728,396
Performance Sampling & Analysis (Years 0 to 10)				
Annual Sampling Labor (events)	41	$58,800	$2,410,800	$2,205,342
Other Direct Sampling Costs (events)	41	$18,000	$738,000	$675,105
Analytical Costs (events)	41	$74,200	$3,042,200	$2,782,931
Data Management (events)	41	$21,360	$875,760	$801,124
New Irrigation System (Years 11 to 30)				
New Irrigation System (years)	20	$28,800	$576,000	$312,844
Pump and Treat O&M (Years 11 to 30)				
Pump and Treat O&M (years)	20	$213,800	$4,276,000	$2,322,435
In Situ Bioremediation (Years 11 to 30)				
Labor, Equipment, and Supplies (years)	20	$1,104,000	$22,080,000	$11,992,370
Electron Donor Materials (years)	20	$7,038,000	$140,760,000	$76,451,356
Performance Sampling & Analysis (Years 11 to 30)				
Annual Sampling Labor (events)	40	$26,400	$1,056,000	$577,959
Other Direct Sampling Costs (events)	40	$7,000	$280,000	$153,247
Analytical Costs (events)	40	$74,200	$2,968,000	$1,624,416
Data Management (events)	40	$8,280	$331,200	$181,269
GW Monitoring Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Performance Monitoring (year)	30	$40,000	$1,200,000	$773,980

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - MNA with Targeted Treatment
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total	Present Value
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$9,727,700	$9,727,700	$3,892,694
Subtotal			$439,669,010	$315,326,116
Design		1%	$4,396,690	$3,153,261
Office Overhead		3%	$13,190,070	$9,459,783
Field Overhead		10%	$43,966,901	$31,532,612
Subtotal			$501,222,671	$359,471,772
Profit		8%	$40,097,814	$28,757,742
Contingency		15%	$75,183,401	$53,920,766
Total			$616,503,886	$442,150,279

TOTAL ALTERNATIVE CAPITAL AND O&M COST $661,771,205

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	30.0	Survey for deed restrictions, monitoring wells, injection wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Performance Wells	ea	340	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Performance Wells	$/ea	46,000	
Exploratory Holes			
Exploratory Boreholes	ea	679	Assume TD 280' (2-inch) - Includes Air Rotary Casing. Added $500 for IDW handling and disposal (100% nonhazardous).
Exploratory Boreholes	$/ea	18,500	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Permeable Reactive Barrier with Sodium Dithionite			
Injection Capital Equipment Cost			
Storage Building	ea	1	Includes insulated 60 ft x 40 ft x 12 ft pre-engineered storage building.
Storage Building	$/ea	81,000	Includes floor, electric, water, sewer, and HVAC
Steel Tanks	ea	2	10,000 gal steel tanks with mixer, pump, and connections. Includes
Steel Tanks	$/ea	14,000	delivery.
Mobile Work Platforms	ea	6	OSHA rated mobile work platform to 500 lbs. Grainger 2324T1
Mobile Work Platforms	$/ea	500	
Hydrant with hose	ea	2	Anti-freeze hydrant installed with 100 ft hose.
Hydrant with hose	$/ea	350	
Injection System Controls	lot	1	Includes pump, chemical metering system, and controls with remote
Injection System Controls	$/lot	20000	access and alarms.
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Injection Wells	ea	679	Assume TD 280' (4-inch Stainless) - Includes mud drilling, well
Injection Wells	$/ea	60,500	installation, and pump w/controls. Unit rate based on pilot study cost. Added $500 for IDW handling and disposal (100% nonhazardous).
Injection Well Piping (4-in)	lf	20,400	Includes excavating trench and installing 4-in stainless steel pipe with
Injection Well Piping (4-in)	$/lf	117.00	fittings. Includes backfill and compaction.
Injection Well Piping (1-in)	lf	6,790	Includes excavating trench and installing 1-in 4-in stainless steel pipe
Injection Well Piping (1-in)	$/lf	27.00	with fittings. Includes backfill and compaction.
New Pump and Treat Treatment System	ea	1	Assume the existing treatment system is used to treat extracted water
	$/ea	0	The existing treatment capacities of 150 GPM will be able to treat the extracted water of up to 50,000 gal/well at 10 GPM. This will allow a minimum of 15 wells to pumped concurrently.
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report
Technical Labor	$/hr	85	preparation.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
PRB with Sodium Dithionite	years	1	Includes one injection event. Includes injection in 679 wells with sodium dithionite. Assumes 10 GPM for a total of 40,000 gal per well over 2.8 days. Assumes 0.95% sodium dithionite solution.
Permeable Reactive Barrier	events	1	
Permeable Reactive Barrier	wells	203	
Labor, Equipment, and Supplies	$/well	9,000	Based on automated injection system and includes performance monitoring.
Sodium Dithionite Materials	$/well	108,000	
O&M (Years 0 to 30)	years	30	
Performance Sampling & Analysis	wells	340	Includes sampling approximately 340 new wells downgradient of the injection wells. The wells will be sampled monthly for Years 0-2 and semi-annually for Years 3-30 in 89 days (4 wells/day) including 4 days for prep and cleanup. There are 81 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redox, and dissolved oxygen). Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	events	81	
	day/event	89	
	hr/event	1,780	
	$/hr	60	
	$/event	106,800	
Other Direct Sampling Costs	$/event	34,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	137,240	Includes laboratory cost to analyze samples for VOCs (434 @ $100), explosives (391 @ $140), and metals (391 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks.
Data Management	$/event	40,800	Includes 2 hrs/well sampled for data management & validation.
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day
Annual Sampling	years	30	
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter
Performance Monitoring Report	$/event	40,000	Includes preparing a performance monitoring report. Assume $40K per report.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect
Field Labor	$/hr	60	wells, signs, and complete checklist for annual report.
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 1,146 wells. Includes, mob, grout, backhoe, and truck.
Abandon Wells	$/lot	13,752,500	Existing wells that are not part of this alternative are not included.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Cost Estimate

CAPITAL COST $108,069,780

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	30	$875.00	$26,250
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Performance (ea)	340	$46,000.00	$15,640,000
Exploratory Holes			
Exploratory Boreholes	679	$18,500.00	$12,561,500
PRB with Sodium Dithionite			
Injection Capital Equipment Cost			
Storage Building	1	$81,000	$81,000
Steel Tanks	2	$14,000.00	$28,000
Mobile Work Platforms	6	$500	$3,000
Hydrant with hose	2	$350	$700
Injection System Controls	1	$20,000	$20,000
Mob/Site Preparation	1	$3,000.00	$3,000
Injection Wells	679	$60,500.00	$41,079,500
Injection Well Piping (4-in)	20,400	$117.00	$2,386,800
Injection Well Piping (1-in)	6,790	$27.00	$183,330
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$73,416,970
Design		2%	$1,468,339
Office Overhead		3%	$2,202,509
Field Overhead		10%	$7,341,697
Subtotal			$84,429,516
Profit		8%	$6,754,361
Contingency		20%	$16,885,903
Total			$108,069,780

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 1 - Permeable Reactive Barrier with Sodium Dithionite
Cost Estimate

OPERATION AND MAINTENANCE $100,937,213

Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
Sodium Dithionite Injections				
Labor, Equipment, and Supplies	1	$1,827,000	$1,827,000	$1,772,066
Sodium Dithionite Materials	1	$21,924,000	$21,924,000	$21,264,791
Performance Sampling & Analysis				
Annual Sampling Labor (events)	81	$106,800	$8,650,800	$6,343,729
Other Direct Sampling Costs (events)	81	$34,000	$2,754,000	$2,019,539
Analytical Costs (events)	81	$137,240	$11,116,440	$8,151,810
Data Management (events)	81	$40,800	$3,304,800	$2,423,447
GW Monitoring Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Performance Monitoring (event)	89	$40,000	$3,560,000	$2,375,928
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$13,752,500	$13,752,500	$5,503,281
Subtotal			$71,984,890	$53,141,006
Design		1%	$719,849	$531,410
Office Overhead		3%	$2,159,547	$1,594,230
Field Overhead		10%	$7,198,489	$5,314,101
Subtotal			$82,062,775	$60,580,746
Profit		8%	$6,565,022	$4,846,460
Contingency		15%	$12,309,416	$9,087,112
Total			$100,937,213	$74,514,318

TOTAL ALTERNATIVE CAPITAL AND O&M COST $209,006,993

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	30.0	Survey for deed restrictions, monitoring wells, injection wells, extraction wells, pipirig, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning sigris located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Performance Wells	ea	170	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Performance Wells	$/ea	46,000	
Exploratory Holes			
Exploratory Boreholes	ea	340	Assume TD 280' (2-inch) - Includes Air Rotary Casing. Added $500 for IDW handling and disposal (100% nonhazardous).
Exploratory Boreholes	$/ea	18,500	
Permeable Reactive Barrier with Calcium Polysulfide			
Injection Capital Equipment Cost			
Storage Building	ea	1	Includes insulated 60 ft x 40 ft x 12 ft pre-engineered storage building. Includes floor, electric, water, sewer, and HVAC.
Storage Building	$/ea	81,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Steel Tanks	ea	2	10,000 gal steel tanks with mixer, pump, and connections. Includes delivery.
Steel Tanks	$/ea	14,000	
Mobile Work Platforms	ea	6	OSHA rated mobile work platform to 500 lbs. Grainger 2324T1
Mobile Work Platforms	$/ea	500	
Hydrant with hose	ea	2	Anti-freeze hydrant installed with 100 ft hose.
Hydrant with hose	$/ea	350	
Injection System Controls	lot	1	Includes pump, chemical metering system, and controls with remote access and alarms
Injection System Controls	$/lot	20000	
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Injection Wells	ea	340	Assume TD 280' (4-inch PVC casing) - Includes mud drilling, well installation, and pump w/controls. Unit rate based on pilot study cost. Added $500 for IDW handling and disposal (100% nonhazardous)
Injection Wells	$/ea	20,500	
Injection Well Piping (4-in)	lf	20,400	Includes excavating trench and installing 4-in Sch 40 PVC pipe with fittings. Includes backfill and compaction.
Injection Well Piping (4-in)	$/lf	12.90	
Injection Well Piping (1-in)	lf	3,400	Includes excavating trench and installing 1-in Sch 40 PVC pipe with fittings. Includes backfill and compaction.
Injection Well Piping (1-in)	$/lf	5.73	
New Pump and Treat Treatment System	ea	1	Assume the existing treatment system is used to treat extracted water. The existing treatment capacities of 150 GPM will be able to treat the extracted water of up to 50,000 gal/well at 10 GPM. This will allow a minimum of 15 wells to pumped concurrently.
	$/ea	0	
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
PRB with Calcium Polysulfide	years	1	Includes one injection event. Includes injection in 340 wells with calcium polysulfide. Assumes 10 GPM for a total of 25,000 gal per well over 1.7 days.
Permeable Reactive Barrier	events	1	
Permeable Reactive Barrier	wells	340	
Labor, Equipment, and Supplies	$/well	7,000	Based on automated injection system and includes performance monitoring.
Calcium Polysulfide Materials	$/well	22,500	Includes 25,000 gal average per well and assumes calcium polysulfide is 33% of sodium dithionite solution.
O&M (Years 0 to 30)	years	30	
Performance Sampling & Analysis	wells	170	Includes sampling approximately 170 new wells downgradient of the injection wells. The wells will be sampled monthly for Years 0-2 and semi-annually for Years 3-30 in 47 days (4 wells/day) including 4 days for prep and cleanup. There are 81 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redox, and dissolved oxygen). Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	events	81	
	day/event	47	
	hr/event	940	
	$/hr	60	
	$/event	56,400	
Other Direct Sampling Costs	$/event	17,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	70,940	Includes laboratory cost to analyze samples for VOCs (239 @ $100), explosives (196 @ $140), and metals (196 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks.
Data Management	$/event	20,400	Includes 2 hrs/well sampled for data management & validation.
O&M (Years 0 to 30)			Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
Groundwater Sampling & Analysis			
Annual Sampling	years	30	
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Performance Monitoring Report	$/year	40,000	Includes preparing a performance monitoring report. Assume $40K per report.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also
Field Labor	$/hr	60	inspect wells, signs, and complete checklist for annual report.
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 637 wells. Includes, mob, grout, backhoe, and truck.
Abandon Wells	$/lot	7,644,500	Existing wells that are not part of this alternative are not included.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Cost Estimate

CAPITAL COST $22,239,686

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	30	$875.00	$26,250
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Exploratory Holes			
Exploratory Boreholes	340	$18,500.00	$6,290,000
PRB with Calcium Polysulfide			
Injection Capital Equipment Cost			
Storage Building	1	$81,000	$81,000
Steel Tanks	2	$14,000.00	$28,000
Mobile Work Platforms	6	$500	$3,000
Hydrant with hose	2	$350	$700
Injection System Controls	1	$20,000	$20,000
Mob/Site Preparation	1	$3,000.00	$3,000
Injection Wells	340	$20,500.00	$6,970,000
Injection Well Piping (4-in)	20,400	$12.90	$263,160
Injection Well Piping (1-in)	3,400	$5.73	$19,482
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$15,108,482
Design		2%	$302,170
Office Overhead		3%	$453,254
Field Overhead		10%	$1,510,848
Subtotal			$17,374,754
Profit		8%	$1,389,980
Contingency		20%	$3,474,951
Total			$22,239,686

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 2 - Permeable Reactive Barrier with Calcium Polysulfide
Cost Estimate

OPERATION AND MAINTENANCE				$52,321,396
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
PRB with Calcium Polysulfide				
Labor, Equipment, and Supplies	1	$2,380,000	$2,380,000	$2,308,438
Calcium Polysulfide Materials	1	$7,650,000	$7,650,000	$7,419,981
Performance Sampling & Analysis				
Annual Sampling Labor (events)	81	$56,400	$4,568,400	$3,350,059
Other Direct Sampling Costs (events)	81	$17,000	$1,377,000	$1,009,770
Analytical Costs (events)	81	$70,940	$5,746,140	$4,213,709
Data Management (events)	81	$20,400	$1,652,400	$1,211,723
GW Monitoring Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Performance Monitoring (year)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$7,644,500	$7,644,500	$3,059,068
Subtotal			$37,313,790	$26,633,141
Design		1%	$373,138	$266,331
Office Overhead		3%	$1,119,414	$798,994
Field Overhead		10%	$3,731,379	$2,663,314
Subtotal			$42,537,721	$30,361,781
Profit		8%	$3,403,018	$2,428,942
Contingency		15%	$6,380,658	$4,554,267
Total			$52,321,396	$37,344,991

TOTAL ALTERNATIVE CAPITAL AND O&M COST	$74,561,082

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Deed Restriction and Notice to Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies.
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	30.0	Survey for deed restrictions, monitoring wells, injection wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area.
Civil Survey Monuments	$/ea	108	RSMeans 01107 700 0600.
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above.
Install Signs on Posts	$/ea	136.50	RSMeans 028907000100 & 1500. Add 50% for custom letters.
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad.
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Detention Pond and Sprinkler System			Includes detention pond to hold 30 days of extraction system flow. Based on existing systems flow of 160,000 GPD. Total for 30 days = 4.8 million gallons. Assume 200 x 250 ft x 15 ft deep. Assumed bermed storage pond with 6 ft cut and 9 ft berm. RSMeans G10301153150.
Earthwork (Cut and Fill)	cy	11,100	
Earthwork (Cut and Fill)	$/cy	5.09	
Liner	sf	69,600	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model.
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to pond (1 ea. 4-in lines @ 2,500-ft) and from pond to irrigation plot (1 ea. 4-in lines @ 500-ft). Includes 1 pump plus a backup pump from treatment bldg. to pond with electrical hookup. Cost
	$/lot	135,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Irrigation System	lot $/lot	1 250,000	Assume new irrigation system is constructed to accommodate the 160,000 GPD. Includes irrigating 200 acres using two each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes replacement sprinkler. Includes pumps, piping, and freeze protection at the sprinkler.
Exploratory Holes			
Exploratory Boreholes	ea	766	Assume TD 280' (2-inch) - Includes Air Rotary Casing. Added $500 for IDW handling and disposal (100% nonhazardous).
Exploratory Boreholes	$/ea	18,500	
Chemical Oxidation Using Potassium Permanganate			
Injection Capital Equipment Cost			
Storage Building	ea	1	Includes insulated 60 ft x 40 ft x 12 ft pre-engineered storage building. Includes floor, electric, water, sewer, and HVAC.
Storage Building	$/ea	81,000	
Steel Tanks	ea	2	10,000 gal steel tanks with mixer, pump, and connections. Includes delivery.
Steel Tanks	$/ea	14,000	
Mobile Work Platforms	ea	6	OSHA rated mobile work platform to 500 lbs. Grainger 2324T1
Mobile Work Platforms	$/ea	500	
Hydrant with hose	ea	2	Anti-freeze hydrant installed with 100 ft hose.
Hydrant with hose	$/ea	350	
Injection System Controls	lot	1	Includes pump, chemical metering system, and controls with remote access and alarms
Injection System Controls	$/lot	20000	
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Injection Wells	ea	203	Assume TD 280' (4-inch PVC casing) - Includes mud drilling, well installation, and pump w/controls. Unit rate based on pilot study cost. Added $500 for IDW handling and disposal (100% nonhazardous).
Injection Wells	$/ea	20,500	
Injection Well Piping (4-in)	lf	20,400	Includes excavating trench and installing 4-in stainless steel pipe with fittings Includes backfill and compaction.
Injection Well Piping (4-in)	$/lf	117.00	
Injection Well Piping (1-in)	lf	6,790	Includes excavating trench and installing 1-in 4-in stainless steel pipe with fittings. Includes backfill and compaction.
Injection Well Piping (1-in)	$/lf	27 00	
New Pump and Treat Treatment System	ea $/ea	1 0	Assume the existing treatment system is used to treat extracted water. The existing treatment capacities of 150 GPM will be able to treat the extracted water of up to 50,000 gal/well at 10 GPM. This will allow a minimum of 15 wells to pumped concurrently.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Extraction Wells and Piping			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Extraction Well Installation	ea	178	Includes installation of 6-in PVC extraction wells with 20-ft stainless steel screened interval. Includes mud drilling, well installation, and pump w/controls. Cost based on RACER parametric model. Added $1,000 for IDW handling and disposal (100% nonhazardous).
Extraction Well Installation	$/ea	42,000	
Extraction Well Piping (4-in)	lf	20,300	Includes excavating trench and installing 4-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (4-in)	$/lf	12.90	
Extraction Well Piping (1-in)	lf	2,030	Includes excavating trench and installing 1-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction
Extraction Well Piping (1-in)	$/lf	5.73	
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 10)			
New Irrigation System	years	10	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years Assumes 4,400 hours operation per year.
	$/year	43,600	
Pump and Treat O&M	Years	10	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. Cost based on PANTEX existing system cost. Assume same labor and equipment required under this alternative, but reduce cost by 20% for less resin/carbon required.
	$/year	427,600	
Chemical Oxidation Using Potassium Permanganate	years	10	Includes semiannual injections for 10 years and 20 events. Includes injection of 203 injection wells with potassium permanganate.
Chemical Oxidation Injection	events	20	Assumes 10 GPM for a total of 30,000 gal per well over 2.1 days.
Chemical Oxidation Injection	wells	203	Assumes 0.50% potassium permanganate solution
Labor, Equipment, and Supplies	$/well	8,000	Based on automated injection system and includes performance monitoring.
Potassium Permanganate Materials	$/well	2,000	Includes 30,000 gal average per well and assumes potassium permanganate in 0.5% solution.
Performance Sampling & Analysis	years	10	
Annual Sampling	wells	178	Includes sampling approximately 178 new extraction wells. The wells will be sampled monthly for Years 0-2 and semi-annually for Years 3-10 in 49 days (4 wells/day) including 4 days for prep and cleanup. There are 41 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redox, and dissolved oxygen). Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	events	41	
	day/event	49	
	hr/event	980	
	$/hr	60	
	$/event	58,800	
Other Direct Sampling Costs	$/event	18,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	74,200	Includes laboratory cost to analyze samples for VOCs (250 @ $100), explosives (205 @ $140), and metals (205 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks
Data Management	$/event	21,360	Includes 2 hrs/well sampled for data management & validation.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 11 to 30)			
New Irrigation System	years $/year	20 28,800	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year
Pump and Treat O&M	Years $/year	20 213,800	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. Cost based on PANTEX existing system cost. Assume same labor is required for Years 11-30 under this alternative, but reduce cost by an additional 50% for less resin/carbon and equipment.
Chemical Oxidation Using Potassium Permanganate	years	20	Includes semiannual injections for Years 11-20. Total events = 40 events. Includes injection of 69 injection wells with potassium permanganate. Assumes 10 GPM for a total of 30,000 gal per well over 2.1 days.
Chemical Oxidation Injection	events	40	
Chemical Oxidation Injection	wells	203	
Labor, Equipment, and Supplies	$/well	2,000	Based on automated injection system and includes performance monitoring.
Potassium Permanganate Materials	$/well	2,000	Includes 30,000 gal average per well and assumes potassium Permanganate in 0.5% solution.
Performance Sampling & Analysis	years	20	
Annual Sampling	wells	69	Includes sampling approximately 69 new extraction wells. The wells will be sampled semi-annually for Years 3-10 in 22 days (4 wells/day) including 4 days for prep and cleanup. There are 40 events. Samples will be collected and analyzed for VOCs, explosives, metals and standard field parameters (temp, conductivity, pH, redo, and dissolved oxygen). Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	events	40	
	day/event	22	
	hr/event	440	
	$/hr	60	
	$/event	26,400	
Other Direct Sampling Costs	$/event	7,000	Includes vehicle, miscellaneous ODCs, field parameter equipment, and H&S services.
Analytical Cost	$/event	74,200	Includes laboratory cost to analyze samples for VOCs (250 @ $100), explosives (205 @ $140), and metals (205 @ $100). Includes 10% duplicate, 5% rinsate, and trip blanks.
Data Management	$/event	8,280	Includes 2 hrs/well sampled for data management & validation.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			
Annual Sampling	years hr/yr $/hr $/year	30 800 60 48,000	Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Performance Monitoring Report	$/year	40,000	Includes preparing a performance monitoring report. Assume $40K per report.
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also
Field Labor	$/hr	60	inspect wells, signs, and complete checklist for annual report.
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 508 wells. Includes, mob, grout, backhoe, and truck.
Abandon Wells	$/lot	9,727,700	Existing wells that are not part of this alternative are not included.

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Cost Estimate

CAPITAL COST $45,267,319

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	30	$875.00	$26,250
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Detention Pond			
Earthwork (Cut and Fill) (cy)	11,100	$5.09	$56,499
Liner (sf)	69,600	$1.29	$89,784
Pumps and Piping (lot)	1	$135,000.00	$135,000
Irrigation System (lot)	1	$250,000.00	$250,000
Exploratory Holes			
Exploratory Boreholes	766	$18,500.00	$14,171,000
Chemical Oxidation Using Potassium Permanganate			
Injection Capital Equipment Cost			
Storage Building	1	$81,000	$81,000
Steel Tanks	2	$14,000.00	$28,000
Mobile Work Platforms	6	$500	$3,000
Hydrant with hose	2	$350	$700
Injection System Controls	1	$20,000	$20,000
Mob/Site Preparation	1	$3,000.00	$3,000
Injection Wells	203	$20,500.00	$4,161,500
Injection Well Piping (4-in)	20,400	$117.00	$2,386,800
Injection Well Piping (1-in)	6,790	$27.00	$183,330
Extraction Wells and Piping			
Mob/Site Preparation	1	$3,000	$3,000
Extraction Well Installation	178	$42,000	$7,476,000
Extraction Well Piping (4-in)	20,300	$12.90	$261,870
Extraction Well Piping (1-in)	2,030	$5.73	$11,632

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$30,752,255
Design		2%	$615,045
Office Overhead		3%	$922,568
Field Overhead		10%	$3,075,225
Subtotal			$35,365,093
Profit		8%	$2,829,207
Contingency		20%	$7,073,019
Total			$45,267,319

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Cost Estimate

OPERATION AND MAINTENANCE				$136,474,738
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
New Irrigation System (Years 0 to 10)				
New Irrigation System (years)	10	$43,600	$436,000	$370,026
Pump and Treat O&M (Years 0 to 10)				
Pump and Treat O&M (years)	10	$427,600	$4,276,000	$3,628,970
Chemical Oxidation (Years 0 to 10)				
Labor, Equipment, and Supplies (years)	10	$3,248,000	$32,480,000	$27,565,239
Potassium Permanganate Materials (years)	10	$812,000	$8,120,000	$6,891,310
Performance Sampling & Analysis (Years 0 to 10)				
Annual Sampling Labor (events)	41	$58,800	$2,410,800	$2,205,342
Other Direct Sampling Costs (events)	41	$18,000	$738,000	$675,105
Analytical Costs (events)	41	$74,200	$3,042,200	$2,782,931
Data Management (events)	41	$21,360	$875,760	$801,124
New Irrigation System (Years 11 to 30)				
New Irrigation System (years)	20	$28,800	$576,000	$312,844
Pump and Treat O&M (Years 11 to 30)				
Pump and Treat O&M (years)	20	$213,800	$4,276,000	$2,322,435
Chemical Oxidation (Years 11 to 30)				
Labor, Equipment, and Supplies (events)	40	$406,000	$16,240,000	$15,711,784
Potassium Permanganate Materials (events)	40	$80,000	$3,200,000	$3,095,918
Performance Sampling & Analysis (Years 11 to 30)				
Annual Sampling Labor (events)	40	$26,400	$1,056,000	$577,959
Other Direct Sampling Costs (events)	40	$7,000	$280,000	$153,247
Analytical Costs (events)	40	$74,200	$2,968,000	$1,624,416
Data Management (events)	40	$8,280	$331,200	$181,269
GW Monitoring Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Performance Monitoring (year)	30	$40,000	$1,200,000	$773,980

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Alternative 5 - Modification No. 3 - Chemical Oxidation using Potassium Permanganate
Cost Estimate

Activity (unit)	Quantity	Unit Cost	Total	Present Value
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$9,727,700	$9,727,700	$3,892,694
Subtotal			$97,329,010	$76,853,006
Design		1%	$973,290	$768,530
Office Overhead		3%	$2,919,870	$2,305,590
Field Overhead		10%	$9,732,901	$7,685,301
Subtotal			$110,955,071	$87,612,427
Profit		8%	$8,876,406	$7,008,994
Contingency		15%	$16,643,261	$13,141,864
Total			$136,474,738	$107,763,285

TOTAL ALTERNATIVE CAPITAL AND O&M COST $181,742,057

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Capital Cost			
Land Use Controls			
Public	hrs	1,000	Assume 1000 hrs to perform title search, review and revise deed, and provide notice to public.
Legal/Technical Labor	$/hr	100	
Groundwater Use Restrictions			
Groundwater Use Restrictions	hrs	240	Assume 240 hrs to place groundwater use restrictions with local and state regulatory agencies
Legal/Technical Labor	$/hr	100	
Site Work			
Civil Survey	day	20.0	Survey for deed restrictions, monitoring wells, extraction wells, piping, pond, and sprinkler system. RSMeans 01107 700 1100.
Civil Survey	$/day	875	
Civil Survey Monuments	ea	20	Assume 20 monuments around groundwater use restriction area. RSMeans 01107 700 0600.
Civil Survey Monuments	$/ea	108	
Survey Drawings	hours	300	Assume plat map drawings for deed restrictions.
Survey Drawings	$/hr	50	
Install Signs on Posts	ea	20	Assume warning signs located at each monument noted above. RSMeans 028907000100 & 1500. Add 50% for custom letters.
Install Signs on Posts	$/ea	136.50	
Monitoring Wells			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote. Inc mob/demob and decon pad.
Perched Wells	ea	2	Includes installation of 4-in PVC monitoring wells to an average depth of 300 ft. Includes drilling with air rotary rig, well installation, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Perched Wells	$/ea	46,000	
Ogallala Wells	ea	8	Includes installation of 5-in stainless steel monitoring wells to an average depth of 450 ft. Includes drilling with air rotary rig, well installation, outer steel casing to 300 ft, Geologist, and IDW handling (100% nonhazardous). Cost based on vendor quote and historical well installation cost.
Ogallala Wells	$/ea	135,000	
Treatment System Upgrades	ea	1	Based on existing treatment capacities, it is anticipated that the existing system will be able to treat the increased flow except for the chromium contaminated water. It is assumed that the existing system capacity of 150 GPM will need to be tripled. Included is an additional 300 GPM ion exchange system with piping. Cost based on PANTEX existing system cost and includes cost for placement of initial ion exchange canisters plus allowances for new piping, controls, canister units, shipping, and setup. Assume no additional building area is required.
	$/ea	350,000	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
Detention Pond and Sprinkler System			
Earthwork (Cut and Fill)	cy	38,700	Includes two detention ponds to hold 30 days of extraction system flow. Based on existing and new systems flow of 590,000 GPD. Total for 30 days = 17.7 million gallons. For Pond No. 1, assume 200 x 250 ft x 15 ft deep. For Pond No. 2, assume 400 x 310 ft x 15 ft deep. Assumed bermed storage pond with 6 ft cut and 9 ft berm. RSMeans G10301153150.
Earthwork (Cut and Fill)	$/cy	5.09	
Liner	sf	223,600	Includes 6-in sand layer, 40-mil HDPE liner, and 3-in pea gravel ballast with perimeter anchor trench. Cost based on RACER parametric model.
Liner	$/sf	1.29	
Pumps and Piping	lot	1	Includes underground cast iron piping from treatment building to both ponds (1 ea. 6-in lines @ 7,100-ft) and from ponds to irrigation plots (multiple 4-in lines @ 11,000-ft). Includes 1 pump plus a backup pump from treatment bldg. to ponds with electrical hookup. Cost based on RACER parametric model
	$/lot	590,000	
Irrigation System	lot	1	Assume new irrigation system is constructed to accommodate the 590,000 GPD. Includes irrigating 700 acres using six each self-propelled center pivot sprinkler system that rotate around the pivot point and has the lowest labor requirements of the aboveground systems. Includes two replacement sprinklers. Includes pumps, piping, and freeze protection at the sprinkler.
	$/lot	700,000	
Enhanced Pump and Treat (Vertical Wells)			
Mob/Site Preparation	$/lot	3,000	Based on vendor quote.
Extraction Well Installation	ea	25	
Extraction Well Installation	$/ea	42,000	Includes installation of 6-in PVC extraction wells with 20-ft stainless steel screened interval. Includes mud drilling, well installation, and pump w/controls. Cost based on RACER parametric model. Added $1,000 for IDW handling and disposal (100% nonhazardous).
Extraction Well Piping (4-in)	lf	17,650	Includes excavating trench and installing 4-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (4-in)	$/lf	12.90	
Extraction Well Piping (1-in)	lf	4,515	Includes excavating trench and installing 1-in Sch. 40 PVC pipe with fittings. Includes backfill and compaction.
Extraction Well Piping (1-in)	$/lf	5.73	
Plans and Reports			
Corrective Action Completion Report	hrs	1,000	Includes reviewing construction QC data, O&M manuals, and report preparation.
Technical Labor	$/hr	85	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells
Key Parameters and Assumptions

Key Parameters and Assumptions:

Item	Unit	Value	Notes
O&M (Years 0 to 30)			
Pump and Treat O&M	Years	30	Based on existing estimated contractor O&M cost for extraction wells, GAC units, ion exchange, controls, and other miscellaneous equipment. Program Management, Design, Engineering Support, and Overhead included in markups. Sampling and analysis of extraction wells is not included. The flow will increase by 300 GPM over the existing 110 GPM flow. The cost for the new and current system was calculated based on unit rates of the current system.
	$/year	1,509,000	
New Irrigation System Zone No. 1	years	30	O&M of the sprinkler will be $148/acre and includes power and maintenance. Assume sprinkler and pump are replaced every 10 years. Assumes 4,400 hours operation per year.
	$/year	101,200	
O&M (Years 0 to 30)			
Groundwater Sampling & Analysis			Includes sampling approximately 28 existing wells in the Ogallala aquifer at various sampling intervals for a total of 68 wells sampled per year. Also includes sampling approximately 35 wells in the Perched aquifer at various sampling intervals for a total of 59 wells sampled per year. Also includes sampling approximately 8 new wells in the Ogallala aquifer and 2 new in the Perched aquifer at various sampling intervals for a total of 14 wells (assume semi-annual sampling). The 141 wells will be sampled in 40 days (4 wells/day) including 4 days for prep and cleanup. Samples will be collected and analyzed for explosives and MNA parameters. Assumes 2 sampling technicians at 10 hours/day.
Annual Sampling	years	30	
	hr/yr	800	
	$/hr	60	
	$/year	48,000	
Other Direct Sampling Costs	$/year	16,000	Includes vehicle, miscellaneous ODCs, and H&S services.
Analytical Cost	$/year	46,085	Includes laboratory cost to analyze samples for explosives (163 @ $140) and MNA parameters (141 @ $165). Includes 10% duplicate and 5% rinsate for explosives.
Data Management	$/year	12,960	Includes 1.5 hrs/well sampled for data management & validation.
Reporting			
Sampling and Analysis Reports	$/year	40,000	Includes preparing a quarterly sampling data summary to meet the requirements of the S&A plan. Assume $10K per quarter.
Site Inspection and Maintenance	years	30	
Site Inspection	events	60	Inspect site semi-annually.
Site Inspections	hrs/year	80	Inspect properties to verify land use controls are in place. Also inspect wells, signs, and complete checklist for annual report.
Field Labor	$/hr	60	
Site Maintenance	$/year	2,000	Assume periodic maintenance cost of $2000/year.
Well Abandonment (Year 30)			
Abandon Wells	lot	1	Includes 152 vertical wells. Includes, mob, grout, backhoe, and truck. Existing wells that are not part of this alternative are not included.
Abandon Wells	$/lot	3,089,520	

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells
Cost Estimate

CAPITAL COST $8,262,382

Activity (unit)	Quantity	Unit Cost	Total
Land Use Controls			
Deed Restriction and Notice to Public (hrs)	1,000	$100.00	$100,000
Groundwater Use Restrictions			
Groundwater Use Restrictions (hrs)	240	$100.00	$24,000
Site Work			
Civil Survey (day)	20	$875.00	$17,500
Civil Survey Monuments (ea)	20	$108.00	$2,160
Survey Drawings (hrs)	300	$50.00	$15,000
Install Signs on Post (ea)	20	$136.50	$2,730
Monitoring Wells			
Mob/Site Preparation (lot)	1	$3,000.00	$3,000
Perched Wells (ea)	2	$46,000.00	$92,000
Ogallala Wells (ea)	8	$135,000.00	$1,080,000
Treatment System Upgrades	1	$350,000.00	$350,000
Detention Pond and Irrigation System			
Earthwork (Cut and Fill) (cy)	38,700	$5.09	$196,983
Liner (sf)	223,600	$1.29	$288,444
Pumps and Piping (lot)	1	$590,000.00	$590,000
Irrigation System (lot)	1	$700,000.00	$700,000
Enhanced Pump & Treat (Vertical Wells)			
Mob/Site Preparation	1	$3,000	$3,000
Extraction Well Installation	25	$42,000.00	$1,050,000
Extraction Well Piping (4-in)	17,650	$12.90	$227,685
Extraction Well Piping (1-in)	4,515	$5.73	$25,871
Plans and Reports			
Corrective Action Completion Report (hrs)	1,000	$85.00	$85,000
Subtotal			$4,853,373
Design		8%	$388,270
Office Overhead		5%	$242,669
Field Overhead		15%	$728,006
Subtotal			$6,212,317
Profit		8%	$496,985
Contingency		25%	$1,553,079
Total			$8,262,382

Pantex Plant Groundwater Corrective Measures Study (CMS), Amarillo, Texas
Recommended Alternative - Enhanced Pump and Treat using Horizontal Wells and Vertical Wells
Cost Estimate

OPERATION AND MAINTENANCE				$88,939,226
Activity (unit)	Quantity	Unit Cost	Total	Present Value
O&M (Years 0 to 30)				
Pump and Treat O&M				
Pump and Treat O&M (years)	30	$1,509,000	$45,270,000	$29,198,378
New Irrigation System				
New Irrigation System (years)	30	$101,200	$3,036,000	$1,958,168
O&M Sampling & Analysis				
Annual Sampling Labor (years)	30	$48,000	$1,440,000	$928,775
Other Direct Sampling Costs (years)	30	$16,000	$480,000	$309,592
Analytical Costs (years)	30	$46,085	$1,382,550	$891,721
Data Management (years)	30	$12,960	$388,800	$250,769
Reporting				
Sampling and Analysis Reports (year)	30	$40,000	$1,200,000	$773,980
Site Inspection and Maintenance				
Site Inspection (years)	30	$4,800	$144,000	$92,878
Site Maintenance (years)	30	$2,000	$60,000	$38,699
Well Abandonment (Year 30)				
Abandon Wells (lot)	1	$3,089,520	$3,089,520	$1,236,320
Subtotal			$56,490,870	$35,679,280
Design		8%	$4,519,270	$2,854,342
Office Overhead		5%	$2,824,544	$1,783,964
Field Overhead		15%	$8,473,631	$5,351,892
Subtotal			$72,308,314	$45,669,479
Profit		8%	$5,784,665	$3,653,558
Contingency		15%	$10,846,247	$6,850,422
Total			$88,939,226	$56,173,459

TOTAL ALTERNATIVE CAPITAL AND O&M COST	$97,201,608

Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	Cumulative Flux Exiting GHB RDX (kg)	Cumulative Flux Exiting GHB Water (million gallons)	Peak Instantaneous Flux RDX (kg/year)
					Baseline Human Health Scenarios				
1	MSPerched_20051108D_TRB	No	No	No	Yes	Baseline HHRA FTM	3,368	28,596	60.94 kg/Year (at T=5 Years)
2	MSPerched_20051108E_TRB	Yes	No	No	Yes	Baseline HHRA FTM with retardation and decay	2,773	28,596	68.70 kg/Year (at T=10 Years)
3	MSPerched011306	Yes	No	No	No [1]	MSPerched_20051108E_TRB with reduced recharge at Playas and Ditches	2,449	12,522	66.38 kg/Year (at T=10 Years)
4	MSPerched_20051127B_TRB	No	No	No	No [1]	Model MSPerched_20051108D_TRB with reduced recharge at Playas and Ditches	3,022	12,522	60.49 kg/Year (at T=5 Years)
					Existing System Scenarios				
5	MSPerched_20051108B_TRB	Yes	Yes	Yes	Yes	Base model evaluation of existing system pumping, injection and reactive transport	2,015	28,482	58.86 kg/Year (at T=7 Years)
6	MSPerched_20051127A_TRB	Yes	Yes	Yes	No [1]	Model MSPerched_20051108B_TRB with reduced recharge at Playas and Ditches	1,777	12,496	54.10 kg/Year (at T=5 Years)
7	MSPerched_20051108C_TRB	No	Yes	Yes	Yes	Base model evaluation of existing system pumping, injection and nonreactive transport	2,380	28,484	54.11 kg/Year (at T=5 Years)
8	MSPerched_20051122B_TRB	Yes	Yes	No	Yes	Model MSPerched_20051108B_TRB without injection in stress period 2	995	26,772	40.97 kg/Year (at T=5 Years)
9	MSPerched_20051122C_TRB	No	Yes	No	Yes	Model MSPerched_20051108C_TRB without injection in stress period 2	2,028	26,772	49.76 kg/Year (at T=5 Years)
10	MSPerched_20051127C_TRB [2]	No	Yes	Yes	Yes	Model MSPerched_20051108c_TRB with 60 years of active remediation	1,885	28,390	54.87 kg/Year (at T=10 Years)
11	MSPerched_20051127D_TRB [2]	Yes	Yes	Yes	Yes	Model MSPerched_20051108B_TRB with 60 years of active remediation	1,885	28,390	54.87 kg/Year (at T=10 Years)

Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	Cumulative Flux Exiting GHB RDX (kg)	Cumulative Flux Exiting GHB Water (million gallons)	Peak Instantaneous Flux RDX (kg/year)
12	MSPerched121205a [2]	Yes	Yes	No	Yes	Model MSPerched1127D_TRBb without injection in stress period 2, extended pumping to 60 years	831	25,523	40.97 kg/Year (at T=5 Years)
						Horizontal Well Scenarios			
13	MSPerched110805b	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 10	1,898	26,476	54.80 kg/Year (at T=10 Years)
14	MSPerched110805c	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 11	1,336	27,583	49.93 kg/Year (at T=5 Years)
15	MSPerched110905a	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 12	1,293	27,589	33.32 kg/Year (at T=5 Years)
16	MSPerched110905b	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 13	1,820	28,297	54.57 kg/Year (at T=5 Years)
17	MSPerched110905c	Yes	Yes	Yes	Yes	1 horizontal well simulated during stress period 2 with DRAIN REACH 14	1,323	28,223	30.74 kg/Year (at T=5 Years)
18	MSPerched110905d	Yes	Yes	Yes	Yes	2 horizontal wells simulated during stress period 2 with DRAIN REACHES 14 and 15	1,128	27,948	23.49 kg/Year (at T=0 Years)
19	MSPerched111005a	Yes	Yes	Yes	Yes	6 horizontal wells simulated during stress period 2 with DRAIN REACHES 10, 11,12,13,14 and 15	608	24,952	23.49 kg/Year (at T=0 Years)
20	MSPerched112905a	Yes	Yes	Yes	Yes	8 horizontal wells simulated during stress period 2 with DRAIN REACHES 10, 11,12,13,14,15, 20 and 21	567	24,100	23.49 kg/Year (at T=0 Years)
21	MSPerched112905b	Yes	Yes	Yes	Yes	10 horizontal wells simulated during stress period 2 with all DRAIN REACHES	584	21,336	23.77 kg/Year (at T=0 Years)
22	MSPerched_20051201a_TRB	Yes	Yes	No	Yes	Model MSPerched111005a without injection in stress period 2	518	24,419	23.49 kg/Year (at T=0 Years)
23	MSPerched_20051202a_TRB	Yes	Yes	No	Yes	Model MSPerched112905a without injection in stress period 2	480	23,599	23.49 kg/Year (at T=0 Years)

Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	Cumulative Flux Exiting GHB RDX (kg)	Cumulative Flux Exiting GHB Water (million gallons)	Peak Instantaneous Flux RDX (kg/year)
24	MSPerched_20051202c_TRB	Yes	Yes	No	No [1]	Model MSPerched112905a with reduced recharge at Playas and Ditches, no injection during stress period 2	514	9,018	23.49 kg/Year (at T=0 Years)
25	MSPerched_20051202b_TRB	Yes	Yes	No	Yes	Model MSPerched112905b , no injection during stress period 2	497	20,834	23.77 kg/Year (at T=0 Years)
26	MSPerched121205b [2]	Yes	Yes	No	Yes	Model MSPerched1201A_TRBb without injection in stress period 2, extended pumping and horizontal wells to 60 years	396	22,479	23.54 kg/Year (at T=0 Years)
				Vertical Extraction Well Scenarios					
27	MSPerched111405b	Yes	Yes	Yes	Yes	8 lines of extraction wells located throughout the RDX plume	192	26,717	23.49 kg/Year (at T=0 Years)
28	MSPerched111405c	Yes	Yes	Yes	Yes	7 lines of extraction wells located throughout the RDX plume	358	26,788	23.49 kg/Year (at T=0 Years)
29	MSPerched111405d	Yes	Yes	Yes	Yes	6 lines of extraction wells located throughout the RDX plume	501	26,839	23.49 kg/Year (at T=0 Years)
30	MSPerched111405e	Yes	Yes	Yes	Yes	5 lines of extraction wells located throughout the RDX plume	1,186	27,469	48.47 kg/Year (at T=5 Years)
31	MSPerched111405f	Yes	Yes	Yes	Yes	4 lines of extraction wells located throughout the RDX plume	1,290	27,534	51.70 kg/Year (at T=5 Years)
32	MSPerched111405g	Yes	Yes	Yes	Yes	3 lines of extraction wells located throughout the RDX plume	1,458	27,653	53.70 kg/Year (at T=5 Years)
33	MSPerched111405h	Yes	Yes	Yes	Yes	2 lines of extraction wells located throughout the RDX plume	1,629	27,826	54.18 kg/Year (at T=5 Years)
34	MSPerched111405i	Yes	Yes	Yes	Yes	1 lines of extraction wells located throughout the RDX plume	1,815	28,059	54.62 kg/Year (at T=5 Years)
35	MSPerched120105a	Yes	Yes	No	Yes	Model MSPerched11405b without injection in stress period 2	161	26,015	23.49 kg/Year (at T=0 Years)
				Enhanced decay Scenarios					

Run	Model Identifier	Reactive Transport	Extraction	Injection	Normal Recharge	Description	Cumulative Flux Exiting GHB RDX (kg)	Cumulative Flux Exiting GHB Water (million gallons)	Peak Instantaneous Flux RDX (kg/year)
36	MSPerched_20051221b_TRB (3)	Yes	No	No	Yes	Biodecay amendment (T1/2=10 days) applied for 30 years. Base model MSPerched_20051108E_TRB	489	28,411	26.67 kg/Year (at T=5 Years)
37	MSPerched_20051222a_TRB (3)	Yes	Yes	Yes	Yes	Biodecay amendment (T1/2=10 days) applied for 30 years. Base model MSPerched_20051108B_TRB	393	28,172	23.46 kg/Year (at T=5 Years)
38	MSPerched_20060419b_TRB (3)	Yes	No	No	Yes	Biodecay amendment (T1/2=10 days) applied for 30 years in focused area.	646	28,284	23.46 kg/Year (at T=0 Years)

Unless otherwise noted, a model is composed of 4 stress periods:

Stress Period 1 = 3 years (model calibration; always includes historical pumping and injection)

Stress Period 2 = 30 years (pumping/Injection, where applicable, and constant RDX source applied)

Stress Period 3 = 20 years (constant RDX source applied)

Stress Period 4 = 250 years

Reactive transport assumes an RDX K_d =0.171 L/kg and an RDX degradation half-life of 25 years.

Historical extraction and injection rates presented in Table A-4.

(1) Recharge reduced by 10x at Playas and Ditches

(2) Model comprises 5 stress periods to account for an additional 30 years of pumping/injection:

Stress Period 1 = 3 years (model calibration; always includes historical pumping and injection)

Stress Period 2 = 30 years (pumping/Injection, where applicable, and constant source applied)

Stress Period 3 = 20 years (pumping/Injection, where applicable, and constant source applied)

Stress Period 4 = 10 years (pumping/Injection)

Stress Period 5 = 240 years

(3) Model stress periods are spread across three model stages to accommodate a time-varying RDX half-life (Each model stage is initiated with the output of the last).

Model Timestep = 30 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	2005.2	618.2	178.4	195.1	209.0	98.2	100.0	100.0	100.0	98.5
2	MSPerched_20051108E_TRB	2005.2	618.2	178.4	195.1	209.0	98.2	100.0	100.0	100.0	98.5
3	MSPerched011306	1500.1	561.5	169.5	178.3	181.2	73.5	90.8	95.0	91.4	85.4
4	MSPerched_20051127B_TRB	1500.1	561.5	169.5	178.3	181.2	73.5	90.8	95.0	91.4	85.4
5	MSPerched_20051108B_TRB	2042.2	508.7	136.8	121.2	168.0	100.0	82.3	76.6	62.1	79.2
6	MSPerched_20051127A_TRB	1502.6	477.9	134.0	109.5	142.3	73.6	77.3	75.1	56.1	67.1
7	MSPerched_20051108C_TRB	2010.1	523.8	140.1	119.7	161.3	98.4	84.7	78.5	61.4	76.0
8	MSPerched_20051122B_TRB	1914.7	238.5	97.3	61.6	88.0	93.8	38.6	54.5	31.6	41.5
9	MSPerched_20051122C_TRB	1914.7	238.5	97.3	61.6	88.0	93.8	38.6	54.5	31.6	41.5
10	MSPerched_20051127C_TRB	2010.1	523.8	140.1	119.7	161.3	98.4	84.7	78.5	61.4	76.0
11	MSPerched_20051127D_TRB	2010.1	523.8	140.1	119.7	161.3	98.4	84.7	78.5	61.4	76.0
12	MSPerched121205a	1914.7	238.5	97.3	61.6	88.0	93.8	38.6	54.5	31.6	41.5
13	MSPerched110805b	1620.6	514.3	138.4	115.6	147.6	79.4	83.2	77.6	59.2	69.5
14	MSPerched110805c	1970.1	398.2	109.0	63.2	83.2	96.5	64.4	61.1	32.4	39.2
15	MSPerched110905a	1914.7	214.3	109.0	92.8	149.6	93.8	34.7	61.1	47.6	70.5
16	MSPerched110905b	2004.8	510.0	135.4	105.5	111.7	98.2	82.5	75.9	54.1	52.6
17	MSPerched110905c	2004.4	370.2	114.0	105.5	160.0	98.1	59.9	63.9	54.1	75.4
18	MSPerched110905d	1975.8	207.4	110.8	101.6	158.2	96.7	33.5	62.1	52.1	74.5
19	MSPerched111005a	1514.1	121.4	87.3	53.0	69.2	74.1	19.6	48.9	27.1	32.6
20	MSPerched112905a	1424.1	112.3	87.1	52.7	65.6	69.7	18.2	48.8	27.0	30.9
21	MSPerched112905b	922.2	123.1	90.1	61.2	80.2	45.2	19.9	50.5	31.4	37.8
22	MSPerched_20051201a_TRB	1496.7	109.3	85.3	50.8	64.2	73.3	17.7	47.8	26.1	30.2
23	MSPerched_20051202a_TRB	1419.6	102.2	85.2	50.7	61.5	69.5	16.5	47.8	26.0	29.0
24	MSPerched_20051202c_TRB	1052.1	108.6	83.7	51.9	63.6	51.5	17.6	46.9	26.6	30.0
25	MSPerched_20051202b_TRB	920.7	114.0	88.4	59.3	76.5	45.1	18.4	49.5	30.4	36.0
26	MSPerched121205b	1505.2	105.9	84.8	50.5	65.3	73.7	17.1	47.5	25.9	30.8
27	MSPerched111405b	1514.1	121.4	87.3	53.0	69.2	74.1	19.6	48.9	27.1	32.6
28	MSPerched111405c	1906.2	118.1	67.1	17.6	32.3	93.3	19.1	37.6	9.0	15.2
29	MSPerched111405d	1907.6	150.8	72.5	18.6	32.3	93.4	24.4	40.6	9.5	15.2
30	MSPerched111405e	1964.0	427.1	98.0	23.5	32.3	96.2	69.1	54.9	12.0	15.2
31	MSPerched111405f	1964.2	442.8	111.1	49.9	32.3	96.2	71.6	62.3	25.6	15.2
32	MSPerched111405g	1966.6	466.4	122.1	72.8	42.6	96.3	75.4	68.4	37.3	20.1
33	MSPerched111405h	1970.1	483.6	128.4	89.3	71.3	96.5	78.2	71.9	45.8	33.6
34	MSPerched111405i	1976.4	505.5	135.1	106.7	110.6	96.8	81.8	75.7	54.7	52.1
35	MSPerched120105a	1869.5	69.5	44.9	15.2	32.3	91.5	11.2	25.2	7.8	15.2
36	MSPerched_20051221b_TRB	1810.3	568.5	163.1	178.0	190.0	88.6	92.0	91.4	91.3	89.5
37	MSPerched_20051222a_TRB	2034.7	510.2	136.9	120.4	166.8	99.6	82.5	76.7	61.7	78.6
38	MSPerched_20060419b_TRB	2034.6	597.9	172.3	190.7	212.2	99.6	96.7	96.5	97.7	100.0

Model Timestep = 50 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	3207.3	1020.7	300.8	317.3	311.8	97.8	100.0	100.0	100.0	98.1
2	MSPerched_20051108E_TRB	3207.3	1020.7	300.8	317.3	311.8	97.8	100.0	100.0	100.0	98.1
3	MSPerched011306	2104.4	867.4	271.5	266.9	238.4	64.2	85.0	90.3	84.1	75.0
4	MSPerched_20051127B_TRB	2104.4	867.4	271.5	266.9	238.4	64.2	85.0	90.3	84.1	75.0
5	MSPerched_20051108B_TRB	3278.2	898.0	243.4	227.4	273.1	100.0	88.0	80.9	71.7	85.9
6	MSPerched_20051127A_TRB	2133.1	789.8	227.0	192.9	206.8	65.1	77.4	75.4	60.8	65.1
7	MSPerched_20051108C_TRB	3248.5	921.9	250.6	232.5	269.2	99.1	90.3	83.3	73.3	84.7
8	MSPerched_20051122B_TRB	3014.4	409.2	140.7	84.6	117.1	92.0	40.1	46.8	26.7	36.8
9	MSPerched_20051122C_TRB	3014.4	409.2	140.7	84.6	117.1	92.0	40.1	46.8	26.7	36.8
10	MSPerched_20051127C_TRB	3246.4	863.6	229.6	187.0	241.5	99.0	84.6	76.3	58.9	76.0
11	MSPerched_20051127D_TRB	3246.4	863.6	229.6	187.0	241.5	99.0	84.6	76.3	58.9	76.0
12	MSPerched121205a	2994.3	300.6	130.5	69.1	102.1	91.3	29.5	43.4	21.8	32.1
13	MSPerched110805b	2517.7	878.2	240.7	211.8	220.3	76.8	86.0	80.0	66.7	69.3
14	MSPerched110805c	3148.5	687.2	179.8	115.5	136.0	96.0	67.3	59.8	36.4	42.8
15	MSPerched110905a	3084.4	500.3	188.4	173.9	239.9	94.1	49.0	62.6	54.8	75.5
16	MSPerched110905b	3233.9	892.8	239.7	207.1	203.8	98.6	87.5	79.7	65.3	64.1
17	MSPerched110905c	3238.2	747.9	213.5	210.2	265.7	98.8	73.3	71.0	66.3	83.6
18	MSPerched110905d	3197.5	563.0	204.8	200.7	260.8	97.5	55.2	68.1	63.2	82.1
19	MSPerched111005a	2325.8	294.3	131.4	79.2	92.7	70.9	28.8	43.7	25.0	29.2
20	MSPerched112905a	2127.5	224.7	125.5	70.6	80.6	64.9	22.0	41.7	22.3	25.4
21	MSPerched112905b	1049.4	208.0	126.3	75.9	94.1	32.0	20.4	42.0	23.9	29.6
22	MSPerched_20051201a_TRB	2269.2	203.3	116.9	59.4	74.2	69.2	19.9	38.9	18.7	23.3
23	MSPerched_20051202a_TRB	2104.9	140.8	114.2	55.9	68.5	64.2	13.8	37.9	17.6	21.5
24	MSPerched_20051202c_TRB	1458.0	194.5	124.4	67.8	77.2	44.5	19.1	41.4	21.4	24.3
25	MSPerched_20051202b_TRB	1041.3	137.8	117.7	64.5	83.5	31.8	13.5	39.1	20.3	26.3
26	MSPerched121205b	2260.8	123.5	113.5	55.4	72.5	69.0	12.1	37.7	17.5	22.8
27	MSPerched111405b	2325.8	294.3	131.4	79.2	92.7	70.9	28.8	43.7	25.0	29.2
28	MSPerched111405c	3048.7	339.5	112.4	49.9	58.0	93.0	33.3	37.4	15.7	18.2
29	MSPerched111405d	3050.7	377.6	119.7	51.6	58.0	93.1	37.0	39.8	16.2	18.3
30	MSPerched111405e	3142.4	740.9	172.7	74.9	63.0	95.9	72.6	57.4	23.6	19.8
31	MSPerched111405f	3142.8	759.2	188.4	103.7	63.1	95.9	74.4	62.6	32.7	19.8
32	MSPerched111405g	3147.8	794.2	205.9	135.6	78.0	96.0	77.8	68.4	42.8	24.5
33	MSPerched111405h	3157.0	829.0	220.0	166.8	121.8	96.3	81.2	73.1	52.6	38.3
34	MSPerched111405i	3174.4	873.9	235.7	200.5	180.0	96.8	85.6	78.4	63.2	56.6
35	MSPerched120105a	2936.4	178.6	66.2	19.4	38.2	89.6	17.5	22.0	6.1	12.0
36	MSPerched_20051221b_TRB	3012.9	971.4	285.9	300.6	294.1	91.9	95.2	95.0	94.7	92.5
37	MSPerched_20051222a_TRB	3269.0	897.7	244.6	228.2	272.3	99.7	87.9	81.3	71.9	85.7
38	MSPerched_20060419b_TRB	3270.8	988.5	279.5	297.8	317.8	99.8	96.8	92.9	93.9	100.0

Model Timestep = 100 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	6172.4	1998.2	596.9	606.2	541.4	97.3	100.0	100.0	100.0	97.1
2	MSPerched_20051108E_TRB	6172.4	1998.2	596.9	606.2	541.4	97.3	100.0	100.0	100.0	97.1
3	MSPerched011306	3263.7	1483.4	484.0	425.5	318.9	51.5	74.2	81.1	70.2	57.2
4	MSPerched_20051127B_TRB	3263.7	1483.4	484.0	425.5	318.9	51.5	74.2	81.1	70.2	57.2
5	MSPerched_20051108B_TRB	6299.4	1894.8	545.1	524.7	513.2	99.3	94.8	91.3	86.6	92.0
6	MSPerched_20051127A_TRB	3341.7	1439.0	448.7	364.7	297.9	52.7	72.0	75.2	60.2	53.4
7	MSPerched_20051108C_TRB	6269.7	1918.8	552.3	529.9	509.3	98.8	96.0	92.5	87.4	91.3
8	MSPerched_20051122B_TRB	5848.5	1283.6	397.0	324.6	304.4	92.2	64.2	66.5	53.5	54.6
9	MSPerched_20051122C_TRB	5848.5	1283.6	397.0	324.6	304.4	92.2	64.2	66.5	53.5	54.6
10	MSPerched_20051127C_TRB	6342.7	1834.5	506.0	452.1	481.7	100.0	91.8	84.8	74.6	86.4
11	MSPerched_20051127D_TRB	6342.7	1834.5	506.0	452.1	481.7	100.0	91.8	84.8	74.6	86.4
12	MSPerched121205a	5674.1	783.5	265.6	161.7	185.1	89.5	39.2	44.5	26.7	33.2
13	MSPerched110805b	4956.6	1767.6	512.3	460.2	387.0	78.1	88.5	85.8	75.9	69.4
14	MSPerched110805c	6088.1	1630.2	461.4	387.0	351.2	96.0	81.6	77.3	63.8	63.0
15	MSPerched110905a	6044.7	1463.1	478.0	456.3	467.0	95.3	73.2	80.1	75.3	83.7
16	MSPerched110905b	6241.2	1880.9	538.2	500.2	439.2	98.4	94.1	90.2	82.5	78.7
17	MSPerched110905c	6255.0	1741.3	513.9	505.9	504.6	98.6	87.1	86.1	83.5	90.5
18	MSPerched110905d	6204.6	1550.7	503.0	493.9	497.5	97.8	77.6	84.3	81.5	89.2
19	MSPerched111005a	4654.2	1094.8	370.2	286.5	226.4	73.4	54.8	62.0	47.3	40.6
20	MSPerched112905a	4248.5	928.6	336.1	238.8	179.8	67.0	46.5	56.3	39.4	32.2
21	MSPerched112905b	2062.5	831.9	320.3	223.9	180.6	32.5	41.6	53.7	36.9	32.4
22	MSPerched_20051201a_TRB	4511.7	920.7	324.7	228.2	180.1	71.1	46.1	54.4	37.6	32.3
23	MSPerched_20051202a_TRB	4152.4	740.0	286.4	179.9	142.6	65.5	37.0	48.0	29.7	25.6
24	MSPerched_20051202c_TRB	2295.5	616.2	283.9	147.6	112.0	36.2	30.8	47.6	24.4	20.1
25	MSPerched_20051202b_TRB	1990.5	640.1	270.4	166.1	145.3	31.4	32.0	45.3	27.4	26.0
26	MSPerched121205b	4134.4	418.7	209.2	95.2	100.0	65.2	21.0	35.0	15.7	17.9
27	MSPerched111405b	4654.2	1094.8	370.2	286.5	226.4	73.4	54.8	62.0	47.3	40.6
28	MSPerched111405c	5945.1	1254.9	383.3	307.3	257.3	93.7	62.8	64.2	50.7	46.1
29	MSPerched111405d	5947.7	1293.6	390.9	309.2	257.5	93.8	64.7	65.5	51.0	46.2
30	MSPerched111405e	6070.5	1679.3	452.9	342.9	270.1	95.7	84.0	75.9	56.6	48.4
31	MSPerched111405f	6071.0	1698.0	468.8	371.8	270.2	95.7	85.0	78.5	61.3	48.4
32	MSPerched111405g	6079.8	1736.9	488.0	405.8	286.8	95.9	86.9	81.8	66.9	51.4
33	MSPerched111405h	6099.0	1781.5	506.1	442.1	335.3	96.2	89.2	84.8	72.9	60.1
34	MSPerched111405i	6135.1	1840.4	527.1	482.8	400.6	96.7	92.1	88.3	79.6	71.8
35	MSPerched120105a	5712.2	997.4	299.1	230.0	199.5	90.1	49.9	50.1	37.9	35.8
36	MSPerched_20051221b_TRB	5976.8	1948.6	581.9	589.3	523.4	94.2	97.5	97.5	97.2	93.8
37	MSPerched_20051222a_TRB	6291.1	1900.1	546.1	525.1	512.4	99.2	95.1	91.5	86.6	91.9
38	MSPerched_20060419b_TRB	6291.5	1985.2	581.2	595.1	557.8	99.2	99.3	97.4	98.2	100.0

Model Timestep = 150 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	9100.4	2961.0	888.1	888.0	761.3	97.7	100.0	100.0	100.0	97.7
2	MSPerched_20051108E_TRB	9100.4	2961.0	888.1	888.0	761.3	97.7	100.0	100.0	100.0	97.7
3	MSPerched011306	4198.5	1994.0	666.5	542.9	371.6	45.1	67.3	75.0	61.1	47.7
4	MSPerched_20051127B_TRB	4198.5	1994.0	666.5	542.9	371.6	45.1	67.3	75.0	61.1	47.7
5	MSPerched_20051108B_TRB	9239.3	2861.0	837.4	808.0	734.8	99.2	96.6	94.3	91.0	94.3
6	MSPerched_20051127A_TRB	4295.0	1959.4	634.0	485.7	352.5	46.1	66.2	71.4	54.7	45.2
7	MSPerched_20051108C_TRB	9209.6	2884.9	844.5	813.1	730.9	98.9	97.4	95.1	91.6	93.8
8	MSPerched_20051122B_TRB	8745.3	2235.9	684.9	601.8	519.5	93.9	75.5	77.1	67.8	66.7
9	MSPerched_20051122C_TRB	8745.3	2235.9	684.9	601.8	519.5	93.9	75.5	77.1	67.8	66.7
10	MSPerched_20051127C_TRB	9314.8	2811.1	801.5	739.9	708.4	100.0	94.9	90.2	83.3	90.9
11	MSPerched_20051127D_TRB	9314.8	2811.1	801.5	739.9	708.4	100.0	94.9	90.2	83.3	90.9
12	MSPerched121205a	8510.0	1703.4	542.1	424.3	386.0	91.4	57.5	61.0	47.8	49.5
13	MSPerched110805b	7738.9	2692.8	792.3	725.8	587.3	83.1	90.9	89.2	81.7	75.4
14	MSPerched110805c	9009.2	2590.3	751.7	667.6	569.9	96.7	87.5	84.6	75.2	73.1
15	MSPerched110905a	8972.4	2425.6	769.1	738.0	686.9	96.3	81.9	86.6	83.1	88.1
16	MSPerched110905b	9177.8	2846.0	830.1	782.9	660.2	98.5	96.1	93.5	88.2	84.7
17	MSPerched110905c	9193.9	2707.1	806.1	789.0	725.9	98.7	91.4	90.8	88.9	93.2
18	MSPerched110905d	9141.5	2515.9	795.0	776.7	718.6	98.1	85.0	89.5	87.5	92.2
19	MSPerched111005a	7403.2	2008.5	646.5	547.1	421.5	79.5	67.8	72.8	61.6	54.1
20	MSPerched112905a	6925.3	1819.8	605.6	489.8	364.6	74.3	61.5	68.2	55.2	46.8
21	MSPerched112905b	4456.6	1679.6	578.7	460.0	351.8	47.8	56.7	65.2	51.8	45.1
22	MSPerched_20051201a_TRB	7231.1	1823.5	597.5	484.0	370.3	77.6	61.6	67.3	54.5	47.5
23	MSPerched_20051202a_TRB	6799.8	1618.6	551.7	425.3	322.1	73.0	54.7	62.1	47.9	41.3
24	MSPerched_20051202c_TRB	2996.0	1009.0	433.1	222.5	143.5	32.2	34.1	48.8	25.1	18.4
25	MSPerched_20051202b_TRB	4342.4	1471.5	523.6	395.3	310.5	46.6	49.7	59.0	44.5	39.8
26	MSPerched121205b	6540.6	1213.4	447.3	301.6	236.9	70.2	41.0	50.4	34.0	30.4
27	MSPerched111405b	7403.2	2008.5	646.5	547.1	421.5	79.5	67.8	72.8	61.6	54.1
28	MSPerched111405c	8854.9	2211.3	672.5	586.3	474.1	95.1	74.7	75.7	66.0	60.8
29	MSPerched111405d	8857.6	2250.0	680.1	588.2	474.3	95.1	76.0	76.6	66.2	60.9
30	MSPerched111405e	8987.0	2637.9	742.7	622.7	487.8	96.5	89.1	83.6	70.1	62.6
31	MSPerched111405f	8987.6	2656.6	758.6	651.7	488.0	96.5	89.7	85.4	73.4	62.6
32	MSPerched111405g	8997.3	2695.8	778.0	685.9	504.8	96.6	91.0	87.6	77.2	64.8
33	MSPerched111405h	9019.2	2741.3	796.3	722.6	553.7	96.8	92.6	89.7	81.4	71.0
34	MSPerched111405i	9060.0	2801.8	817.8	763.9	619.7	97.3	94.6	92.1	86.0	79.5
35	MSPerched120105a	8592.5	1943.8	585.1	504.7	411.7	92.2	65.6	65.9	56.8	52.8
36	MSPerched_20051221b_TRB	8904.5	2911.2	873.1	871.1	743.3	95.6	98.3	98.3	98.1	95.4
37	MSPerched_20051222a_TRB	9201.0	2865.0	837.8	807.9	733.8	98.8	96.8	94.3	91.0	94.2
38	MSPerched_20060419b_TRB	9231.2	2951.3	873.5	878.3	779.3	99.1	99.7	98.3	98.9	100.0

Model Timestep = 200 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	12019.1	3920.9	1178.5	1168.5	979.8	98.2	100.0	100.0	100.0	98.2
2	MSPerched_20051108E_TRB	12019.1	3920.9	1178.5	1168.5	979.8	98.2	100.0	100.0	100.0	98.2
3	MSPerched011306	5045.9	2463.1	837.3	645.6	416.9	41.2	62.8	71.1	55.2	41.8
4	MSPerched_20051127B_TRB	5045.9	2463.1	837.3	645.6	416.9	41.2	62.8	71.1	55.2	41.8
5	MSPerched_20051108B_TRB	12160.2	3821.5	1128.0	1088.7	953.5	99.3	97.5	95.7	93.2	95.5
6	MSPerched_20051127A_TRB	5149.6	2431.9	805.8	589.5	398.3	42.1	62.0	68.4	50.5	39.9
7	MSPerched_20051108C_TRB	12130.5	3845.4	1135.1	1093.9	949.6	99.1	98.1	96.3	93.6	95.1
8	MSPerched_20051122B_TRB	11657.8	3194.1	974.7	881.6	737.1	95.2	81.5	82.7	75.5	73.9
9	MSPerched_20051122C_TRB	11657.8	3194.1	974.7	881.6	737.1	95.2	81.5	82.7	75.5	73.9
10	MSPerched_20051127C_TRB	12242.0	3773.4	1092.6	1021.5	928.0	100.0	96.2	92.7	87.4	93.0
11	MSPerched_20051127D_TRB	12242.0	3773.4	1092.6	1021.5	928.0	100.0	96.2	92.7	87.4	93.0
12	MSPerched121205a	11409.1	2657.4	830.6	702.3	601.8	93.2	67.8	70.5	60.1	60.3
13	MSPerched110805b	10627.9	3644.6	1080.2	1003.0	802.0	86.8	93.0	91.7	85.8	80.4
14	MSPerched110805c	11926.6	3549.8	1042.0	948.0	788.1	97.4	90.5	88.4	81.1	79.0
15	MSPerched110905a	11891.1	3385.4	1059.4	1018.5	905.3	97.1	86.3	89.9	87.2	90.7
16	MSPerched110905b	12098.1	3806.3	1120.6	1063.6	878.9	98.8	97.1	95.1	91.0	88.1
17	MSPerched110905c	12114.6	3667.6	1096.6	1069.8	944.6	99.0	93.5	93.0	91.6	94.7
18	MSPerched110905d	12061.9	3476.3	1085.5	1057.5	937.3	98.5	88.7	92.1	90.5	93.9
19	MSPerched111005a	10285.3	2958.4	933.8	823.4	635.2	84.0	75.5	79.2	70.5	63.6
20	MSPerched112905a	9791.8	2765.4	891.6	764.3	576.3	80.0	70.5	75.7	65.4	57.7
21	MSPerched112905b	7275.4	2614.5	861.6	730.3	559.3	59.4	66.7	73.1	62.5	56.0
22	MSPerched_20051201a_TRB	10106.8	2771.6	884.3	759.5	583.2	82.6	70.7	75.0	65.0	58.4
23	MSPerched_20051202a_TRB	9659.6	2562.3	837.1	698.9	532.9	78.9	65.3	71.0	59.8	53.4
24	MSPerched_20051202c_TRB	3719.6	1418.0	587.3	304.7	179.4	30.4	36.2	49.8	26.1	18.0
25	MSPerched_20051202b_TRB	7151.7	2403.7	805.6	664.5	516.8	58.4	61.3	68.4	56.9	51.8
26	MSPerched121205b	9330.4	2136.8	726.5	566.5	437.8	76.2	54.5	61.6	48.5	43.9
27	MSPerched111405b	10285.3	2958.4	933.8	823.4	635.2	84.0	75.5	79.2	70.5	63.6
28	MSPerched111405c	11769.8	3170.2	962.5	866.4	692.0	96.1	80.9	81.7	74.1	69.3
29	MSPerched111405d	11772.5	3208.9	970.1	868.3	692.3	96.2	81.8	82.3	74.3	69.4
30	MSPerched111405e	11903.1	3597.0	1032.8	903.0	705.9	97.2	91.7	87.6	77.3	70.7
31	MSPerched111405f	11903.7	3615.8	1048.7	932.0	706.0	97.2	92.2	89.0	79.8	70.7
32	MSPerched111405g	11913.7	3655.0	1068.1	966.1	722.9	97.3	93.2	90.6	82.7	72.4
33	MSPerched111405h	11936.2	3700.8	1086.5	1002.9	771.9	97.5	94.4	92.2	85.8	77.3
34	MSPerched111405i	11978.0	3761.4	1108.1	1044.4	838.1	97.8	95.9	94.0	89.4	84.0
35	MSPerched120105a	11501.6	2901.0	874.6	784.1	628.9	94.0	74.0	74.2	67.1	63.0
36	MSPerched_20051221b_TRB	11823.2	3871.1	1163.4	1151.6	961.7	96.6	98.7	98.7	98.6	96.4
37	MSPerched_20051222a_TRB	12118.4	3822.5	1129.6	1092.2	950.0	99.0	97.5	95.8	93.5	95.2
38	MSPerched_20060419b_TRB	12152.1	3911.8	1164.0	1159.1	998.0	99.3	99.8	98.8	99.2	100.0

Model Timestep = 250 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	14935.9	4880.2	1468.6	1448.8	1198.0	98.5	100.0	100.0	100.0	98.5
2	MSPerched_20051108E_TRB	14935.9	4880.2	1468.6	1448.8	1198.0	98.5	100.0	100.0	100.0	98.5
3	MSPerched011306	5857.0	2915.7	1003.6	742.7	459.7	38.6	59.7	68.3	51.3	37.8
4	MSPerched_20051127B_TRB	5857.0	2915.7	1003.6	742.7	459.7	38.6	59.7	68.3	51.3	37.8
5	MSPerched_20051108B_TRB	15077.4	4781.0	1418.2	1369.1	1171.7	99.5	98.0	96.6	94.5	96.3
6	MSPerched_20051127A_TRB	5963.7	2885.9	972.5	687.1	441.3	39.3	59.1	66.2	47.4	36.3
7	MSPerched_20051108C_TRB	15047.8	4804.9	1425.3	1374.3	1167.8	99.3	98.5	97.0	94.9	96.0
8	MSPerched_20051122B_TRB	14573.2	4153.2	1264.8	1161.8	955.1	96.1	85.1	86.1	80.2	78.5
9	MSPerched_20051122C_TRB	14573.2	4153.2	1264.8	1161.8	955.1	96.1	85.1	86.1	80.2	78.5
10	MSPerched_20051127C_TRB	15160.6	4733.2	1382.9	1301.9	1146.4	100.0	97.0	94.2	89.9	94.3
11	MSPerched_20051127D_TRB	15160.6	4733.2	1382.9	1301.9	1146.4	100.0	97.0	94.2	89.9	94.3
12	MSPerched121205a	14322.1	3615.8	1120.5	982.2	819.5	94.5	74.1	76.3	67.8	67.4
13	MSPerched110805b	13539.0	4602.5	1369.9	1282.6	1019.4	89.3	94.3	93.3	88.5	83.8
14	MSPerched110805c	14843.0	4509.1	1332.1	1228.3	1006.3	97.9	92.4	90.7	84.8	82.7
15	MSPerched110905a	14807.8	4344.8	1349.6	1298.8	1123.5	97.7	89.0	91.9	89.6	92.4
16	MSPerched110905b	15015.2	4765.7	1410.8	1344.0	1097.1	99.0	97.7	96.1	92.8	90.2
17	MSPerched110905c	15031.9	4627.1	1386.8	1350.2	1162.9	99.2	94.8	94.4	93.2	95.6
18	MSPerched110905d	14979.1	4435.8	1375.7	1337.8	1155.5	98.8	90.9	93.7	92.3	95.0
19	MSPerched111005a	13195.1	3915.9	1223.4	1102.9	852.6	87.0	80.2	83.3	76.1	70.1
20	MSPerched112905a	12698.7	3722.1	1180.9	1043.4	793.2	83.8	76.3	80.4	72.0	65.2
21	MSPerched112905b	10174.1	3569.1	1150.3	1008.6	775.3	67.1	73.1	78.3	69.6	63.7
22	MSPerched_20051201a_TRB	13015.4	3728.7	1173.8	1038.9	800.4	85.9	76.4	79.9	71.7	65.8
23	MSPerched_20051202a_TRB	12565.2	3518.6	1126.3	978.0	749.7	82.9	72.1	76.7	67.5	61.6
24	MSPerched_20051202c_TRB	4471.2	1843.1	746.2	393.0	218.4	29.5	37.8	50.8	27.1	18.0
25	MSPerched_20051202b_TRB	10048.5	3357.9	1094.2	942.6	732.6	66.3	68.8	74.5	65.1	60.2
26	MSPerched121205b	12221.8	3089.3	1014.5	843.9	652.8	80.6	63.3	69.1	58.2	53.7
27	MSPerched111405b	13195.1	3915.9	1223.4	1102.9	852.6	87.0	80.2	83.3	76.1	70.1
28	MSPerched111405c	14685.7	4129.3	1252.6	1146.6	910.1	96.9	84.6	85.3	79.1	74.8
29	MSPerched111405d	14688.4	4168.0	1260.2	1148.5	910.3	96.9	85.4	85.8	79.3	74.8
30	MSPerched111405e	14819.2	4556.3	1323.0	1183.2	924.0	97.7	93.4	90.1	81.7	76.0
31	MSPerched111405f	14819.8	4575.0	1338.9	1212.2	924.1	97.8	93.7	91.2	83.7	76.0
32	MSPerched111405g	14829.8	4614.2	1358.2	1246.3	941.0	97.8	94.5	92.5	86.0	77.4
33	MSPerched111405h	14852.5	4660.0	1376.7	1283.1	990.0	98.0	95.5	93.7	88.6	81.4
34	MSPerched111405i	14894.6	4720.8	1398.3	1324.7	1056.2	98.2	96.7	95.2	91.4	86.8
35	MSPerched120105a	14416.5	3859.9	1164.6	1064.2	846.8	95.1	79.1	79.3	73.5	69.6
36	MSPerched_20051221b_TRB	14740.0	4830.5	1453.6	1431.9	1179.9	97.2	99.0	99.0	98.8	97.0
37	MSPerched_20051222a_TRB	15035.8	4780.1	1421.3	1368.9	1167.0	99.2	97.9	96.8	94.5	95.9
38	MSPerched_20060419b_TRB	15069.3	4871.3	1454.2	1439.5	1216.3	99.4	99.8	99.0	99.4	100.0

Model Timestep = 300 years

		Cumulative Water Volume Across GHB Reaches (millions of gallons)					Ranking (Percentage of Maximum)				
Run #	Model	volMilGal_0	volMilGal_1	volMilGal_2	volMilGal_3	volMilGal_4	Rank_R0	Rank_R1	Rank_R2	Rank_R3	Rank_R4
1	MSPerched_20051108D_TRB	17852.3	5839.5	1758.8	1729.1	1416.1	98.8	100.0	100.0	100.0	98.7
2	MSPerched_20051108E_TRB	17852.3	5839.5	1758.8	1729.1	1416.1	98.8	100.0	100.0	100.0	98.7
3	MSPerched011306	6653.0	3361.8	1168.2	837.8	501.6	36.8	57.6	66.4	48.5	35.0
4	MSPerched_20051127B_TRB	6653.0	3361.8	1168.2	837.8	501.6	36.8	57.6	66.4	48.5	35.0
5	MSPerched_20051108B_TRB	17993.9	5740.3	1708.3	1649.4	1389.9	99.5	98.3	97.1	95.4	96.9
6	MSPerched_20051127A_TRB	6760.9	3332.4	1137.2	782.3	483.3	37.4	57.1	64.7	45.2	33.7
7	MSPerched_20051108C_TRB	17964.2	5764.2	1715.4	1654.5	1386.0	99.4	98.7	97.5	95.7	96.6
8	MSPerched_20051122B_TRB	17489.2	5112.4	1554.9	1442.0	1173.2	96.7	87.5	88.4	83.4	81.8
9	MSPerched_20051122C_TRB	17489.2	5112.4	1554.9	1442.0	1173.2	96.7	87.5	88.4	83.4	81.8
10	MSPerched_20051127C_TRB	18077.3	5692.5	1673.1	1582.2	1364.6	100.0	97.5	95.1	91.5	95.1
11	MSPerched_20051127D_TRB	18077.3	5692.5	1673.1	1582.2	1364.6	100.0	97.5	95.1	91.5	95.1
12	MSPerched121205a	17237.6	4574.9	1410.6	1262.3	1037.5	95.4	78.3	80.2	73.0	72.3
13	MSPerched110805b	16454.2	5561.5	1660.0	1562.8	1237.4	91.0	95.2	94.4	90.4	86.3
14	MSPerched110805c	17759.2	5468.4	1622.2	1508.5	1224.4	98.2	93.6	92.2	87.2	85.4
15	MSPerched110905a	17724.2	5304.1	1639.7	1579.1	1341.6	98.0	90.8	93.2	91.3	93.5
16	MSPerched110905b	17931.6	5725.0	1700.9	1624.3	1315.2	99.2	98.0	96.7	93.9	91.7
17	MSPerched110905c	17948.3	5586.4	1676.9	1630.4	1381.0	99.3	95.7	95.3	94.3	96.3
18	MSPerched110905d	17895.5	5395.0	1665.9	1618.1	1373.6	99.0	92.4	94.7	93.6	95.8
19	MSPerched111005a	16110.1	4874.8	1513.5	1383.1	1070.5	89.1	83.5	86.1	80.0	74.6
20	MSPerched112905a	15613.2	4680.9	1470.9	1323.5	1011.2	86.4	80.2	83.6	76.5	70.5
21	MSPerched112905b	13087.1	4527.5	1440.2	1288.5	993.0	72.4	77.5	81.9	74.5	69.2
22	MSPerched_20051201a_TRB	15930.2	4687.6	1463.8	1319.0	1018.3	88.1	80.3	83.2	76.3	71.0
23	MSPerched_20051202a_TRB	15479.5	4477.3	1416.3	1258.0	967.6	85.6	76.7	80.5	72.8	67.5
24	MSPerched_20051202c_TRB	5162.8	2233.6	891.4	475.1	254.8	28.6	38.3	50.7	27.5	17.8
25	MSPerched_20051202b_TRB	12961.2	4316.2	1384.1	1222.5	950.3	71.7	73.9	78.7	70.7	66.2
26	MSPerched121205b	15133.4	4047.3	1304.3	1123.6	870.4	83.7	69.3	74.2	65.0	60.7
27	MSPerched111405b	16110.1	4874.8	1513.5	1383.1	1070.5	89.1	83.5	86.1	80.0	74.6
28	MSPerched111405c	17601.7	5088.5	1542.8	1426.8	1128.2	97.4	87.1	87.7	82.5	78.7
29	MSPerched111405d	17604.4	5127.2	1550.4	1428.7	1128.4	97.4	87.8	88.1	82.6	78.7
30	MSPerched111405e	17735.3	5515.5	1613.1	1463.4	1142.1	98.1	94.5	91.7	84.6	79.6
31	MSPerched111405f	17735.9	5534.2	1629.0	1492.4	1142.2	98.1	94.8	92.6	86.3	79.6
32	MSPerched111405g	17745.9	5573.5	1648.4	1526.6	1159.1	98.2	95.4	93.7	88.3	80.8
33	MSPerched111405h	17768.7	5619.3	1666.8	1563.4	1208.1	98.3	96.2	94.8	90.4	84.2
34	MSPerched111405i	17810.9	5680.0	1688.4	1604.9	1274.3	98.5	97.3	96.0	92.8	88.8
35	MSPerched120105a	17332.4	4819.1	1454.8	1344.4	1064.9	95.9	82.5	82.7	77.8	74.2
36	MSPerched_20051221b_TRB	17656.3	5789.8	1743.7	1712.2	1398.0	97.7	99.1	99.1	99.0	97.5
37	MSPerched_20051222a_TRB	17953.2	5745.0	1705.6	1653.2	1391.4	99.3	98.4	97.0	95.6	97.0
38	MSPerched_20060419b_TRB	17985.8	5830.6	1744.4	1719.7	1434.4	99.5	99.8	99.2	99.5	100.0

Model Timestep = 30 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)				
1	MSPerched_20051108D_TRB	7.8	1050.4	369.4	472.3	442.9	100.0	72.5	100.0	100.0	100.0
2	MSPerched_20051108E_TRB	3.1	1449.5	87.4	277.4	194.1	39.9	100.0	23.7	58.7	43.8
3	MSPerched011306	2.4	1372.8	77.2	250.1	163.0	30.9	94.7	20.9	53.0	36.8
4	MSPerched_20051127B_TRB	6.2	1035.6	360.1	455.5	395.6	80.4	71.4	97.5	96.4	89.3
5	MSPerched_20051108B_TRB	2.6	1108.7	45.2	134.8	131.2	33.7	76.4	12.2	28.5	29.6
6	MSPerched_20051127A_TRB	2.1	1048.9	46.0	125.6	112.5	27.3	72.2	12.5	26.6	25.4
7	MSPerched_20051108C_TRB	6.7	787.2	308.6	319.3	306.4	86.1	54.3	83.6	67.6	69.2
8	MSPerched_20051122B_TRB	2.1	580.0	16.2	61.9	53.8	27.8	40.0	4.4	13.1	12.2
9	MSPerched_20051122C_TRB	5.3	741.6	180.1	172.4	161.9	68.7	51.2	48.8	36.5	36.6
10	MSPerched_20051127C_TRB	2.7	1096.7	51.9	139.4	131.7	35.4	75.7	14.0	29.5	29.7
11	MSPerched_20051127D_TRB	2.7	1096.7	51.9	139.4	131.7	35.4	75.7	14.0	29.5	29.7
12	MSPerched121205a	2.1	580.0	16.2	61.9	53.8	27.8	40.0	4.4	13.1	12.2
13	MSPerched110805b	2.1	1087.3	50.4	134.2	119.2	27.2	75.0	13.6	28.4	26.9
14	MSPerched110805c	2.4	848.5	27.2	62.4	47.1	30.7	58.5	7.4	13.2	10.6
15	MSPerched110905a	2.7	571.4	21.4	102.3	118.0	34.3	39.4	5.8	21.7	26.6
16	MSPerched110905b	2.6	1069.3	48.3	120.2	66.3	33.0	73.8	13.1	25.5	15.0
17	MSPerched110905c	2.7	572.2	22.3	120.1	130.2	35.3	39.5	6.0	25.4	29.4
18	MSPerched110905d	2.7	402.0	20.1	114.8	128.1	35.1	27.7	5.4	24.3	28.9
19	MSPerched111005a	1.8	286.5	9.1	51.3	35.2	23.2	19.8	2.5	10.9	8.0
20	MSPerched112905a	1.4	285.1	9.0	51.1	33.8	18.2	19.7	2.4	10.8	7.6
21	MSPerched112905b	1.4	294.3	8.1	54.6	40.1	18.4	20.3	2.2	11.6	9.1
22	MSPerched_20051201a_TRB	1.6	265.7	8.2	48.8	32.6	21.2	18.3	2.2	10.3	7.4
23	MSPerched_20051202a_TRB	1.3	265.0	8.2	46.7	31.6	17.2	18.3	2.2	10.3	7.1
24	MSPerched_20051202c_TRB	1.3	282.2	8.2	50.3	32.9	17.1	19.5	2.2	10.6	7.4
25	MSPerched_20051202b_TRB	1.4	275.5	7.3	52.3	38.1	17.5	19.0	2.0	11.1	8.6
26	MSPerched121205b	1.6	246.0	8.1	47.5	32.0	21.2	17.0	2.2	10.1	7.2
27	MSPerched111405b	1.8	286.5	9.1	51.3	35.2	23.2	19.8	2.5	10.9	8.0
28	MSPerched111405c	0.7	191.7	4.1	11.2	17.0	8.9	13.2	1.1	2.4	3.8
29	MSPerched111405d	0.7	297.0	7.0	11.6	17.0	8.9	20.5	1.9	2.4	3.8
30	MSPerched111405e	0.7	865.7	30.8	13.3	17.0	9.2	59.7	8.3	2.8	3.8
31	MSPerched111405f	0.7	918.3	32.6	44.4	17.0	9.2	63.4	8.8	9.4	3.8
32	MSPerched111405g	0.7	983.8	38.4	78.0	21.1	9.2	67.9	10.4	16.5	4.8
33	MSPerched111405h	0.7	1021.8	42.6	99.0	38.5	9.3	70.5	11.5	21.0	8.7
34	MSPerched111405i	0.7	1068.3	47.8	121.9	80.3	9.4	73.6	12.9	25.8	18.1
35	MSPerched120105a	0.7	76.2	0.2	10.3	17.0	8.7	5.3	0.0	2.2	3.8
36	MSPerched_20051221b_TRB	3.0	311.5	24.7	110.7	64.6	38.7	21.5	6.7	23.4	14.6
37	MSPerched_20051222a_TRB	2.7	278.0	16.1	84.2	50.8	34.2	19.2	4.4	17.8	11.5
38	MSPerched_20060419b_TRB	3.0	106.2	18.6	46.3	190.9	38.5	7.3	5.0	9.8	43.1

Model Timestep = 50 years

		Cumulative Mass RDX Across GHB Reaches (kg)						Ranking (Percentage of Maximum)			
Run #	Model Location	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5	Reach 0	Reach 1	Reach 2	Reach 3
1	MSPerched_20051108D_TRB	8.7	1148.1	425.7	562.4	564.7	100.0	68.8	100.0	100.0	100.0
2	MSPerched_20051108E_TRB	4.1	1668.5	187.3	383.8	271.8	46.8	100.0	44.0	68.2	48.1
3	MSPerched011306	2.7	1567.4	156.4	329.8	207.3	31.5	93.9	36.7	58.6	36.7
4	MSPerched_20051127B_TRB	6.5	1107.5	420.4	536.0	471.1	74.7	66.4	98.8	95.3	83.4
5	MSPerched_20051108B_TRB	3.7	1260.4	125.4	226.2	206.2	42.6	75.5	29.4	40.2	36.5
6	MSPerched_20051127A_TRB	2.4	1167.0	111.2	191.9	158.3	28.0	69.9	26.1	34.1	28.0
7	MSPerched_20051108C_TRB	7.7	835.8	390.4	357.5	362.7	89.1	50.1	91.7	63.6	64.2
8	MSPerched_20051122B_TRB	2.5	633.1	30.9	73.0	64.2	28.8	37.9	7.2	13.0	11.4
9	MSPerched_20051122C_TRB	5.8	764.5	306.1	215.7	204.9	64.3	45.8	71.9	38.4	36.3
10	MSPerched_20051127C_TRB	3.8	1211.0	116.9	196.0	187.9	42.0	72.6	27.5	34.8	33.3
11	MSPerched_20051127D_TRB	3.8	1211.0	116.9	196.0	187.9	42.0	72.6	27.5	34.8	33.3
12	MSPerched121205a	2.5	604.7	26.1	67.4	59.9	28.4	36.2	6.1	12.0	10.6
13	MSPerched110805b	2.4	1210.3	125.9	211.5	171.9	27.7	72.5	29.6	37.6	30.4
14	MSPerched110805c	3.0	915.8	67.8	89.1	65.4	34.3	54.9	15.9	15.8	11.6
15	MSPerched110905a	3.5	715.1	58.4	161.3	176.4	40.7	42.9	13.7	28.7	31.2
16	MSPerched110905b	3.4	1192.0	126.0	197.0	114.5	39.0	71.4	29.6	35.0	20.3
17	MSPerched110905c	3.7	662.3	75.5	200.5	201.1	42.7	39.7	17.7	35.6	35.6
18	MSPerched110905d	3.7	489.4	67.7	189.9	196.6	42.3	29.3	15.9	33.8	34.8
19	MSPerched111005a	2.0	340.3	21.6	62.4	42.5	22.6	20.4	5.1	11.1	7.5
20	MSPerched112905a	1.5	327.2	19.1	59.2	36.8	17.2	19.6	4.5	10.5	6.9
21	MSPerched112905b	1.5	333.1	17.4	62.4	45.1	17.6	20.0	4.1	11.1	8.0
22	MSPerched_20051201a_TRB	1.7	290.0	15.4	53.3	35.8	20.2	17.4	3.6	9.5	6.3
23	MSPerched_20051202a_TRB	1.4	277.1	14.4	52.3	34.0	16.1	16.6	3.4	9.3	6.0
24	MSPerched_20051202c_TRB	1.4	324.5	18.7	58.6	37.7	16.2	19.4	4.4	10.4	6.7
25	MSPerched_20051202b_TRB	1.4	287.2	13.7	56.5	40.7	16.7	17.2	3.2	10.0	7.2
26	MSPerched121205b	1.7	255.2	14.3	51.1	34.5	20.2	15.3	3.4	9.1	6.1
27	MSPerched111405b	2.0	340.3	21.6	62.4	42.5	22.6	20.4	5.1	11.1	7.5
28	MSPerched111405c	0.8	231.9	17.6	14.1	18.9	8.7	13.9	4.1	2.5	3.3
29	MSPerched111405d	0.8	358.1	23.6	14.8	18.9	8.7	21.5	5.5	2.6	3.3
30	MSPerched111405e	0.8	933.2	86.3	24.0	19.3	9.0	55.9	20.3	4.3	3.4
31	MSPerched111405f	0.8	993.1	85.5	66.8	19.3	9.0	59.5	20.1	11.9	3.4
32	MSPerched111405g	0.8	1075.5	96.8	115.6	25.9	9.1	64.5	22.7	20.6	4.6
33	MSPerched111405h	0.8	1126.9	108.0	152.7	58.5	9.1	67.5	25.4	27.2	10.4
34	MSPerched111405i	0.8	1184.9	121.8	194.2	125.7	9.2	71.0	28.6	34.5	22.3
35	MSPerched120105a	0.7	81.3	0.5	10.7	17.5	8.3	4.9	0.1	1.9	3.1
36	MSPerched_20051221b_TRB	4.1	315.0	44.3	114.9	70.9	46.9	18.9	10.4	20.4	12.6
37	MSPerched_20051222a_TRB	3.7	279.9	32.8	90.4	58.0	42.9	16.8	7.7	16.1	10.3
38	MSPerched_20060419b_TRB	4.1	128.7	23.8	95.8	273.3	46.9	7.7	5.6	17.0	48.4

Model Timestep = 100 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)				
1	MSPerched_20051108D_TRB	9.4	1295.5	504.0	708.5	681.9	100.0	75.0	100.0	100.0	100.0
2	MSPerched_20051108E_TRB	4.4	1728.5	256.2	439.2	321.2	47.1	100.0	50.8	62.0	47.1
3	MSPerched011306	2.8	1618.4	215.0	369.1	231.4	29.5	93.6	42.7	52.1	33.9
4	MSPerched_20051127B_TRB	6.6	1172.1	498.2	663.9	540.3	69.9	67.8	98.9	93.7	79.2
5	MSPerched_20051108B_TRB	4.1	1296.5	193.5	262.4	244.4	43.8	75.0	38.4	37.0	35.8
6	MSPerched_20051127A_TRB	2.5	1194.8	170.4	223.5	180.5	26.4	69.1	33.8	31.5	26.5
7	MSPerched_20051108C_TRB	8.6	938.5	409.1	415.5	441.1	92.1	54.3	81.2	58.6	64.7
8	MSPerched_20051122B_TRB	2.6	668.0	87.0	119.3	93.8	28.0	38.6	17.3	16.8	13.8
9	MSPerched_20051122C_TRB	6.1	851.9	423.1	332.9	265.0	64.9	49.3	84.0	47.0	38.9
10	MSPerched_20051127C_TRB	4.0	1234.3	180.3	234.7	220.4	42.9	71.4	35.8	33.1	32.3
11	MSPerched_20051127D_TRB	4.0	1234.3	180.3	234.7	220.4	42.9	71.4	35.8	33.1	32.3
12	MSPerched121205a	2.5	615.0	47.1	76.2	68.2	26.8	35.6	9.3	10.7	10.0
13	MSPerched110805b	2.5	1242.5	190.9	246.8	202.2	26.3	71.9	37.9	34.8	29.7
14	MSPerched110805c	3.2	936.6	138.0	137.1	101.2	34.3	54.2	27.4	19.4	14.8
15	MSPerched110905a	3.9	741.8	117.5	200.7	215.3	41.5	42.9	23.3	28.3	31.6
16	MSPerched110905b	3.7	1227.5	194.7	230.1	150.1	39.8	71.0	38.6	32.5	22.0
17	MSPerched110905c	4.1	695.5	134.1	236.3	239.3	43.8	40.2	26.6	33.3	35.1
18	MSPerched110905d	4.1	523.4	125.7	226.3	234.9	43.4	30.3	24.9	31.9	34.4
19	MSPerched111005a	2.0	371.6	63.6	94.2	61.0	21.1	21.5	12.6	13.3	8.9
20	MSPerched112905a	1.5	359.6	54.5	83.2	50.9	15.9	20.8	10.8	11.7	7.5
21	MSPerched112905b	1.5	369.9	52.2	85.0	56.5	16.3	21.4	10.4	12.0	8.3
22	MSPerched_20051201a_TRB	1.8	321.3	46.5	77.2	46.1	18.6	18.6	9.2	10.9	6.8
23	MSPerched_20051202a_TRB	1.4	308.5	38.3	65.4	39.7	15.0	17.8	7.6	9.2	5.8
24	MSPerched_20051202c_TRB	1.4	349.1	45.7	69.8	42.7	15.0	20.2	9.1	9.9	6.3
25	MSPerched_20051202b_TRB	1.4	318.3	35.8	67.3	45.9	15.4	18.4	7.1	9.5	6.7
26	MSPerched121205b	1.8	263.5	26.2	53.4	36.7	18.7	15.2	5.2	7.5	5.4
27	MSPerched111405b	2.0	371.6	63.6	94.2	61.0	21.1	21.5	12.6	13.3	8.9
28	MSPerched111405c	0.8	259.4	40.3	19.7	27.7	8.5	15.0	8.0	2.8	4.1
29	MSPerched111405d	0.8	390.9	51.2	20.5	27.7	8.6	22.6	10.2	2.9	4.1
30	MSPerched111405e	0.8	959.9	151.9	34.5	28.8	8.9	55.5	30.1	4.9	4.2
31	MSPerched111405f	0.8	1020.3	150.8	78.6	28.7	8.9	59.0	29.9	11.1	4.2
32	MSPerched111405g	0.8	1104.9	164.4	137.5	39.6	9.0	63.9	32.6	19.4	5.8
33	MSPerched111405h	0.8	1158.6	176.5	188.8	92.3	9.0	67.0	35.0	26.6	13.5
34	MSPerched111405i	0.9	1219.2	191.0	232.1	161.2	9.3	70.5	37.9	32.8	23.6
35	MSPerched120105a	0.7	92.3	10.6	19.0	23.7	8.0	5.3	2.1	2.7	3.5
36	MSPerched_20051221b_TRB	4.4	326.2	50.8	116.1	81.4	47.1	18.9	10.1	16.4	11.9
37	MSPerched_20051222a_TRB	4.1	292.7	41.5	91.7	67.4	44.0	16.9	8.2	12.9	9.9
38	MSPerched_20060419b_TRB	4.4	184.6	45.8	146.5	322.4	47.1	10.7	9.1	20.7	47.3

Model Timestep = 150 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)				
Rank	Model Run	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4
1	MSPerched_20051108D_TRB	10.0	1310.7	548.4	770.2	709.5	100.0	75.5	99.7	100.0	100.0
2	MSPerched_20051108E_TRB	4.4	1736.1	259.0	443.8	326.5	44.4	100.0	47.1	57.6	46.0
3	MSPerched011306	2.8	1621.4	218.0	372.2	233.2	27.7	93.4	39.6	48.3	32.9
4	MSPerched_20051127B_TRB	6.6	1194.2	549.9	690.8	548.1	65.9	68.8	100.0	89.7	77.3
5	MSPerched_20051108B_TRB	4.1	1301.2	194.1	264.0	248.6	41.4	74.9	35.3	34.3	35.0
6	MSPerched_20051127A_TRB	2.5	1196.0	171.4	224.4	181.7	24.8	68.9	31.2	29.1	25.6
7	MSPerched_20051108C_TRB	9.3	954.0	449.8	478.1	470.8	92.8	55.0	81.8	62.1	66.3
8	MSPerched_20051122B_TRB	2.6	673.8	91.6	124.9	98.4	26.4	38.8	16.7	16.2	13.9
9	MSPerched_20051122C_TRB	6.7	864.9	464.0	389.4	288.7	66.9	49.8	84.4	50.6	40.7
10	MSPerched_20051127C_TRB	4.1	1239.1	181.6	235.5	223.0	40.6	71.4	33.0	30.6	31.4
11	MSPerched_20051127D_TRB	4.1	1239.1	181.6	235.5	223.0	40.6	71.4	33.0	30.6	31.4
12	MSPerched121205a	2.5	617.3	53.0	83.4	72.0	25.3	35.6	9.6	10.8	10.1
13	MSPerched110805b	2.5	1246.8	191.7	248.1	205.7	24.8	71.8	34.9	32.2	29.0
14	MSPerched110805c	3.2	941.9	140.1	140.5	106.0	32.4	54.3	25.5	18.2	14.9
15	MSPerched110905a	3.9	746.0	116.2	202.6	219.5	39.1	43.0	21.5	26.3	30.9
16	MSPerched110905b	3.6	1232.2	195.3	231.5	154.2	37.6	71.0	35.5	30.1	21.7
17	MSPerched110905c	4.1	700.2	134.7	237.9	243.5	41.4	40.3	24.5	30.9	34.3
18	MSPerched110905d	4.1	527.9	126.3	226.0	239.0	40.9	30.4	23.0	29.6	33.7
19	MSPerched111005a	2.0	375.6	65.3	97.8	64.9	19.9	21.6	11.9	12.7	9.1
20	MSPerched112905a	1.5	363.9	56.6	87.4	54.5	15.0	21.0	10.3	11.3	7.7
21	MSPerched112905b	1.5	374.3	54.9	89.9	60.1	15.4	21.6	10.0	11.7	8.5
22	MSPerched_20051201a_TRB	1.8	326.5	51.7	63.9	50.0	17.7	18.8	9.4	10.9	7.0
23	MSPerched_20051202a_TRB	1.4	315.3	43.5	72.8	43.0	14.1	18.2	7.9	9.4	6.1
24	MSPerched_20051202c_TRB	1.4	349.8	47.4	71.5	43.4	14.1	20.1	8.6	9.3	6.1
25	MSPerched_20051202b_TRB	1.5	325.4	41.5	74.9	49.0	14.5	18.7	7.5	9.7	6.9
26	MSPerched121205b	1.8	265.1	30.5	57.3	38.5	17.6	15.3	5.5	7.4	5.4
27	MSPerched111405b	2.0	375.6	65.3	97.8	64.9	19.9	21.6	11.9	12.7	9.1
28	MSPerched111405c	0.8	264.0	40.6	20.3	29.4	8.1	15.2	7.4	2.6	4.2
29	MSPerched111405d	0.8	395.5	51.5	21.2	29.5	8.1	22.8	9.4	2.7	4.2
30	MSPerched111405e	0.8	964.9	152.4	35.0	30.4	8.5	55.6	27.7	4.5	4.3
31	MSPerched111405f	0.9	1025.4	151.3	79.2	30.4	8.5	59.1	27.5	10.3	4.3
32	MSPerched111405g	0.9	1110.0	165.2	138.1	41.4	8.5	63.9	30.0	17.9	5.8
33	MSPerched111405h	0.9	1163.8	177.3	189.5	94.6	8.6	67.0	32.2	24.6	13.3
34	MSPerched111405i	0.9	1224.0	191.7	232.8	163.2	8.8	70.5	34.9	30.2	23.0
35	MSPerched120105a	0.8	98.0	12.9	21.4	25.8	7.6	5.6	2.3	2.8	3.6
36	MSPerched_20051221b_TRB	4.4	332.5	51.6	118.9	86.1	44.4	19.2	9.4	15.4	12.1
37	MSPerched_20051222a_TRB	4.2	297.2	41.7	92.9	71.3	41.5	17.1	7.6	12.1	10.0
38	MSPerched_20060419b_TRB	4.4	192.2	48.5	151.2	327.7	44.4	11.1	8.8	19.6	46.2

Model Timestep = 200 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)			
1	MSPerched_20051108D_TRB	10.3	1313.2	558.7	774.5	710.9	100.0	75.6	99.1	100.0	100.0
2	MSPerched_20051108E_TRB	4.4	1737.0	259.5	444.8	327.2	42.9	100.0	46.1	57.4	46.0
3	MSPerched011308	2.8	1621.8	218.3	372.6	233.4	26.8	93.4	38.7	48.1	32.8
4	MSPerched_20051127B_TRB	6.6	1200.4	563.5	695.1	548.6	63.9	69.1	100.0	89.8	77.2
5	MSPerched_20051108B_TRB	4.1	1301.9	194.3	264.7	249.3	40.0	75.0	34.5	34.2	35.1
6	MSPerched_20051127A_TRB	2.5	1196.1	171.4	224.6	181.8	24.0	68.9	30.4	29.0	25.6
7	MSPerched_20051108C_TRB	9.7	956.5	459.1	481.8	471.9	93.4	55.1	81.5	62.2	66.4
8	MSPerched_20051122B_TRB	2.6	674.6	92.2	125.8	99.0	25.6	38.8	16.4	16.2	13.9
9	MSPerched_20051122C_TRB	7.0	866.6	471.6	392.3	289.8	67.7	49.9	83.7	50.7	40.8
10	MSPerched_20051127C_TRB	4.1	1239.4	181.6	235.9	223.6	39.3	71.4	32.2	30.5	31.4
11	MSPerched_20051127D_TRB	4.1	1239.4	181.6	235.9	223.6	39.3	71.4	32.2	30.5	31.4
12	MSPerched121205a	2.5	617.6	53.7	84.2	72.4	24.4	35.6	9.5	10.9	10.2
13	MSPerched110805b	2.5	1247.7	191.9	248.8	206.4	24.2	71.8	34.0	32.1	29.0
14	MSPerched110805c	3.2	942.9	140.5	141.5	106.9	31.3	54.3	24.9	18.3	15.0
15	MSPerched110905a	3.9	746.8	118.4	203.3	220.2	37.9	43.0	21.0	26.3	31.0
16	MSPerched110905b	3.8	1232.9	195.5	232.2	154.9	36.4	71.0	34.7	30.0	21.8
17	MSPerched110905c	4.1	700.9	134.9	238.6	244.2	40.0	40.4	23.9	30.8	34.3
18	MSPerched110905d	4.1	528.7	126.5	228.7	239.8	39.6	30.4	22.5	29.5	33.7
19	MSPerched111005a	2.0	376.5	65.6	98.4	65.5	19.5	21.7	11.6	12.7	9.2
20	MSPerched112905a	1.5	365.0	56.9	88.2	55.1	14.5	21.0	10.1	11.4	7.8
21	MSPerched112905b	1.5	375.7	55.2	90.8	60.8	14.9	21.6	9.8	11.7	8.6
22	MSPerched_20051201a_TRB	1.8	327.6	52.4	84.9	50.6	17.3	18.9	9.3	11.0	7.1
23	MSPerched_20051202a_TRB	1.4	316.7	44.4	73.8	43.6	13.6	18.2	7.9	9.5	6.1
24	MSPerched_20051202c_TRB	1.4	349.9	47.6	71.7	43.5	13.7	20.1	8.4	9.3	6.1
25	MSPerched_20051202b_TRB	1.5	327.2	42.4	78.0	49.7	14.0	18.8	7.5	9.8	7.0
26	MSPerched121205b	1.8	265.5	31.2	58.2	39.0	17.1	15.3	5.5	7.5	5.5
27	MSPerched111405b	2.0	376.5	65.6	98.4	65.5	19.5	21.7	11.6	12.7	9.2
28	MSPerched111405c	0.8	264.8	40.6	20.8	29.9	7.9	15.2	7.2	2.7	4.2
29	MSPerched111405d	0.8	396.3	51.7	21.7	29.9	7.9	22.8	9.2	2.8	4.2
30	MSPerched111405e	0.9	965.9	152.7	35.6	30.9	8.2	55.6	27.1	4.6	4.4
31	MSPerched111405f	0.9	1026.4	151.6	79.7	30.9	8.2	59.1	26.9	10.3	4.4
32	MSPerched111405g	0.9	1111.0	165.4	138.6	41.9	8.3	64.0	29.4	17.9	5.9
33	MSPerched111405h	0.9	1164.9	177.6	190.1	95.1	8.3	67.1	31.5	24.5	13.4
34	MSPerched111405i	0.9	1224.9	192.0	233.3	163.7	8.6	70.5	34.1	30.1	23.0
35	MSPerched120105a	0.8	98.8	13.4	22.0	26.1	7.3	5.7	2.4	2.8	3.7
36	MSPerched_20051221b_TRB	4.4	333.4	52.1	119.9	86.9	43.0	19.2	9.2	15.5	12.2
37	MSPerched_20051222a_TRB	4.2	298.0	42.0	93.7	72.0	40.2	17.2	7.4	12.1	10.1
38	MSPerched_20060419b_TRB	4.4	193.1	49.0	152.2	328.4	43.0	11.1	8.7	19.6	46.2

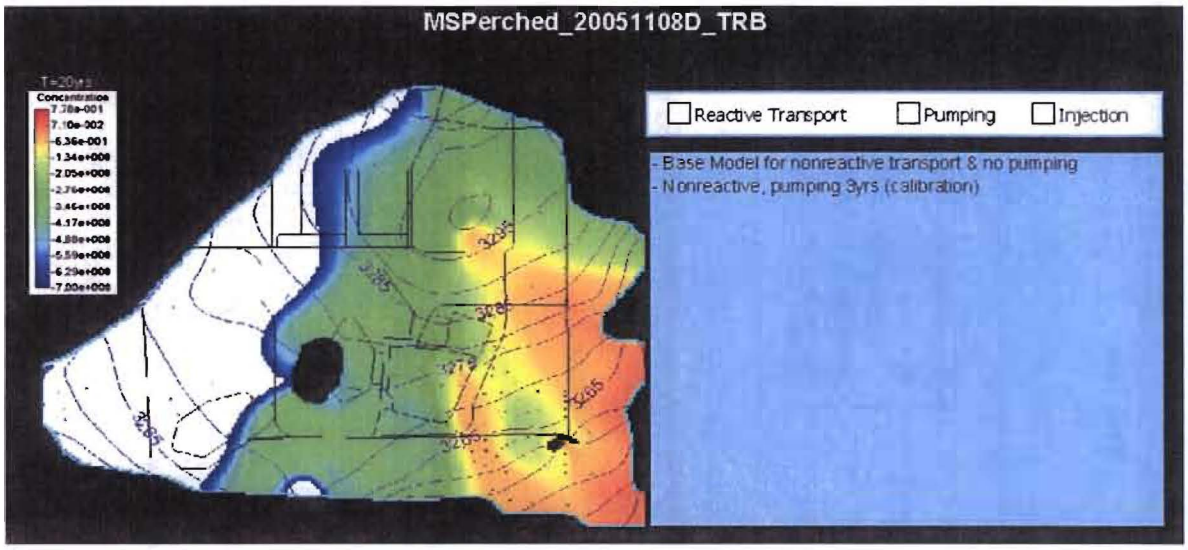
Model Timestep = 250 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)				
Run #	Model Number	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4
1	MSPerched_20051108D_TRB	10.5	1313.4	558.8	774.5	711.0	100.0	75.6	98.4	100.0	100.0
2	MSPerched_20051108E_TRB	4.4	1737.0	259.6	445.0	327.3	42.1	100.0	45.7	57.5	46.0
3	MSPerched011306	2.8	1621.9	218.4	372.7	233.4	26.3	93.4	38.5	48.1	32.8
4	MSPerched_20051127B_TRB	6.6	1202.1	567.7	695.9	548.6	63.0	69.2	100.0	89.9	77.2
5	MSPerched_20051108B_TRB	4.1	1301.9	194.4	264.9	249.4	39.3	75.0	34.2	34.2	35.1
6	MSPerched_20051127A_TRB	2.5	1196.1	171.5	224.7	181.9	23.5	68.9	30.2	29.0	25.6
7	MSPerched_20051108C_TRB	9.9	956.8	459.2	481.8	471.9	94.0	55.1	80.9	62.2	66.4
8	MSPerched_20051122B_TRB	2.6	674.7	92.3	126.0	99.1	25.1	38.8	16.3	16.3	13.9
9	MSPerched_20051122C_TRB	7.2	866.7	471.7	392.3	289.8	67.9	49.9	83.1	50.7	40.8
10	MSPerched_20051127C_TRB	4.1	1239.4	181.7	236.0	223.7	38.5	71.4	32.0	30.5	31.5
11	MSPerched_20051127D_TRB	4.1	1239.4	181.7	236.0	223.7	38.5	71.4	32.0	30.5	31.5
12	MSPerched121205a	2.5	617.6	53.7	84.3	72.5	24.0	35.6	9.5	10.9	10.2
13	MSPerched110805b	2.5	1247.7	191.9	248.9	206.5	24.0	71.8	33.8	32.1	29.1
14	MSPerched110805c	3.2	943.0	140.6	141.7	107.0	30.7	54.3	24.8	18.3	15.1
15	MSPerched110905a	3.9	746.8	118.5	203.5	220.3	37.2	43.0	20.9	26.3	31.0
16	MSPerched110905b	3.6	1233.0	195.6	232.4	155.0	35.7	71.0	34.5	30.0	21.8
17	MSPerched110905c	4.1	700.9	135.0	238.8	244.3	39.3	40.4	23.8	30.8	34.4
18	MSPerched110905d	4.1	528.7	126.8	228.9	239.9	38.9	30.4	22.3	29.5	33.7
19	MSPerched111005a	2.0	376.5	65.7	98.6	65.6	19.2	21.7	11.6	12.7	9.2
20	MSPerched112905a	1.5	365.0	57.0	88.3	55.2	14.2	21.0	10.0	11.4	7.8
21	MSPerched112905b	1.5	375.7	55.3	90.9	60.9	14.6	21.6	9.7	11.7	8.6
22	MSPerched_20051201a_TRB	1.8	327.6	52.5	85.0	50.7	17.1	18.9	9.2	11.0	7.1
23	MSPerched_20051202a_TRB	1.4	318.7	44.5	73.9	43.7	13.4	18.2	7.8	9.5	6.1
24	MSPerched_20051202c_TRB	1.4	349.9	47.6	71.8	43.5	13.4	20.1	8.4	9.3	6.1
25	MSPerched_20051202b_TRB	1.5	327.3	42.5	76.2	49.7	13.8	18.8	7.5	9.8	7.0
26	MSPerched121205b	1.8	265.5	31.3	58.3	39.0	17.0	15.3	5.5	7.5	5.5
27	MSPerched111405b	2.0	376.5	65.7	98.6	65.6	19.2	21.7	11.6	12.7	9.2
28	MSPerched111405c	0.8	264.8	40.9	21.0	30.0	7.7	15.2	7.2	2.7	4.2
29	MSPerched111405d	0.8	396.3	51.8	21.8	30.0	7.7	22.8	9.1	2.8	4.2
30	MSPerched111405e	0.9	965.9	152.7	35.7	31.0	8.1	55.6	26.9	4.6	4.4
31	MSPerched111405f	0.9	1026.4	151.8	79.9	31.0	8.1	59.1	26.7	10.3	4.4
32	MSPerched111405g	0.9	1111.0	165.5	138.8	42.0	8.1	64.0	29.2	17.9	5.9
33	MSPerched111405h	0.9	1164.9	177.6	190.2	95.3	8.2	67.1	31.3	24.6	13.4
34	MSPerched111405i	0.9	1224.9	192.0	233.4	163.8	8.4	70.5	33.8	30.1	23.0
35	MSPerched120105a	0.8	98.8	13.5	22.1	26.2	7.2	5.7	2.4	2.9	3.7
36	MSPerched_20051221b_TRB	4.4	333.4	52.2	120.0	87.0	42.2	19.2	9.2	15.5	12.2
37	MSPerched_20051222a_TRB	4.2	298.0	42.1	93.8	72.1	39.4	17.2	7.4	12.1	10.1
38	MSPerched_20060418b_TRB	4.4	193.1	49.1	152.3	328.5	42.2	11.1	8.7	19.7	46.2

Model Timestep = 300 years

		Cumulative Mass RDX Across GHB Reaches (kg)					Ranking (Percentage of Maximum)				
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	MSPerched_20051108D_TRB	10.7	1313.4	558.8	774.5	711.0	100.0	75.6	98.4	100.0	100.0
2	MSPerched_20051108E_TRB	4.4	1737.0	259.6	445.0	327.4	41.5	100.0	45.7	57.5	46.0
3	MSPerched011306	2.8	1621.9	218.4	372.7	233.4	25.9	93.4	38.4	48.1	32.8
4	MSPerched_20051127B_TRB	6.7	1202.3	568.0	695.9	548.6	62.4	69.2	100.0	89.9	77.2
5	MSPerched_20051108B_TRB	4.1	1301.9	194.4	264.9	249.4	38.8	75.0	34.2	34.2	35.1
6	MSPerched_20051127A_TRB	2.5	1196.1	171.5	224.7	181.9	23.2	68.9	30.2	29.0	25.6
7	MSPerched_20051108C_TRB	10.1	956.8	459.2	481.8	471.9	94.4	55.1	80.8	62.2	66.4
8	MSPerched_20051122B_TRB	2.6	874.7	92.3	126.0	99.2	24.8	38.8	16.3	16.3	13.9
9	MSPerched_20051122C_TRB	7.3	866.7	471.7	392.3	289.8	68.1	49.9	83.0	50.7	40.8
10	MSPerched_20051127C_TRB	4.1	1239.4	181.7	236.1	223.7	38.0	71.4	32.0	30.5	31.5
11	MSPerched_20051127D_TRB	4.1	1239.4	181.7	236.1	223.7	38.0	71.4	32.0	30.5	31.5
12	MSPerched121205a	2.5	617.6	53.7	84.3	72.5	23.7	35.6	9.5	10.9	10.2
13	MSPerched110805b	2.5	1247.7	191.9	249.0	206.5	23.7	71.8	33.8	32.1	29.1
14	MSPerched110805c	3.2	943.0	140.6	141.7	107.0	30.3	54.3	24.8	18.3	15.1
15	MSPerched110905a	3.9	746.8	116.5	203.5	220.4	36.7	43.0	20.9	26.3	31.0
16	MSPerched110905b	3.8	1233.0	195.6	232.4	155.0	35.2	71.0	34.4	30.0	21.8
17	MSPerched110905c	4.1	700.9	135.0	236.8	244.3	38.8	40.4	23.8	30.8	34.4
18	MSPerched110905d	4.1	528.7	126.6	228.9	239.9	38.3	30.4	22.3	29.6	33.7
19	MSPerched111005a	2.0	376.5	65.7	98.6	65.6	19.0	21.7	11.6	12.7	9.2
20	MSPerched112905a	1.5	365.0	57.0	88.3	55.2	14.0	21.0	10.0	11.4	7.8
21	MSPerched112905b	1.5	375.7	55.3	91.0	60.9	14.4	21.6	9.7	11.7	8.6
22	MSPerched_20051201a_TRB	1.8	327.8	52.5	85.0	50.7	16.9	18.9	9.2	11.0	7.1
23	MSPerched_20051202a_TRB	1.4	316.7	44.5	74.0	43.7	13.2	18.2	7.8	9.6	6.1
24	MSPerched_20051202c_TRB	1.4	349.9	47.6	71.8	43.5	13.2	20.1	8.4	9.3	6.1
25	MSPerched_20051202b_TRB	1.5	327.3	42.6	76.3	49.7	13.6	18.8	7.5	9.8	7.0
26	MSPerched121205b	1.8	265.5	31.3	58.3	39.0	16.6	15.3	5.5	7.5	5.5
27	MSPerched111405b	2.0	376.5	65.7	98.6	65.6	19.0	21.7	11.6	12.7	9.2
28	MSPerched111405c	0.8	264.8	40.9	21.0	30.0	7.6	15.2	7.2	2.7	4.2
29	MSPerched111405d	0.8	396.3	51.8	21.9	30.0	7.6	22.8	9.1	2.8	4.2
30	MSPerched111405e	0.9	965.9	152.7	35.8	31.1	8.0	55.6	26.9	4.6	4.4
31	MSPerched111405f	0.9	1026.4	151.7	79.9	31.1	8.0	59.1	26.7	10.3	4.4
32	MSPerched111405g	0.9	1111.0	165.5	138.8	42.1	8.0	64.0	29.1	17.9	5.9
33	MSPerched111405h	0.9	1164.9	177.7	190.3	95.3	8.1	67.1	31.3	24.6	13.4
34	MSPerched111405i	0.9	1224.9	192.0	233.4	163.8	8.3	70.5	33.8	30.1	23.0
35	MSPerched120105a	0.8	98.8	13.5	22.1	26.2	7.1	5.7	2.4	2.9	3.7
36	MSPerched_20051221b_TRB	4.4	333.4	52.2	120.1	87.0	41.8	19.2	9.2	15.5	12.2
37	MSPerched_20051222a_TRB	4.2	298.0	42.1	93.8	72.1	38.9	17.2	7.4	12.1	10.1
38	MSPerched_20060419b_TRB	4.4	193.1	49.2	152.4	328.5	41.8	11.1	8.7	19.7	46.2

RUN1_MSPerched_20051108D_TRB



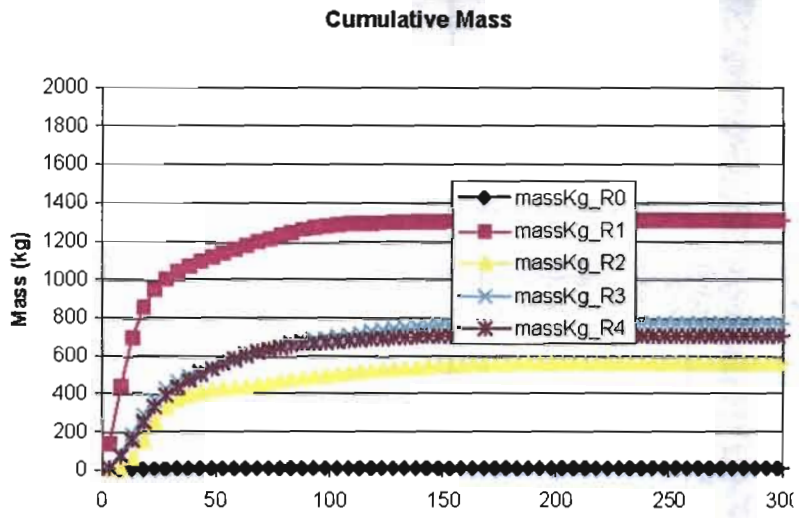
Cumulative Water Across GHB Reaches (millions of gallons)

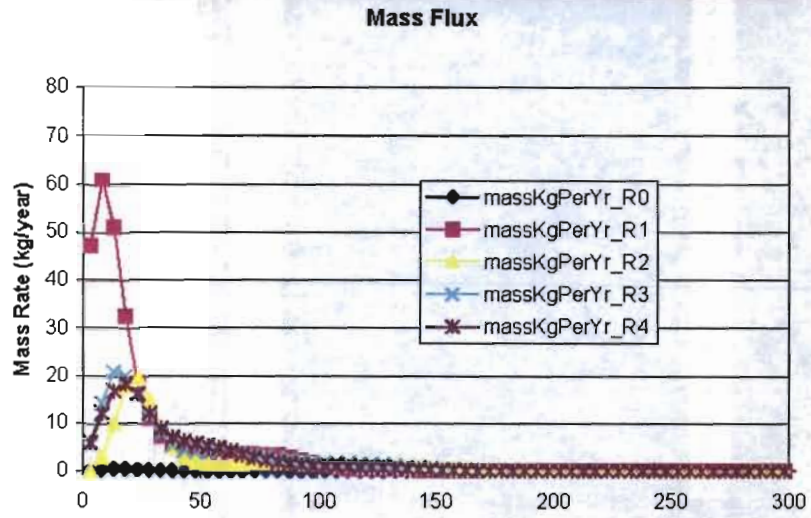
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2005.2	618.2	178.4	195.1	209.0	3205.9
50	3207.3	1020.7	300.8	317.3	311.8	5158.0
100	6172.4	1998.2	596.9	606.2	541.4	9915.1
150	9100.4	2961.0	888.1	888.0	761.3	14598.8
200	12019.1	3920.9	1178.5	1168.5	979.8	19266.7
250	14935.9	4880.2	1468.6	1448.8	1198.0	23931.6
300	17852.3	5839.5	1758.8	1729.1	1416.1	28595.7

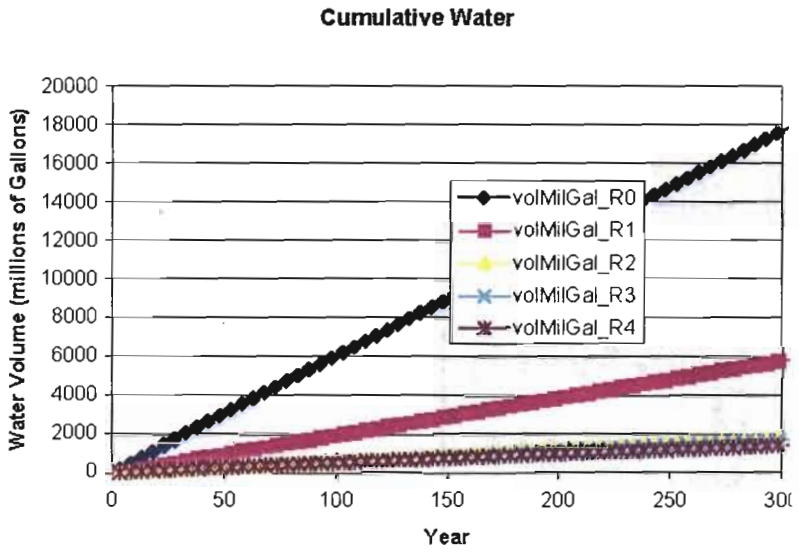
Cumulative Mass Across GHB Reaches (kg)

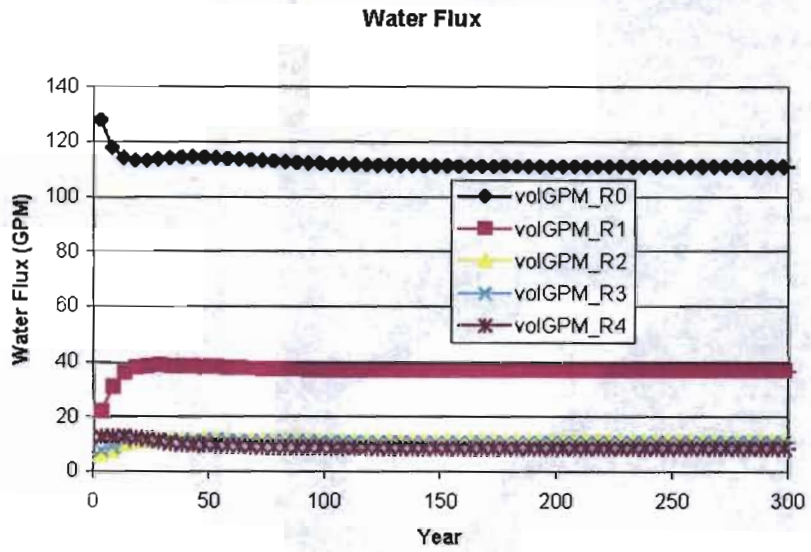
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	7.8	1050.4	369.4	472.3	442.9	2342.8
50	8.7	1148.1	425.7	562.4	564.7	2709.5
100	9.4	1295.5	504.0	708.5	681.9	3199.3
150	10.0	1310.7	548.4	770.2	709.5	3348.8
200	10.3	1313.2	558.7	774.5	710.9	3367.6
250	10.5	1313.4	558.8	774.5	711.0	3368.1
300	10.7	1313.4	558.8	774.5	711.0	3368.3

MSPerched_20051108D_TRB

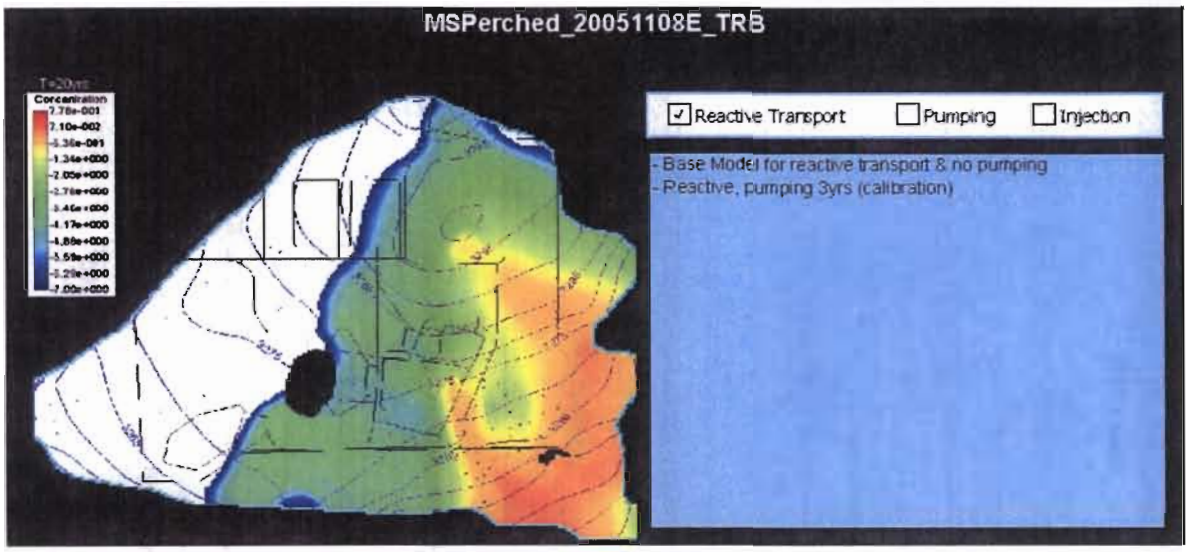








RUN2_MSPerched_20051108E_TRB



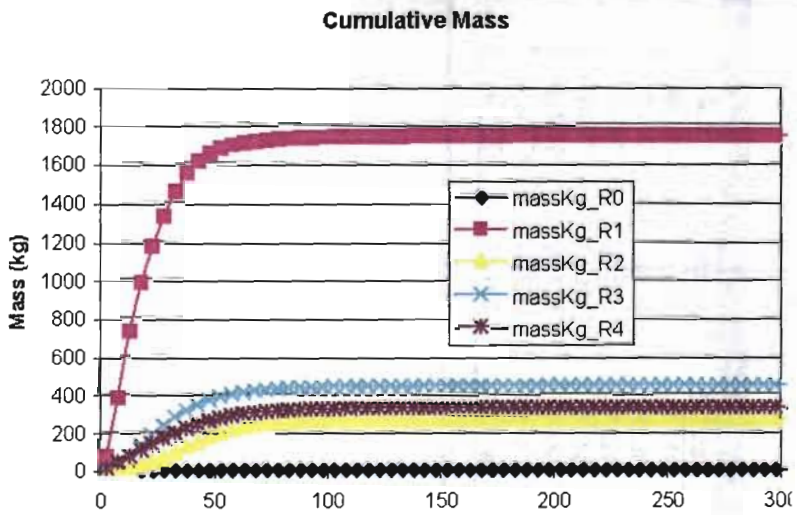
Cumulative Water Across GHB Reaches (millions of gallons)

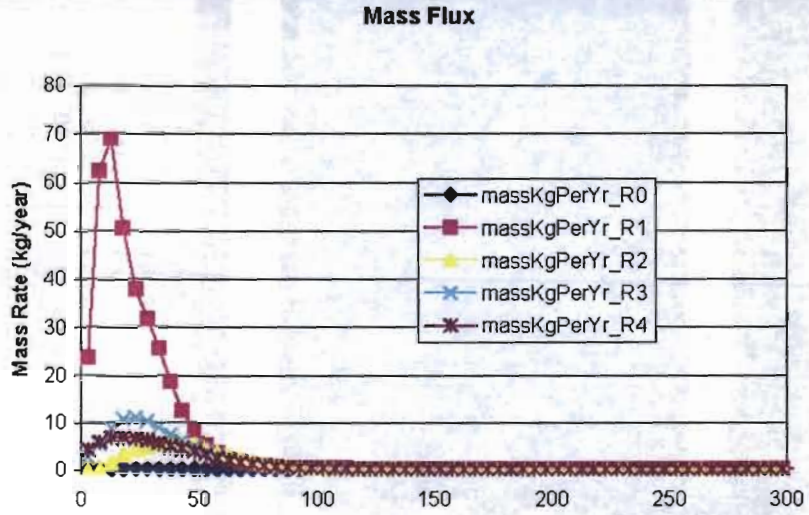
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2005.23	618.18	178.43	195.10	209.01	3205.95
50	3207.29	1020.73	300.85	317.26	311.85	5157.98
100	6172.42	1998.22	596.90	606.18	541.40	9915.13
150	9100.40	2960.97	888.13	887.97	761.32	14598.79
200	12019.14	3920.86	1178.47	1168.50	979.77	19266.73
250	14935.93	4880.25	1468.65	1448.80	1197.96	23931.59
300	17852.26	5839.52	1758.79	1729.06	1416.09	28595.72

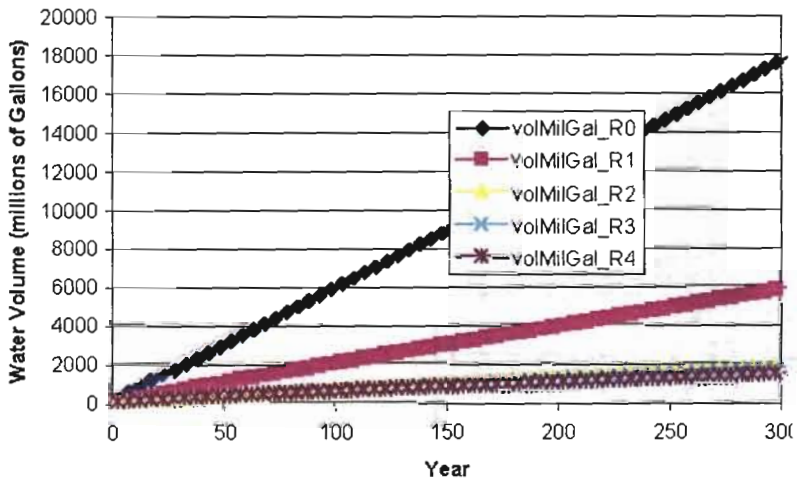
Cumulative Mass Across GHB Reaches (kg)

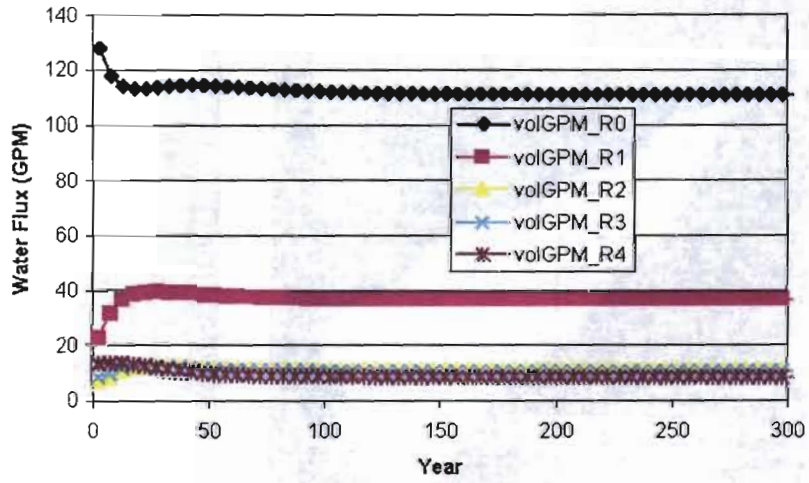
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	3.10	1449.45	87.38	277.39	194.15	2011.46
50	4.06	1668.45	187.28	383.82	271.83	2515.44
100	4.42	1728.49	256.23	439.16	321.16	2749.45
150	4.44	1736.12	258.98	443.81	326.46	2769.81
200	4.44	1736.98	259.52	444.79	327.24	2772.98
250	4.44	1737.01	259.63	444.96	327.35	2773.38
300	4.44	1737.01	259.64	444.99	327.36	2773.45

MSPerched_20051108E_TRB

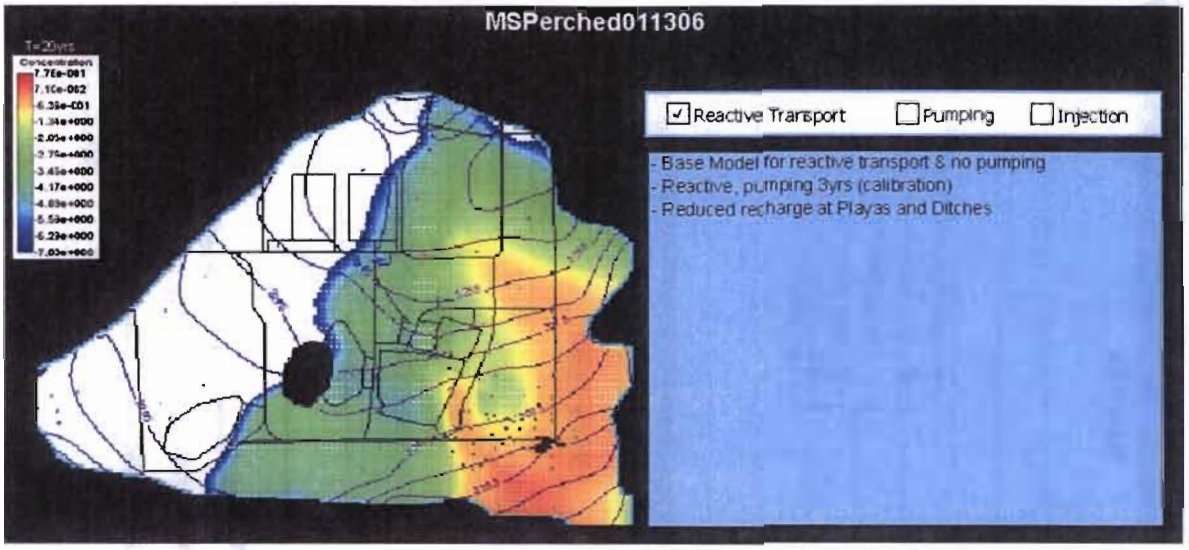








RUN3_MSPerched011306



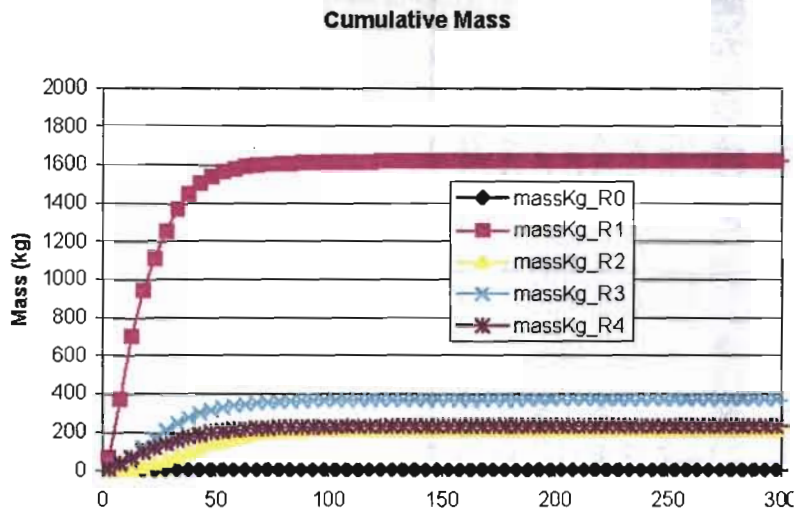
Cumulative Water Across GHB Reaches (millions of gallons)

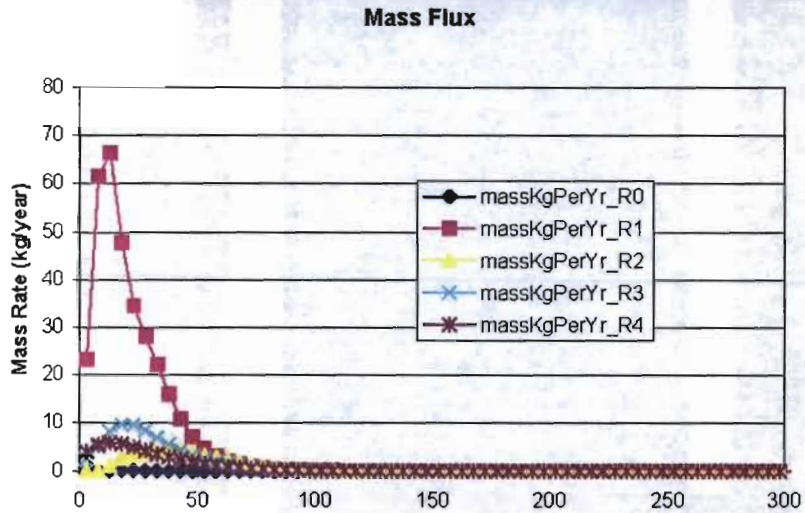
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1500.12	561.48	169.49	178.31	181.15	2590.55
50	2104.36	867.41	271.52	266.92	238.39	3748.61
100	3263.68	1483.42	484.00	425.49	318.88	5975.47
150	4198.46	1994.01	666.47	542.94	371.59	7773.48
200	5045.85	2463.11	837.32	645.57	416.87	9408.72
250	5856.99	2915.74	1003.64	742.72	459.70	10978.79
300	6652.97	3361.76	1168.20	837.79	501.64	12522.35

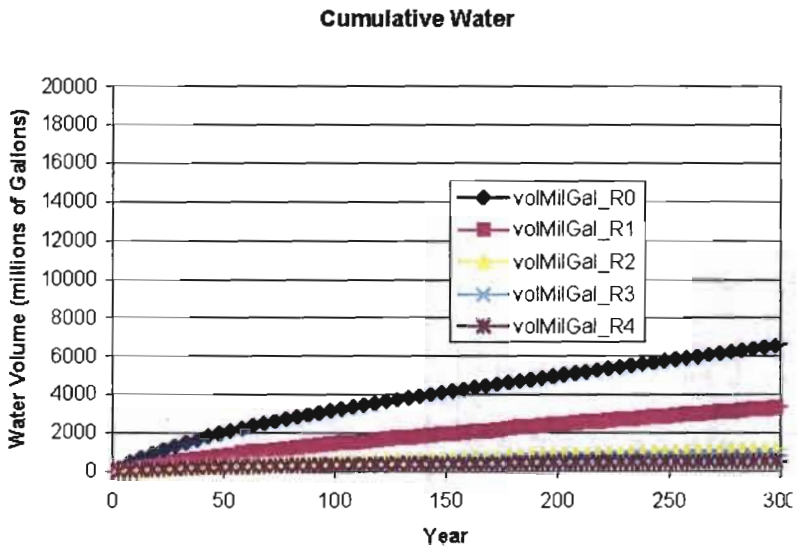
Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.40	1372.85	77.19	250.10	162.95	1865.49
50	2.73	1567.45	156.40	329.55	207.27	2263.40
100	2.77	1618.39	214.96	369.09	231.40	2436.60
150	2.77	1621.44	217.96	372.22	233.16	2447.55
200	2.77	1621.82	218.28	372.64	233.38	2448.90
250	2.77	1621.87	218.35	372.72	233.41	2449.13
300	2.77	1621.88	218.37	372.74	233.41	2449.17

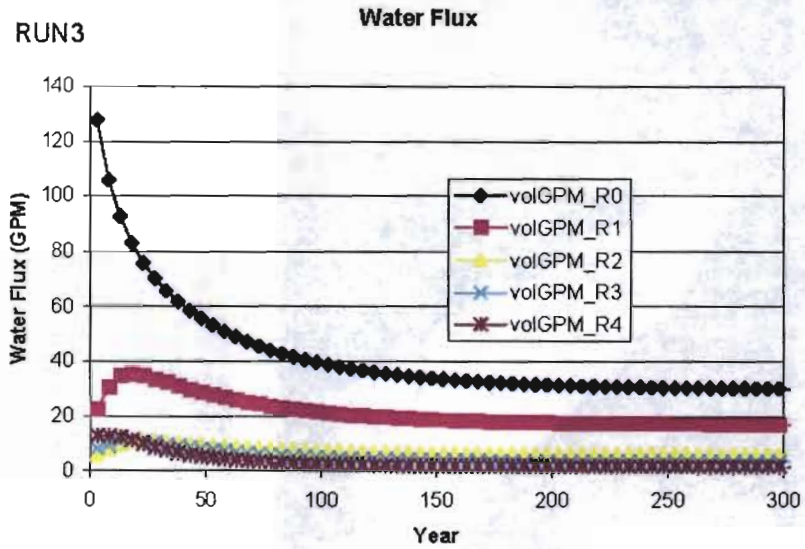
MSPerched011306

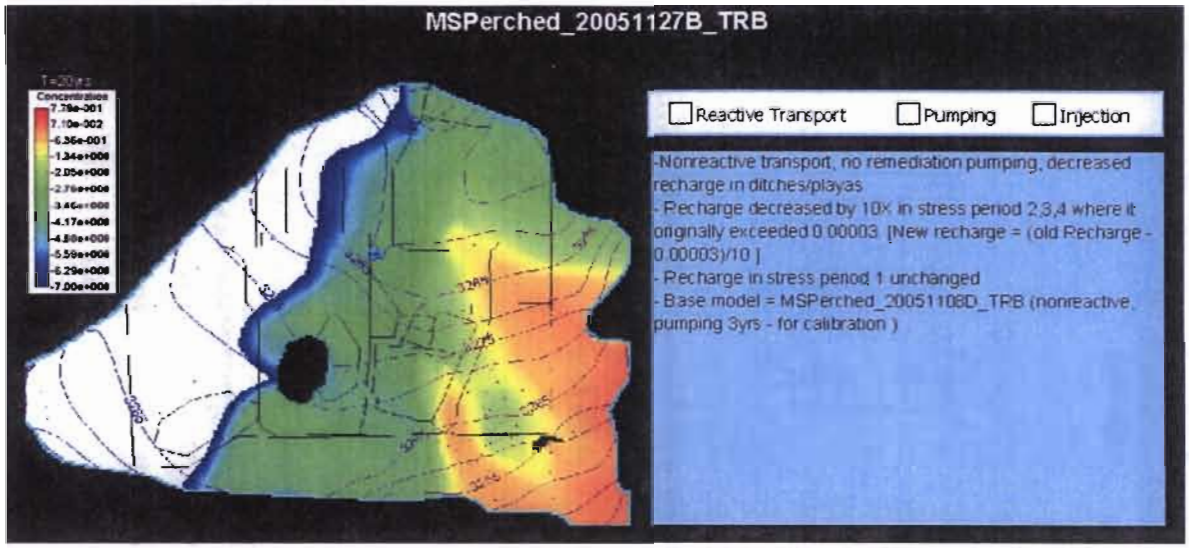






RUN3





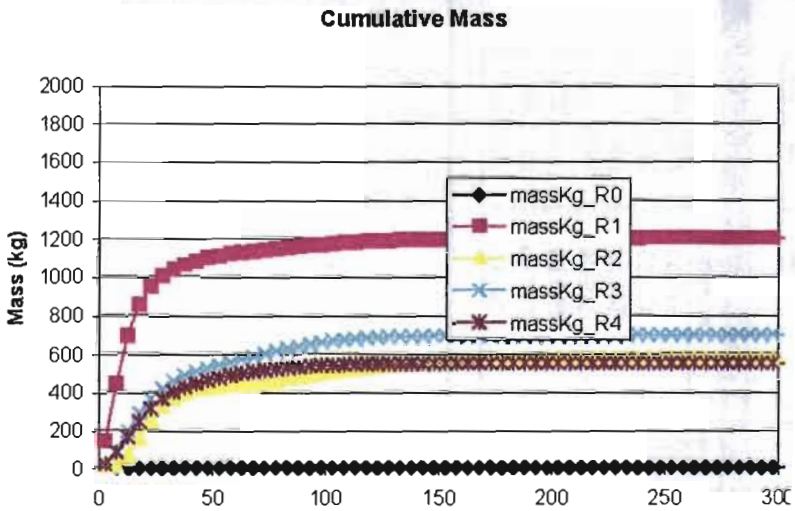
Cumulative Water Across GHB Reaches (millions of gallons)

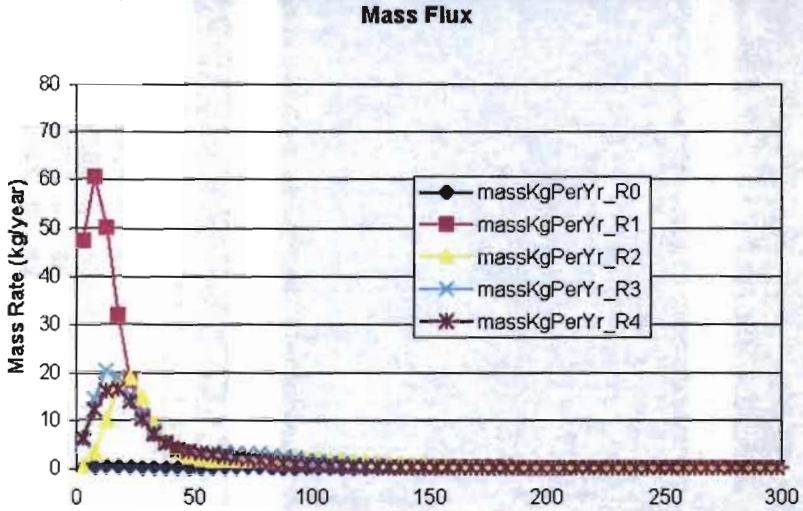
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1500.12	561.48	169.49	178.31	181.15	2590.55
50	2104.36	867.41	271.52	266.92	238.39	3748.61
100	3263.68	1483.42	484.00	425.49	318.88	5975.47
150	4198.46	1994.01	666.47	542.94	371.59	7773.48
200	5045.85	2463.11	837.32	645.57	416.87	9408.72
250	5856.99	2915.74	1003.64	742.72	459.70	10978.79
300	6652.97	3361.76	1168.20	837.79	501.64	12522.35

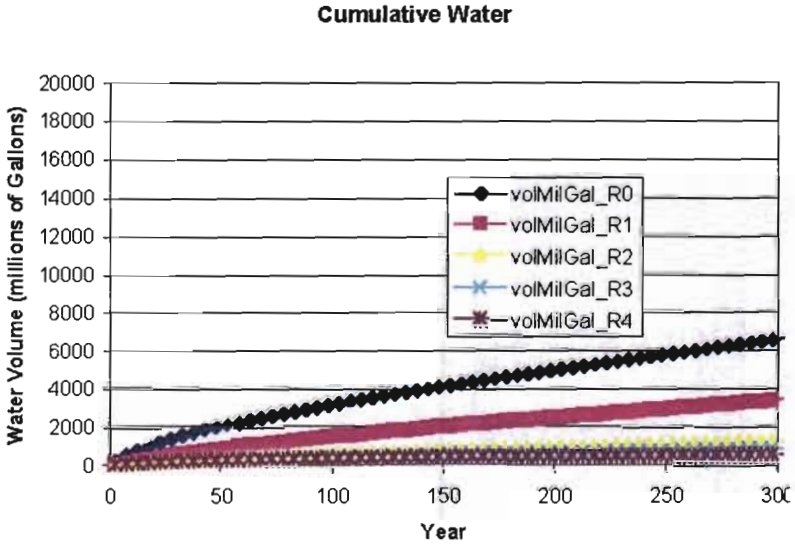
Cumulative Mass Across GHB Reaches (kg)

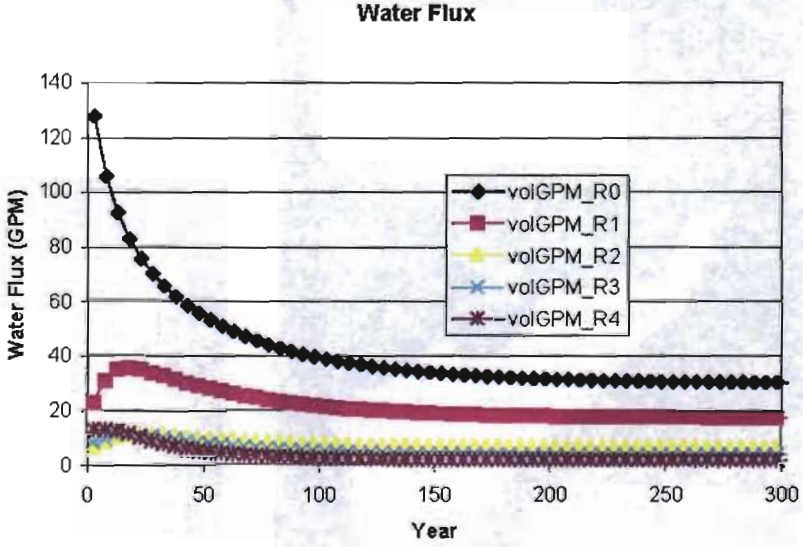
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	6.24	1035.57	360.11	455.54	395.59	2253.05
50	6.47	1107.54	420.44	535.95	471.06	2541.47
100	6.56	1172.10	498.24	663.87	540.32	2881.10
150	6.59	1194.22	549.92	690.83	548.06	2989.63
200	6.61	1200.35	563.54	695.11	548.60	3014.22
250	6.64	1202.06	567.69	695.88	548.65	3020.92
300	6.68	1202.32	568.02	695.92	548.65	3021.57

MSPerched_20051127B_TRB

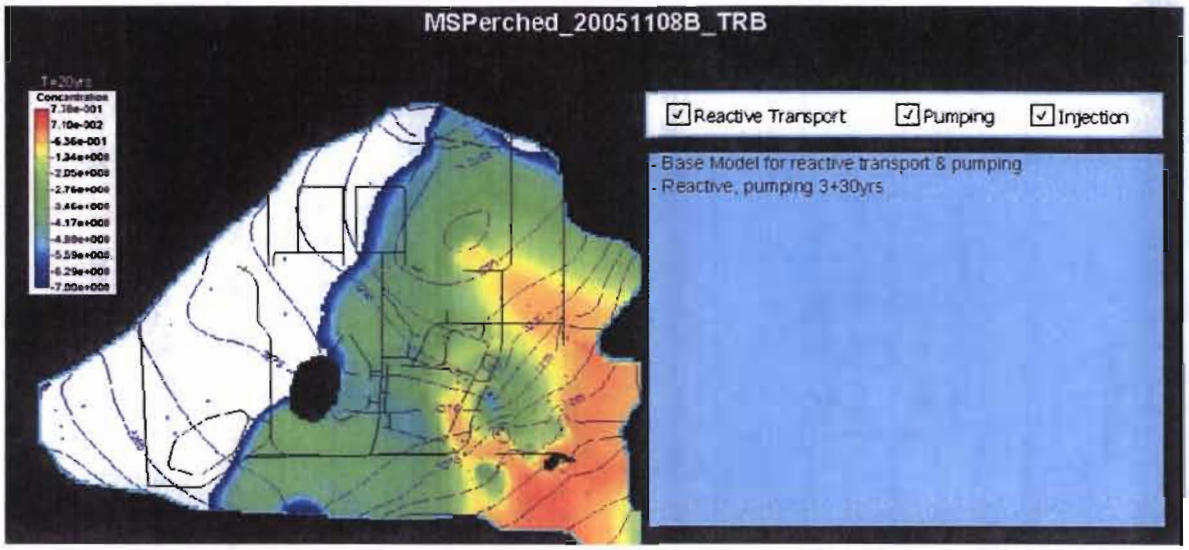








RUN5_MSPerched_20051108B_TRB



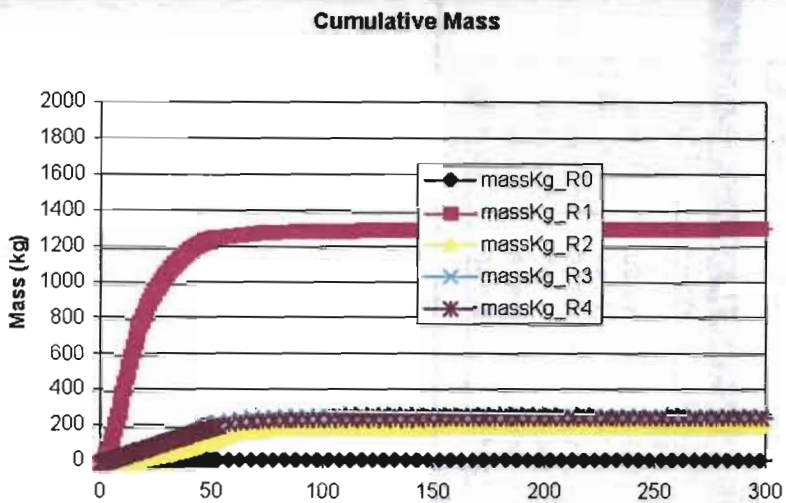
Cumulative Water Across GHB Reaches (millions of gallons)

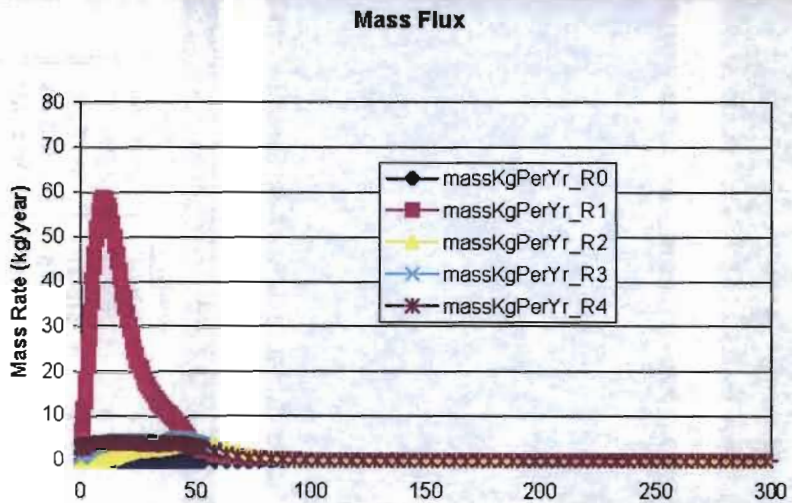
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2042.17	508.74	136.75	121.24	168.04	2976.94
50	3278.21	898.02	243.45	227.38	273.12	4920.17
100	6299.42	1894.85	545.15	524.72	513.21	9777.35
150	9239.26	2861.00	837.43	807.96	734.75	14480.40
200	12160.20	3821.50	1127.95	1088.75	953.48	19151.87
250	15077.44	4780.99	1418.16	1369.10	1171.73	23817.42
300	17993.89	5740.29	1708.32	1649.37	1389.87	28481.74

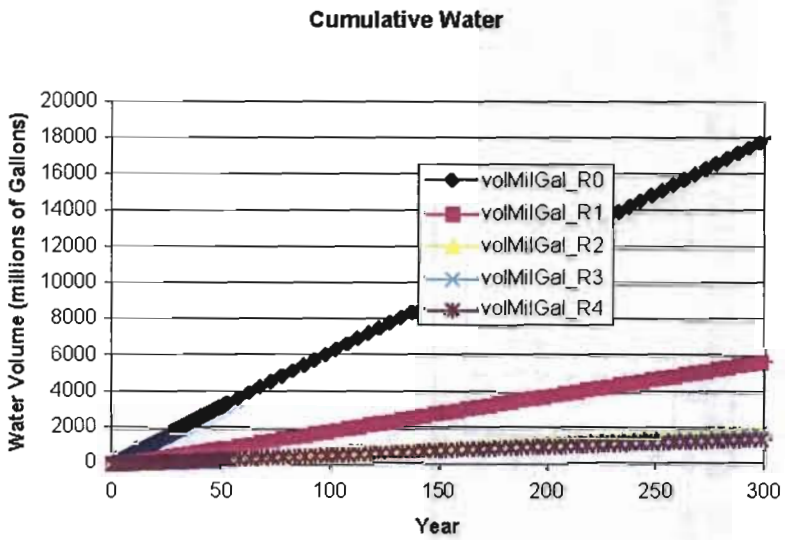
Cumulative Mass Across GHB Reaches (kg)

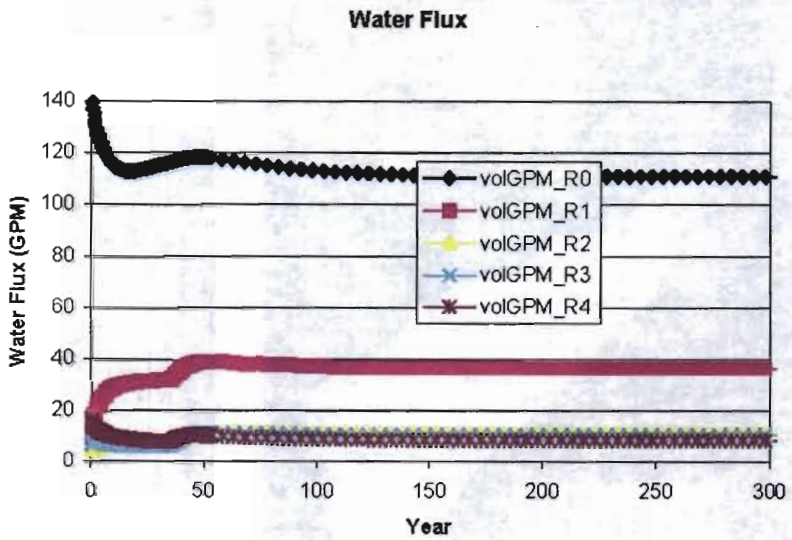
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.62	1106.74	45.22	134.84	131.22	1420.63
50	3.69	1260.40	125.35	226.21	206.20	1821.86
100	4.12	1296.50	193.51	262.41	244.44	2000.98
150	4.14	1301.19	194.08	264.01	248.56	2011.98
200	4.14	1301.91	194.32	264.74	249.27	2014.38
250	4.14	1301.93	194.39	264.89	249.38	2014.73
300	4.14	1301.93	194.41	264.92	249.40	2014.80

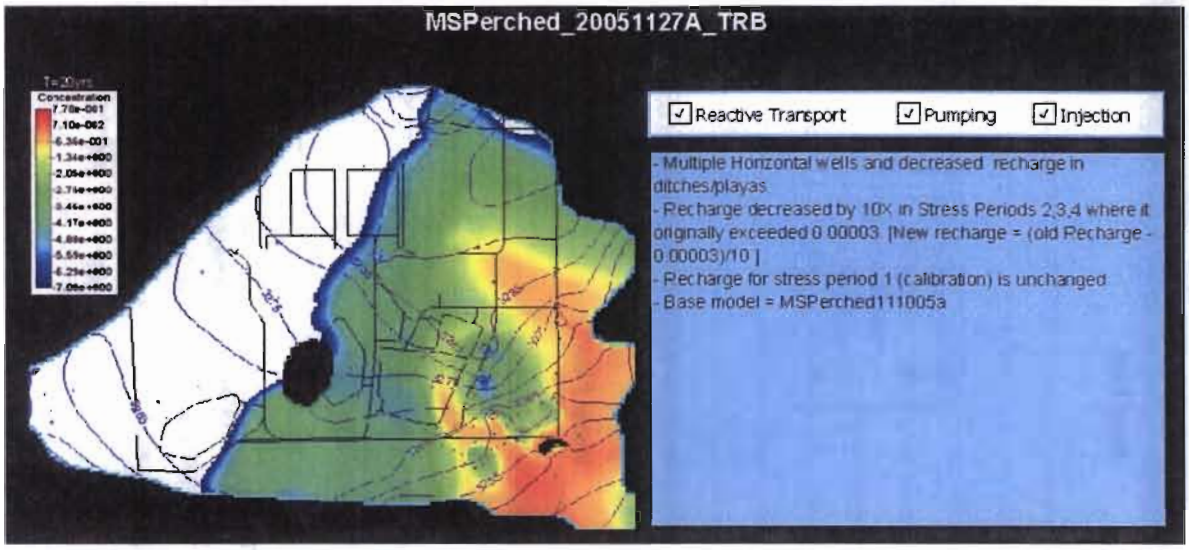
MSPerched_20051108B_TRB











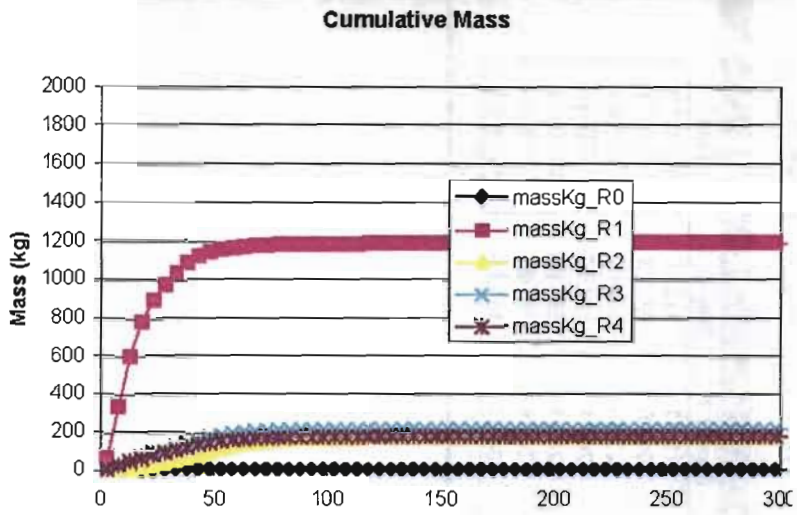
Cumulative Water Across GHB Reaches (millions of gallons)

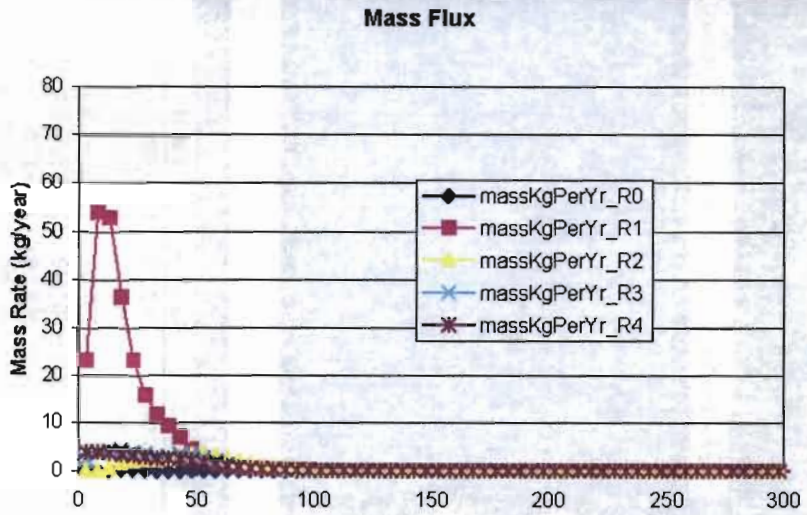
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1502.64	477.94	133.99	109.46	142.33	2366.36
50	2133.12	789.81	226.97	192.91	206.78	3549.59
100	3341.71	1439.01	448.70	364.66	297.87	5891.95
150	4294.95	1959.40	633.99	485.72	352.48	7726.54
200	5149.59	2431.94	805.79	589.52	398.29	9375.13
250	5963.72	2885.88	972.47	687.09	441.30	10950.45
300	6760.92	3332.42	1137.16	782.32	483.31	12496.13

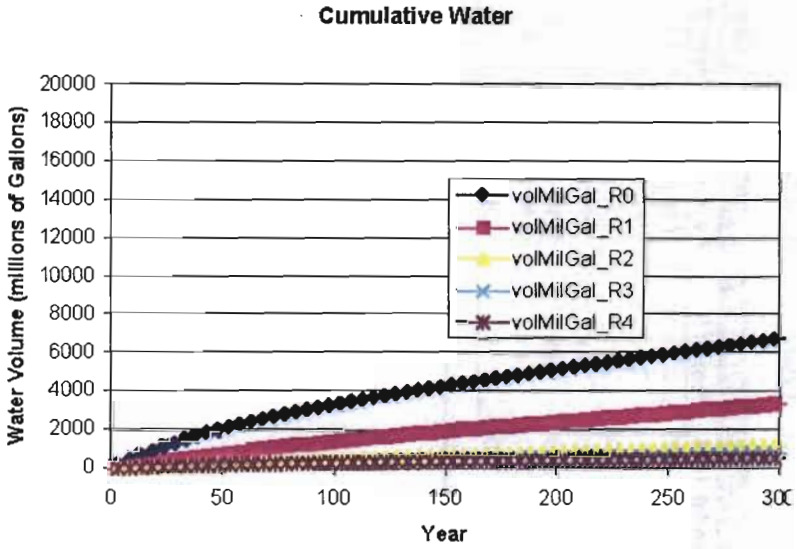
Cumulative Mass Across GHB Reaches (kg)

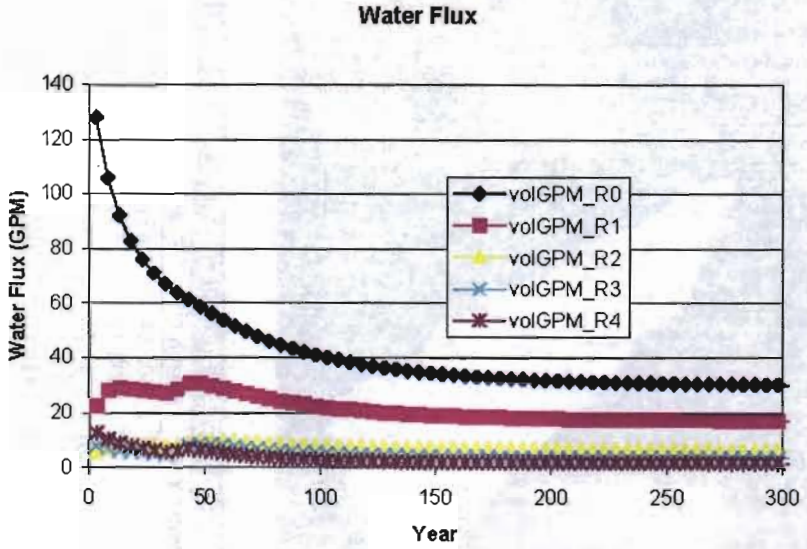
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.12	1046.94	46.01	125.61	112.50	1333.18
50	2.43	1167.04	111.16	191.85	158.27	1630.75
100	2.48	1194.81	170.39	223.49	180.52	1771.69
150	2.48	1195.96	171.41	224.41	181.66	1775.92
200	2.48	1196.10	171.44	224.61	181.83	1776.45
250	2.48	1196.13	171.46	224.68	181.85	1776.60
300	2.48	1196.13	171.47	224.69	181.86	1776.63

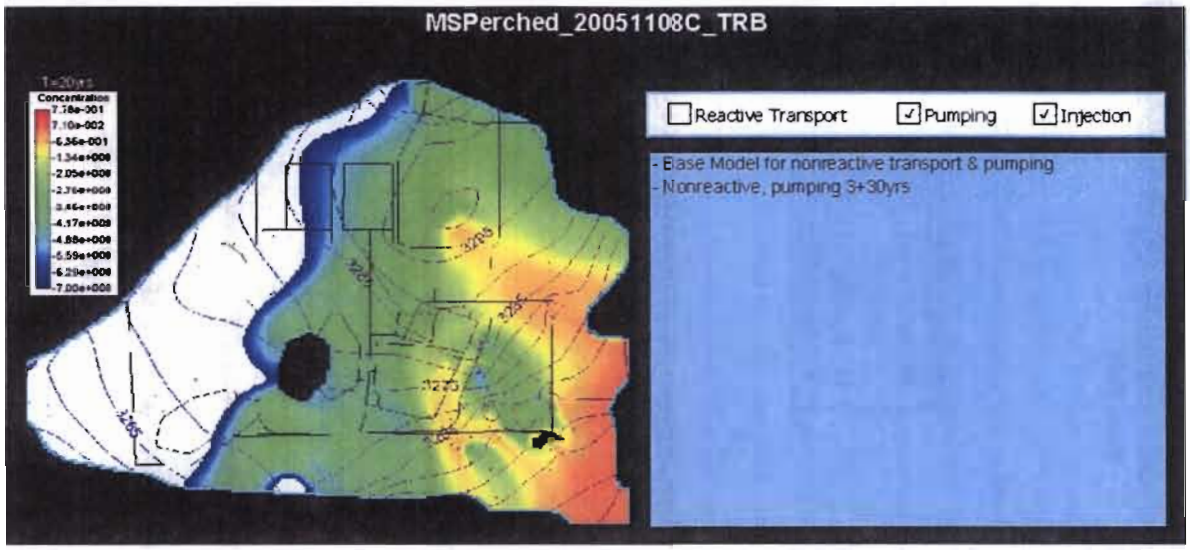
MSPerched_20051127A_TRB











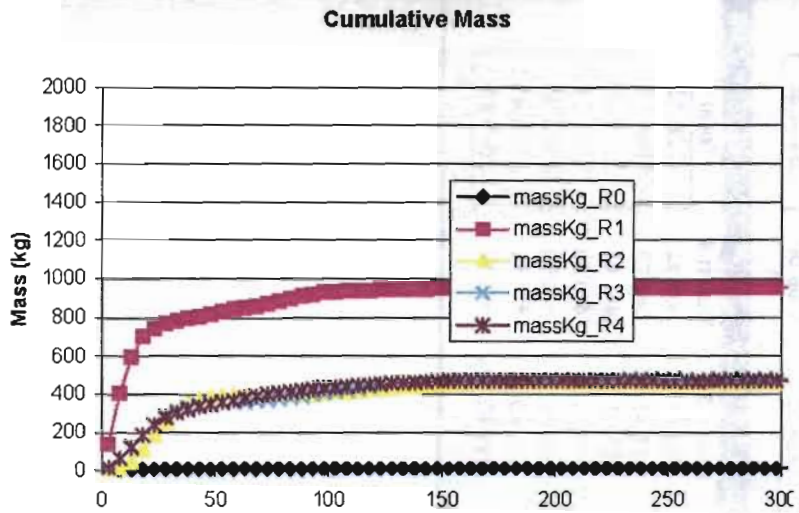
Cumulative Water Across GHB Reaches (millions of gallons)

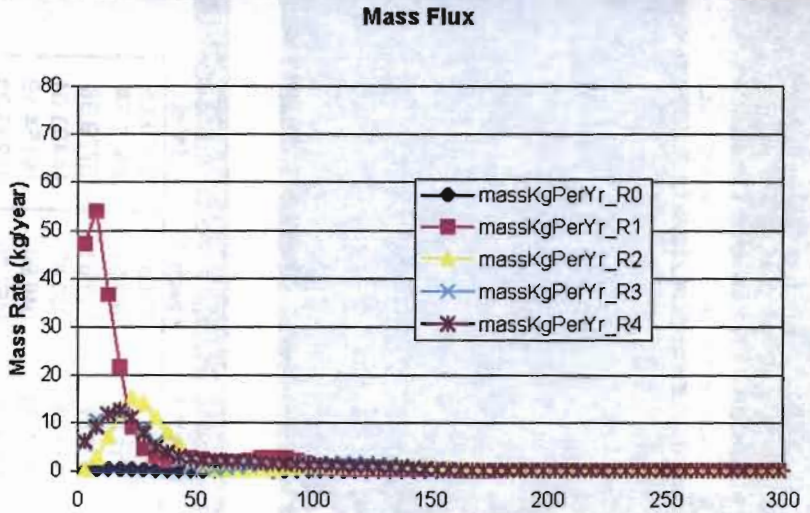
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2010.13	523.84	140.06	119.71	161.31	2955.05
50	3248.54	921.93	250.56	232.53	269.24	4922.78
100	6269.75	1918.75	552.26	529.87	509.33	9779.96
150	9209.58	2884.91	844.54	813.11	730.87	14483.01
200	12130.53	3845.40	1135.06	1093.90	949.60	19154.49
250	15047.77	4804.90	1425.27	1374.25	1167.85	23820.03
300	17964.21	5764.20	1715.43	1654.52	1386.00	28484.35

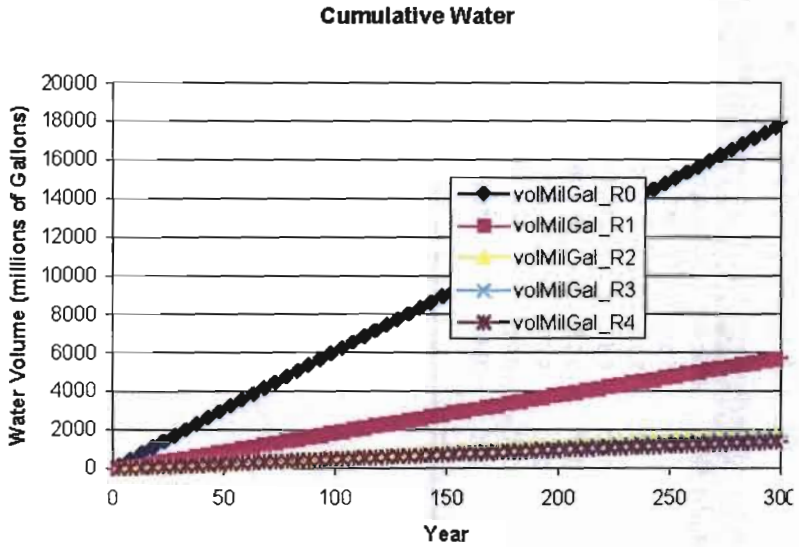
Cumulative Mass Across GHB Reaches (kg)

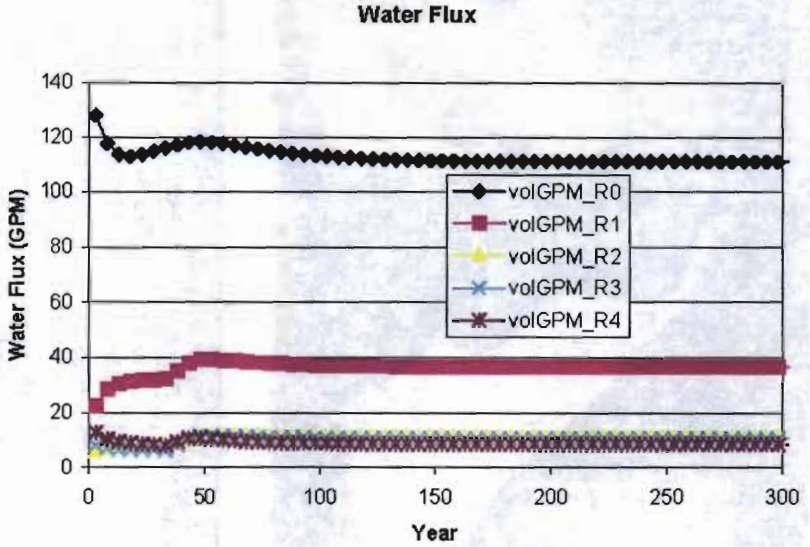
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	6.68	787.23	308.80	319.31	306.42	1728.43
50	7.73	835.79	390.44	357.45	362.73	1954.14
100	8.65	938.47	409.13	415.45	441.05	2212.76
150	9.28	954.00	449.57	478.14	470.60	2361.58
200	9.66	956.51	459.14	481.79	471.90	2379.00
250	9.91	956.77	459.21	481.80	471.91	2379.60
300	10.09	956.85	459.21	481.80	471.91	2379.85

MSPerched_20051108C_TRB

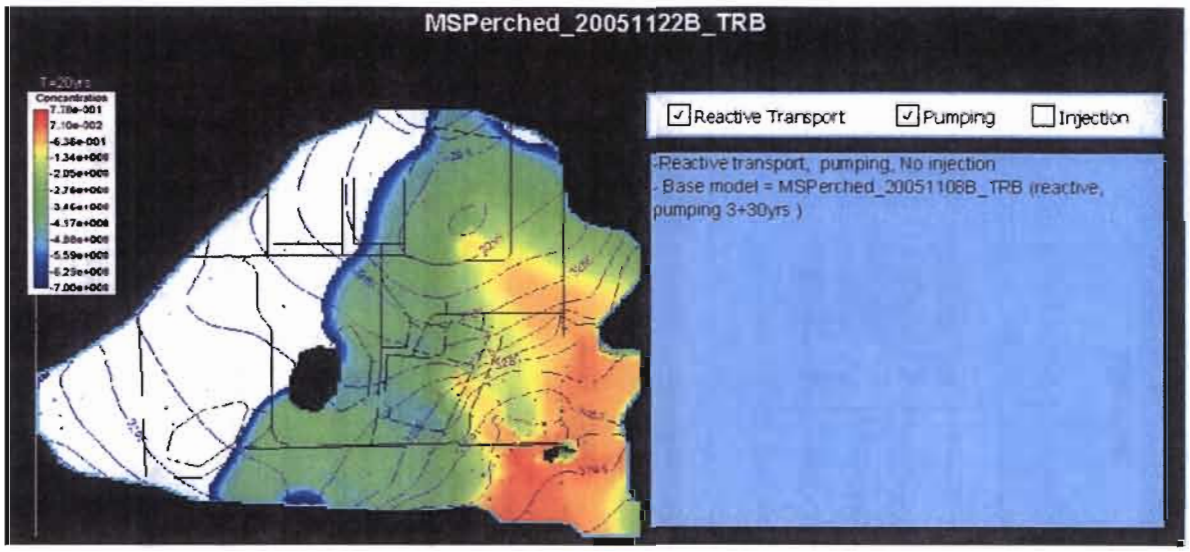








RUN8_MSPerched_20051122b_trb



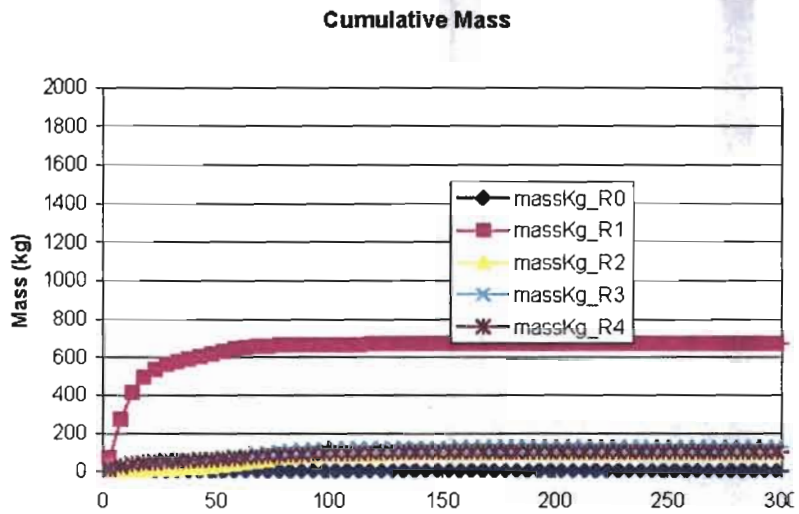
Cumulative Water Across GHB Reaches (millions of gallons)

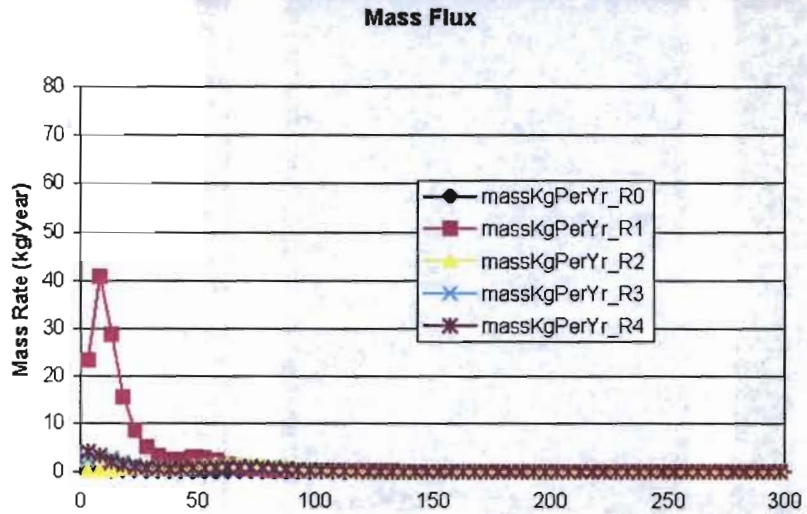
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1914.72	238.47	97.26	61.58	88.04	2400.07
50	3014.45	409.24	140.66	84.65	117.11	3766.10
100	5848.48	1283.59	396.96	324.56	304.39	8157.97
150	8745.27	2235.94	684.87	601.83	519.46	12787.37
200	11657.78	3194.13	974.68	881.63	737.10	17445.32
250	14573.23	4153.17	1264.75	1161.79	955.11	22108.06
300	17489.22	5112.36	1554.87	1442.02	1173.20	26771.66

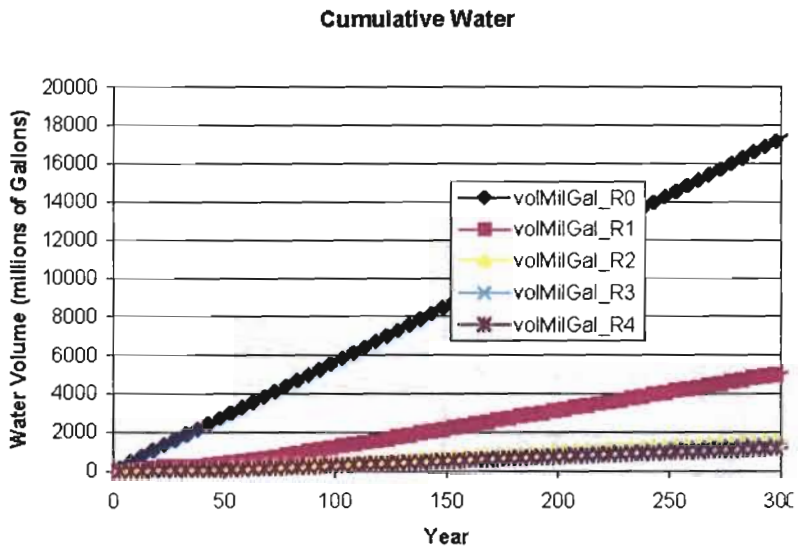
Cumulative Mass Across GHB Reaches (kg)

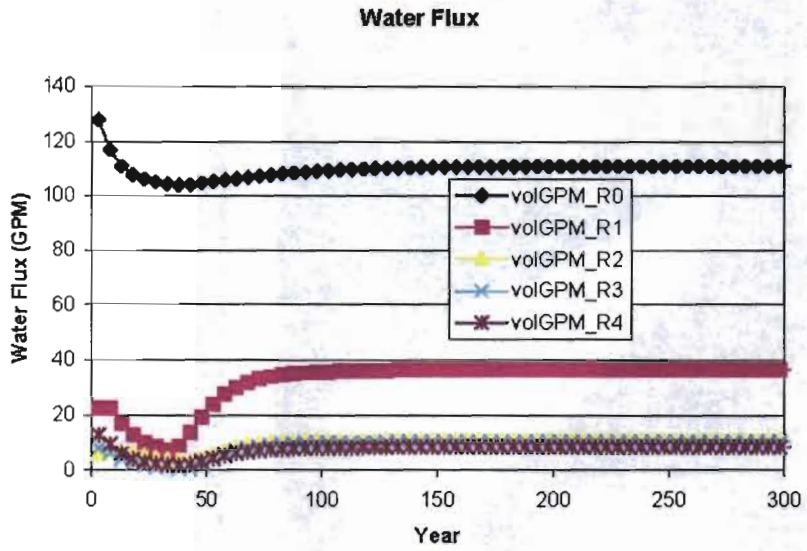
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.14	580.01	16.21	61.94	53.82	714.11
50	2.50	633.11	30.85	72.97	64.18	803.61
100	2.63	668.04	86.99	119.34	93.83	970.82
150	2.64	673.82	91.63	124.92	98.44	991.46
200	2.65	674.63	92.23	125.80	99.04	994.35
250	2.65	674.65	92.32	125.95	99.14	994.71
300	2.65	674.66	92.34	125.98	99.15	994.77

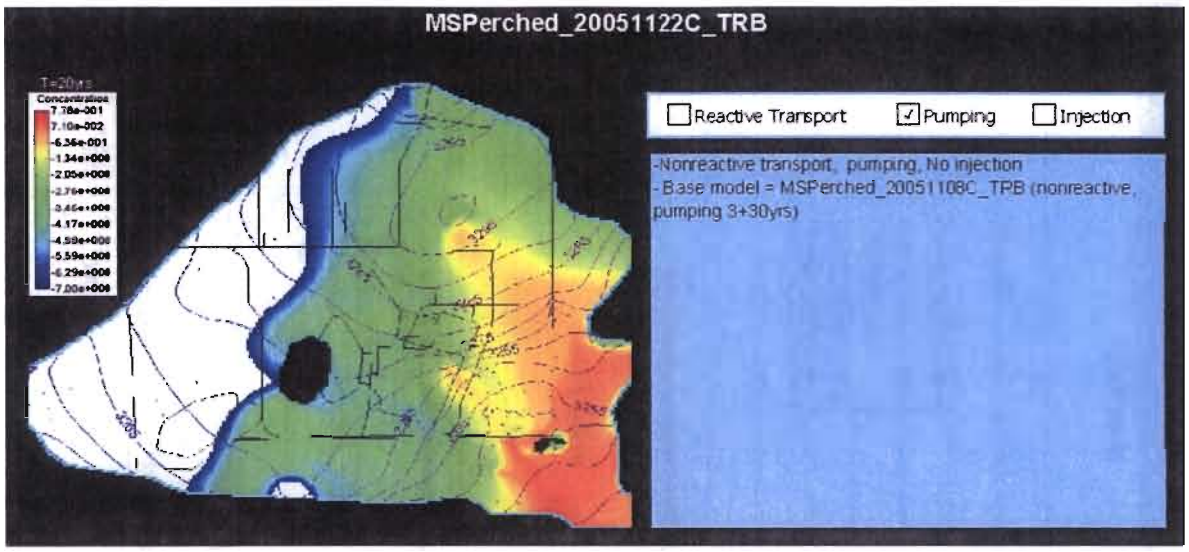
MSPerched_20051122B_TRB











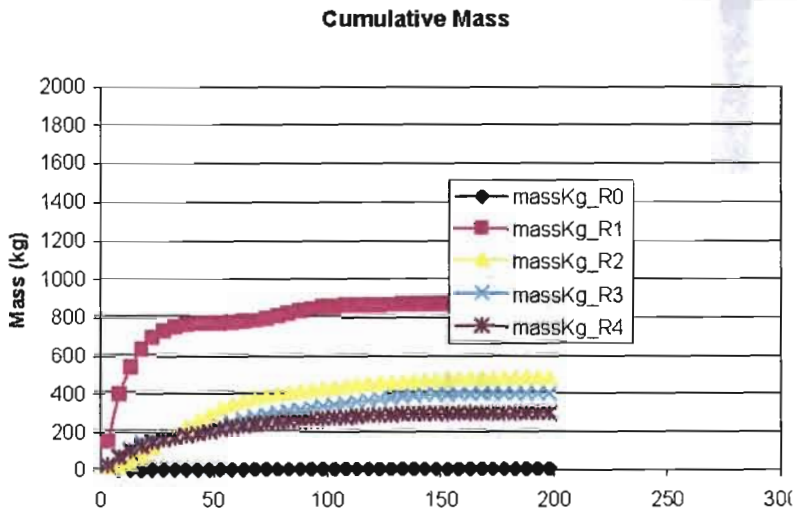
Cumulative Water Across GHB Reaches (millions of gallons)

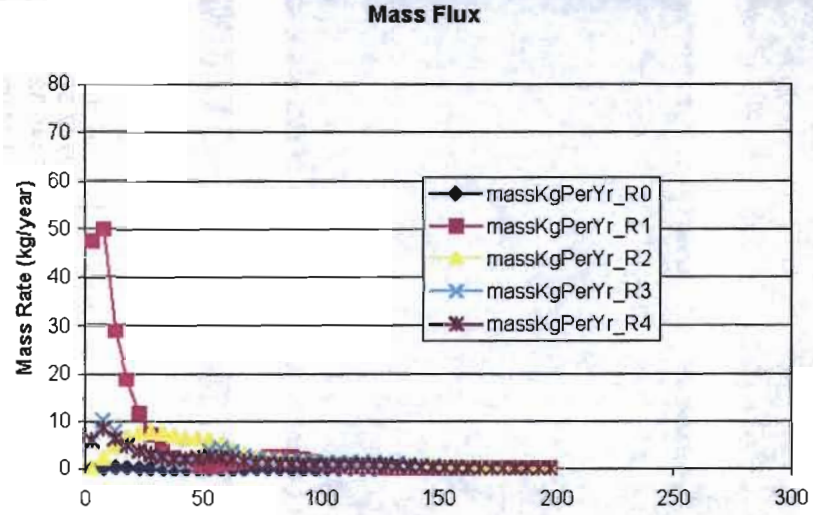
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1914.72	238.47	97.26	61.58	88.04	2400.07
50	3014.45	409.24	140.66	84.65	117.11	3766.10
100	5848.48	1283.59	396.96	324.56	304.39	8157.97
150	8745.27	2235.94	684.87	601.83	519.46	12787.37
200	11657.78	3194.13	974.68	881.63	737.10	17445.32
250	14573.23	4153.17	1264.75	1161.79	955.11	22108.06
300	17489.22	5112.36	1554.87	1442.02	1173.20	26771.66

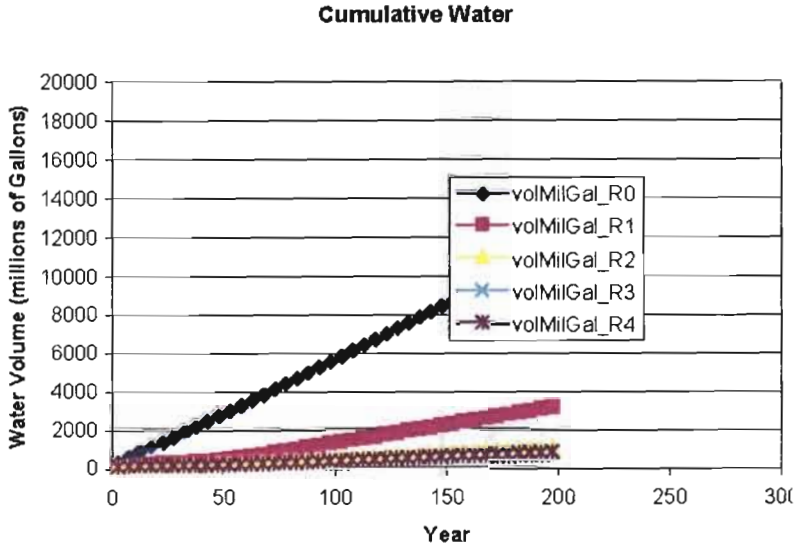
Cumulative Mass Across GHB Reaches (kg)

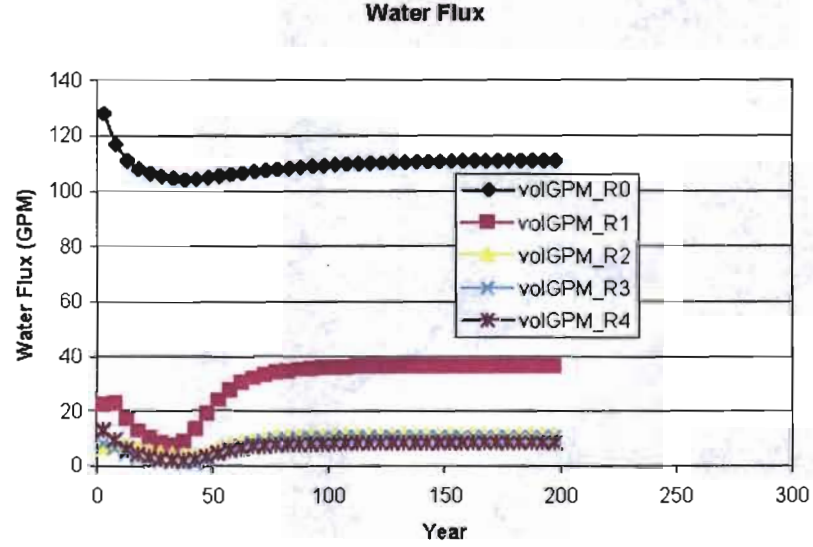
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	5.33	741.62	180.12	172.35	161.94	1261.37
50	5.57	764.47	306.13	215.74	204.88	1496.78
100	6.09	851.89	423.12	332.91	264.97	1878.98
150	6.69	864.89	463.97	389.40	288.71	2013.65
200	7.01	866.57	471.62	392.34	289.79	2027.33
250	7.17	866.69	471.67	392.35	289.80	2027.67
300	7.28	866.72	471.67	392.35	289.80	2027.81

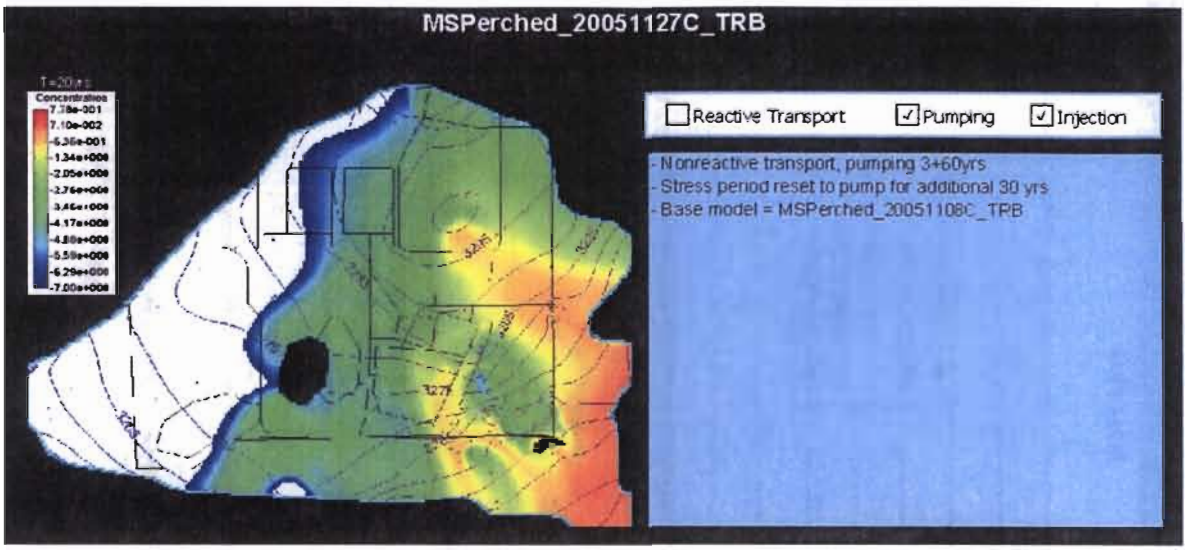
MSPerched_20051122C_TRB











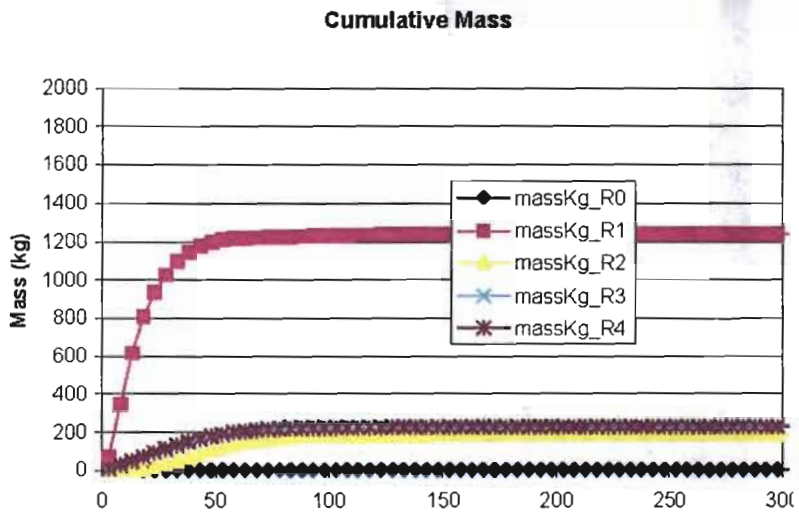
Cumulative Water Across GHB Reaches (millions of gallons)

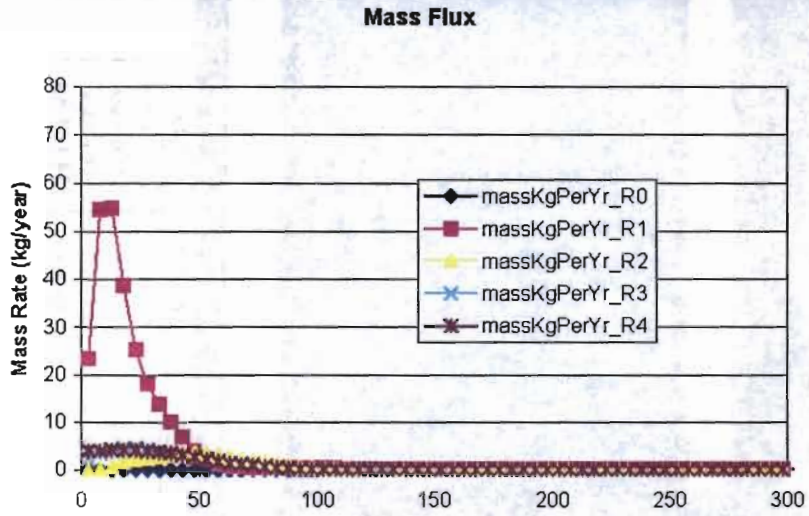
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2010.13	523.84	140.06	119.71	161.31	2955.05
50	3246.37	863.57	229.58	186.97	241.51	4768.00
100	6342.73	1834.54	505.96	452.12	481.68	9617.04
150	9314.77	2811.07	801.50	739.91	708.44	14375.68
200	12242.05	3773.36	1092.57	1021.45	928.01	19057.44
250	15160.57	4733.17	1382.88	1301.95	1146.42	23724.98
300	18077.28	5692.53	1673.05	1582.24	1364.60	28389.71

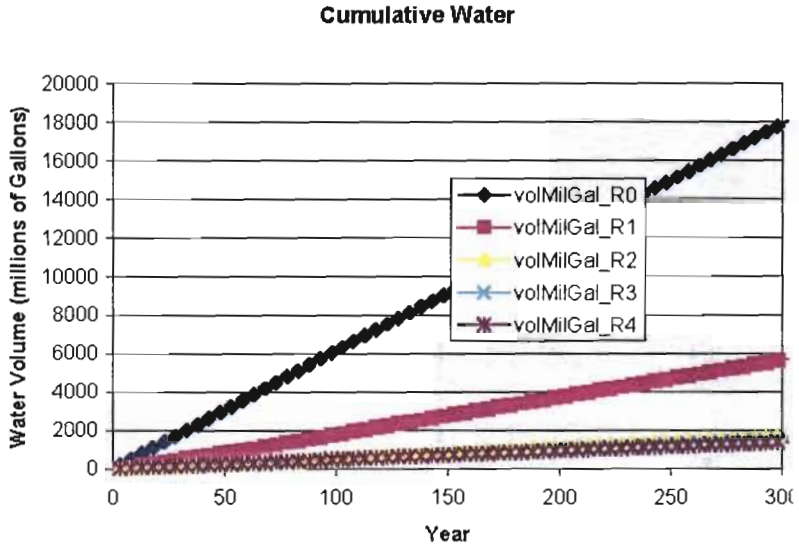
Cumulative Mass Across GHB Reaches (kg)

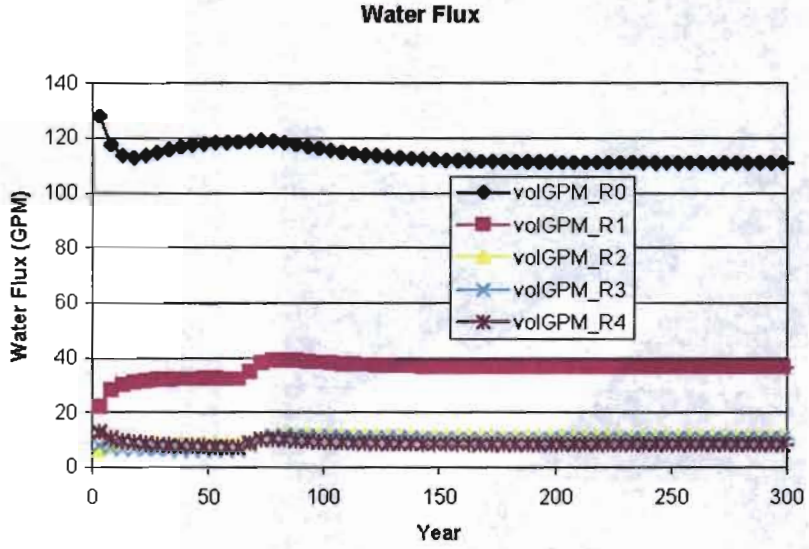
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.75	1096.71	51.87	139.37	131.66	1422.36
50	3.64	1211.03	116.88	195.97	187.88	1715.40
100	4.03	1234.28	180.28	234.74	220.42	1873.76
150	4.06	1239.12	181.61	235.51	223.01	1883.31
200	4.06	1239.39	181.64	235.92	223.58	1884.59
250	4.06	1239.41	181.68	236.04	223.68	1884.87
300	4.07	1239.41	181.69	236.07	223.69	1884.93

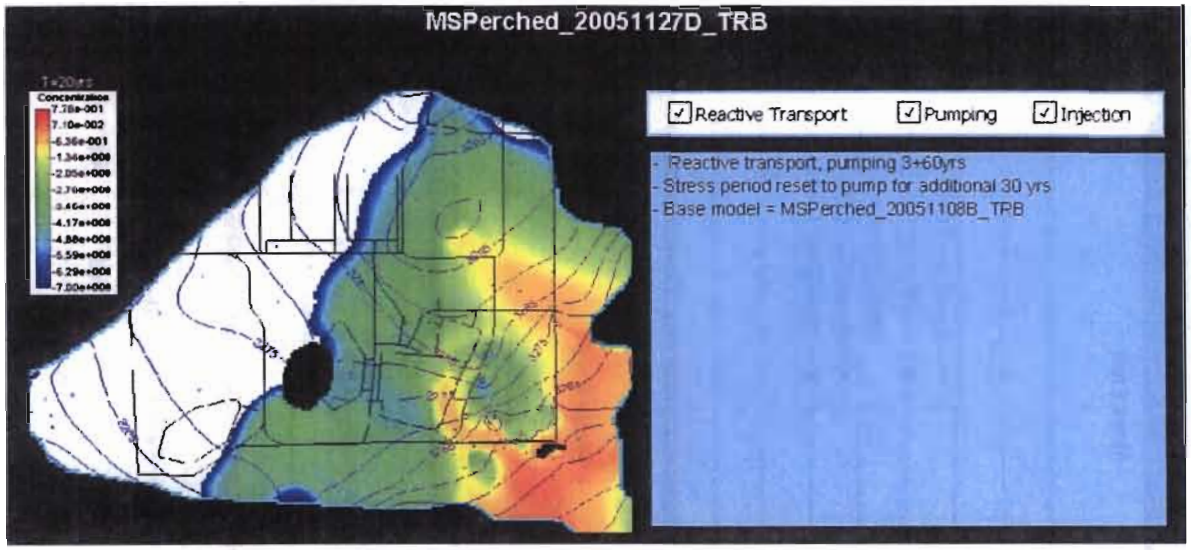
MSPerched_20051127C_TRB











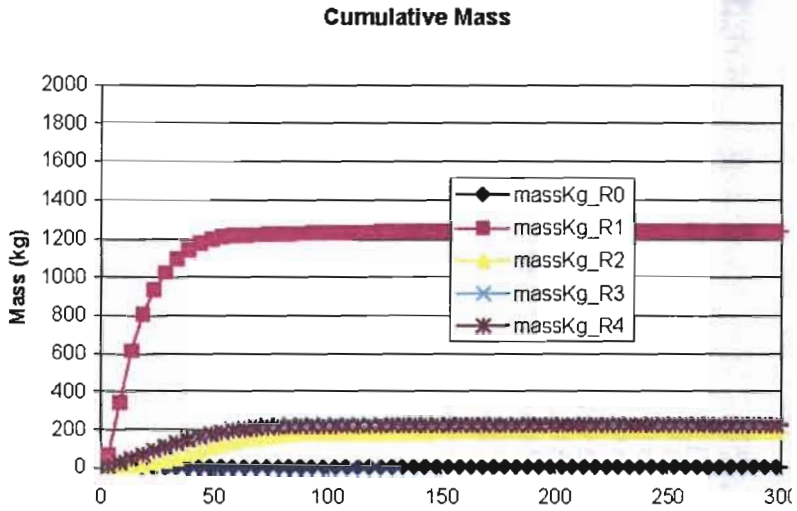
Cumulative Water Across GHB Reaches (millions of gallons)

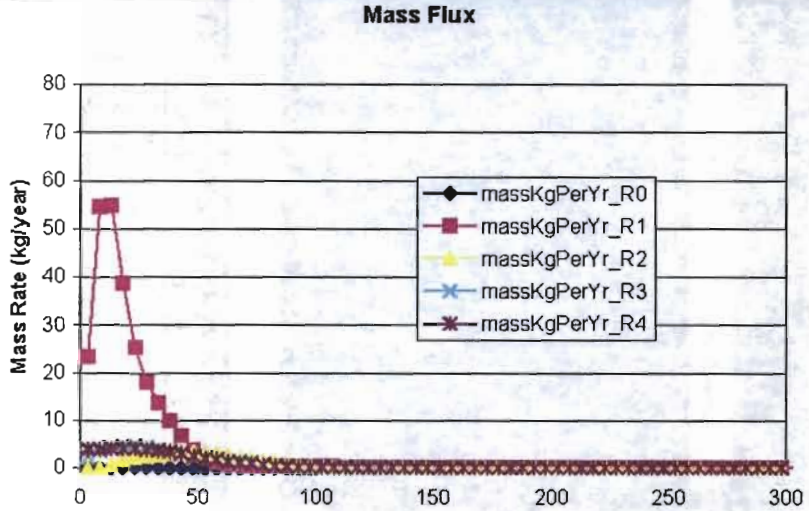
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2010.13	523.84	140.06	119.71	161.31	2955.05
50	3246.37	863.57	229.58	186.97	241.51	4768.00
100	6342.73	1834.54	505.96	452.12	481.68	9617.04
150	9314.77	2811.07	801.50	739.91	708.44	14375.68
200	12242.05	3773.36	1092.57	1021.45	928.01	19057.44
250	15160.57	4733.17	1382.88	1301.95	1146.42	23724.98
300	18077.28	5692.53	1673.05	1582.24	1364.60	28389.71

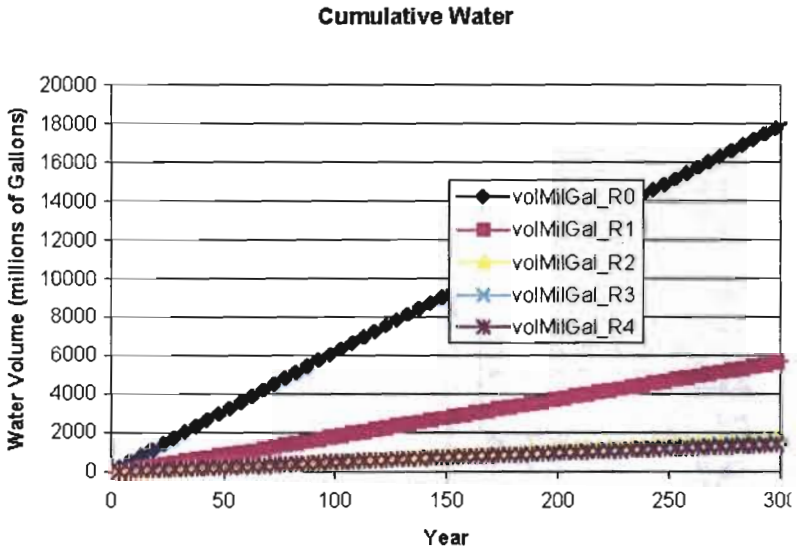
Cumulative Mass Across GHB Reaches (kg)

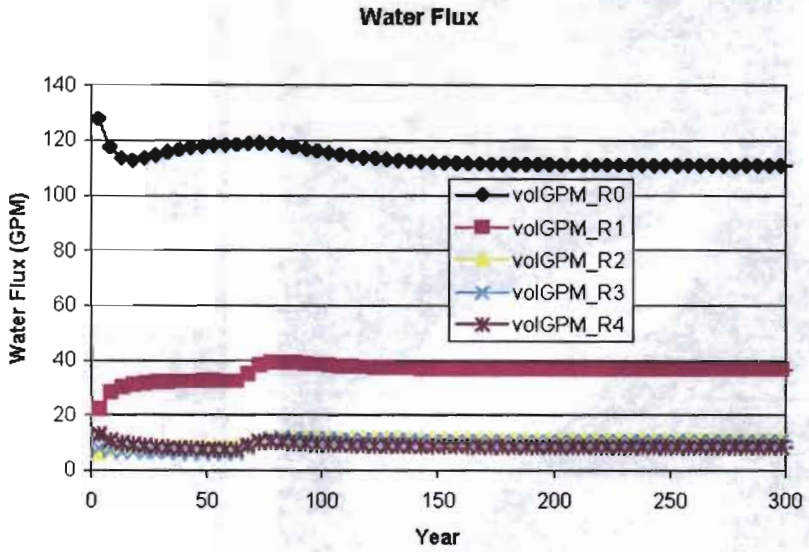
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.75	1096.71	51.87	139.37	131.66	1422.36
50	3.64	1211.03	116.88	195.97	187.88	1715.40
100	4.03	1234.28	180.28	234.74	220.42	1873.75
150	4.06	1239.12	181.61	235.51	223.01	1883.31
200	4.06	1239.39	181.64	235.92	223.58	1884.59
250	4.06	1239.41	181.68	236.04	223.68	1884.87
300	4.07	1239.41	181.69	236.07	223.69	1884.93

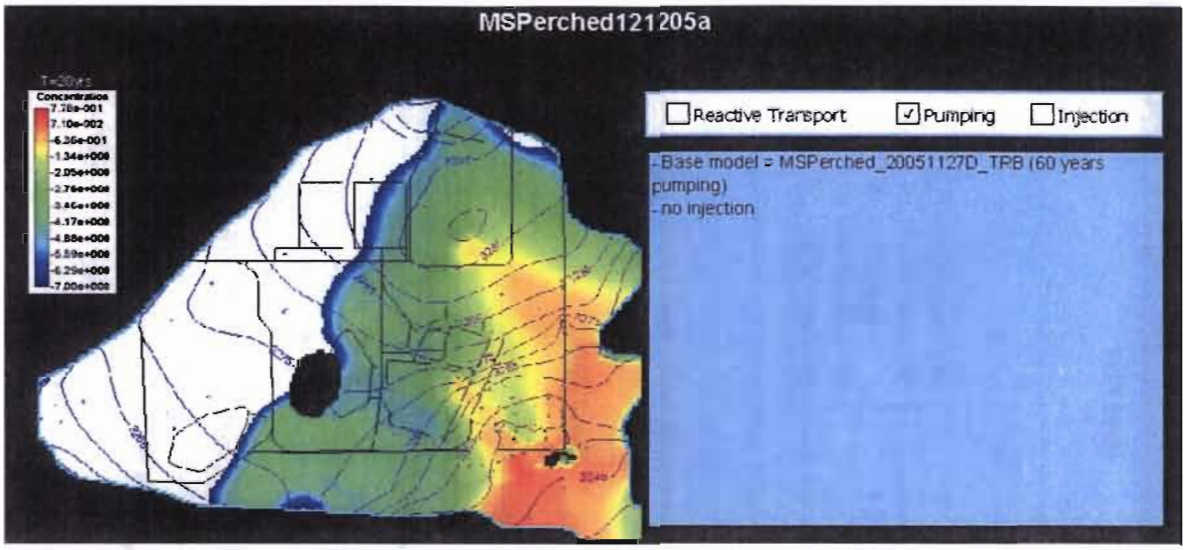
MSPerched_20051127D_TRB











Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1914.72	238.47	97.26	61.58	88.04	2400.07
50	2994.28	300.61	130.53	69.13	102.14	3596.68
100	5674.07	783.46	265.57	161.74	185.14	7069.97
150	8509.95	1703.39	542.13	424.26	386.03	11565.76
200	11409.06	2657.44	830.64	702.28	601.75	16201.17
250	14322.08	3615.79	1120.51	982.16	819.46	20860.00
300	17237.60	4574.86	1410.59	1262.33	1037.49	25522.87

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.14	580.01	16.21	61.94	53.82	714.11
50	2.46	604.67	26.05	67.39	59.94	760.51
100	2.52	614.98	47.06	76.16	68.18	808.90
150	2.53	617.25	52.97	83.42	71.98	828.15
200	2.53	617.56	53.66	84.19	72.42	830.37
250	2.53	617.57	53.74	84.32	72.50	830.66
300	2.53	617.57	53.75	84.35	72.51	830.71

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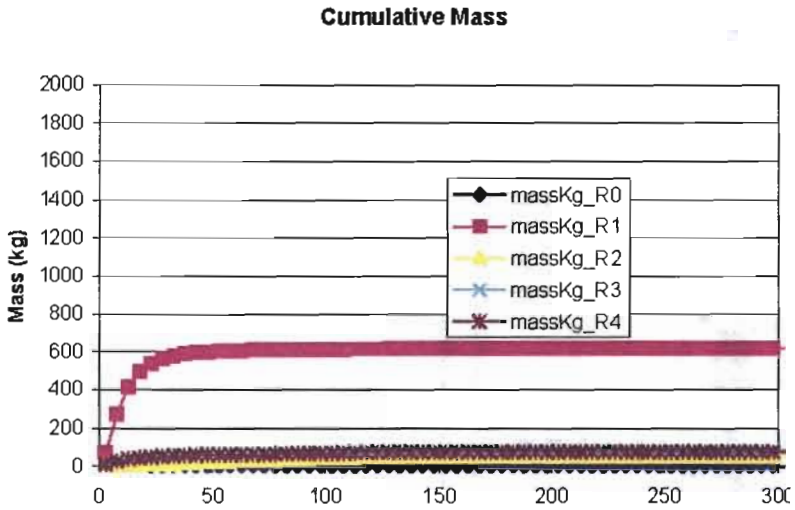

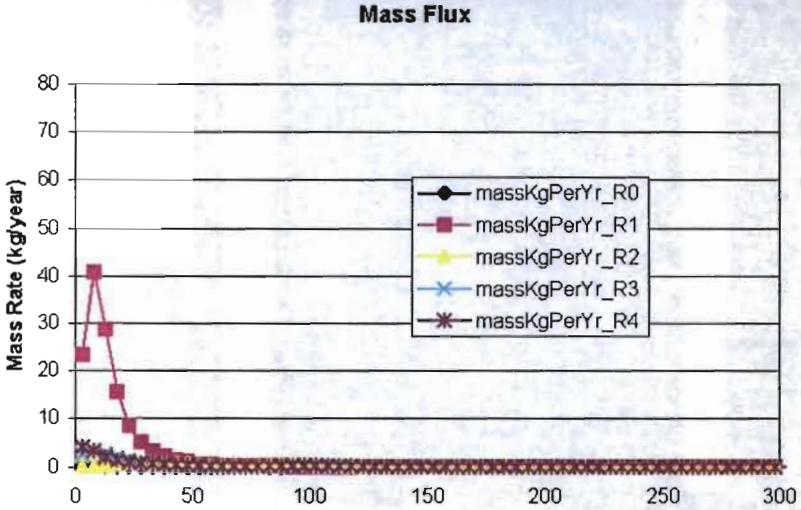

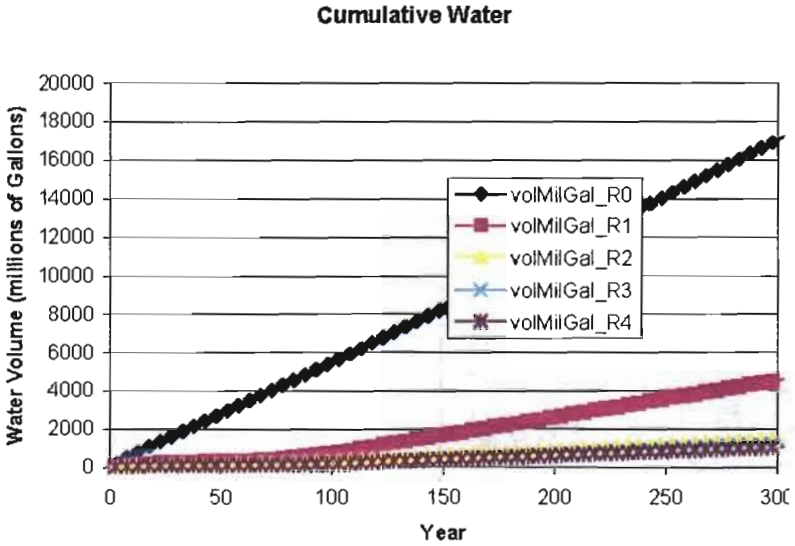

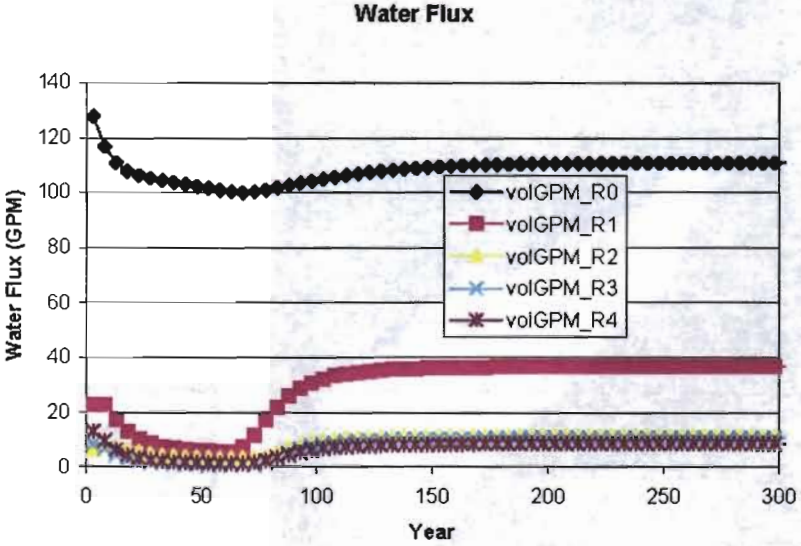

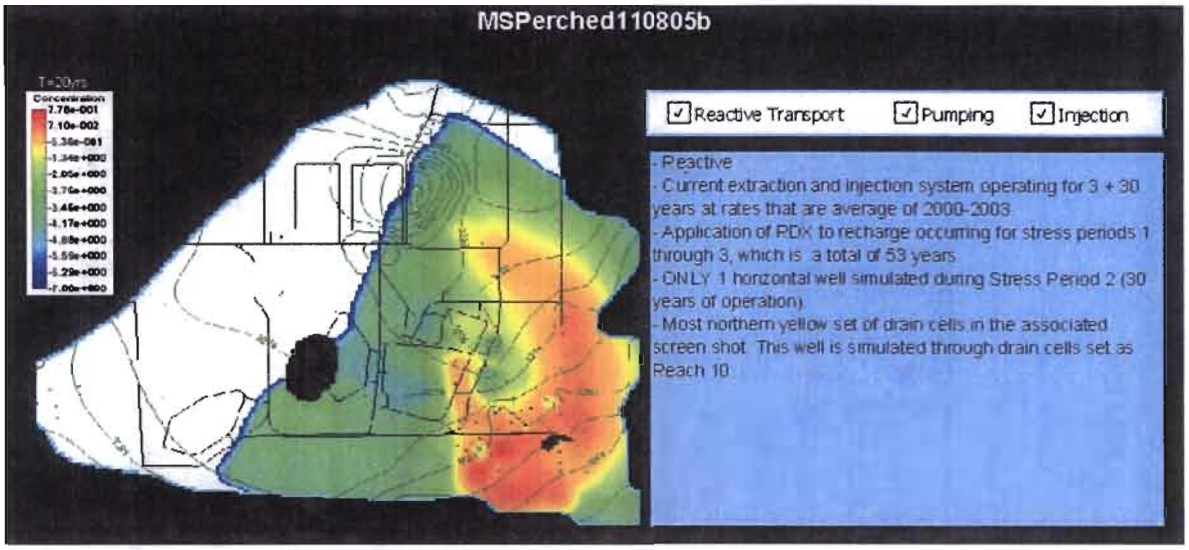

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1620.61	514.31	138.45	115.56	147.56	2536.49
50	2517.74	878.24	240.66	211.76	220.26	4068.66
100	4956.58	1767.57	512.31	460.24	386.99	8083.69
150	7738.86	2692.78	792.33	725.84	587.35	12537.15
200	10627.90	3644.65	1080.23	1002.96	801.97	17157.70
250	13539.00	4602.51	1369.94	1282.63	1019.44	21813.52
300	16454.24	5561.49	1660.00	1562.77	1237.44	26475.94

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.11	1087.33	50.39	134.22	119.21	1393.26
50	2.40	1210.26	125.94	211.52	171.87	1722.00
100	2.47	1242.52	190.90	246.83	202.24	1884.97
150	2.48	1246.81	191.66	248.09	205.71	1894.75
200	2.51	1247.66	191.85	248.79	206.44	1897.26
250	2.53	1247.68	191.93	248.95	206.54	1897.62
300	2.53	1247.69	191.94	248.98	206.55	1897.69

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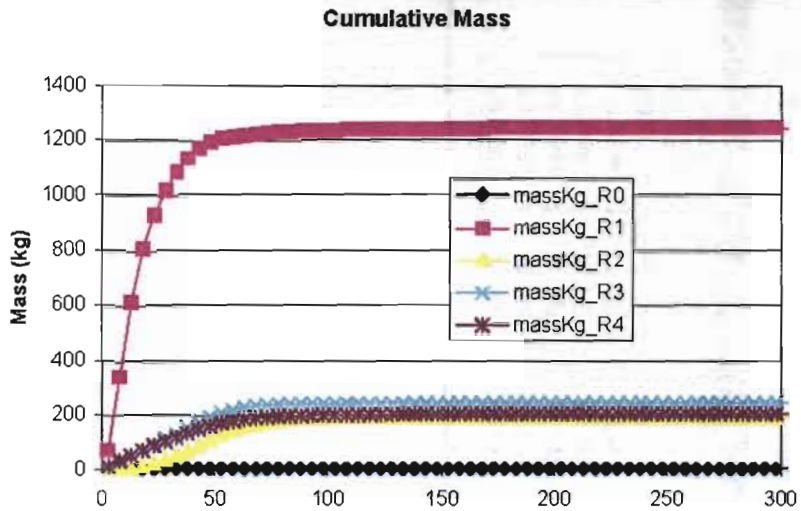
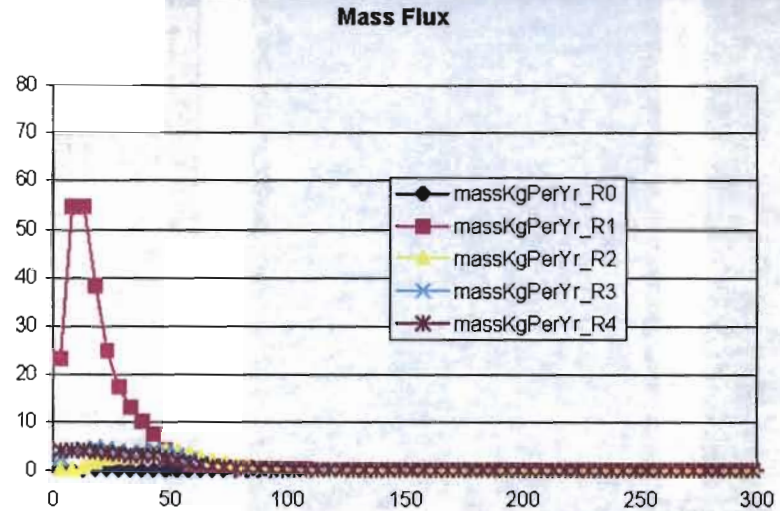
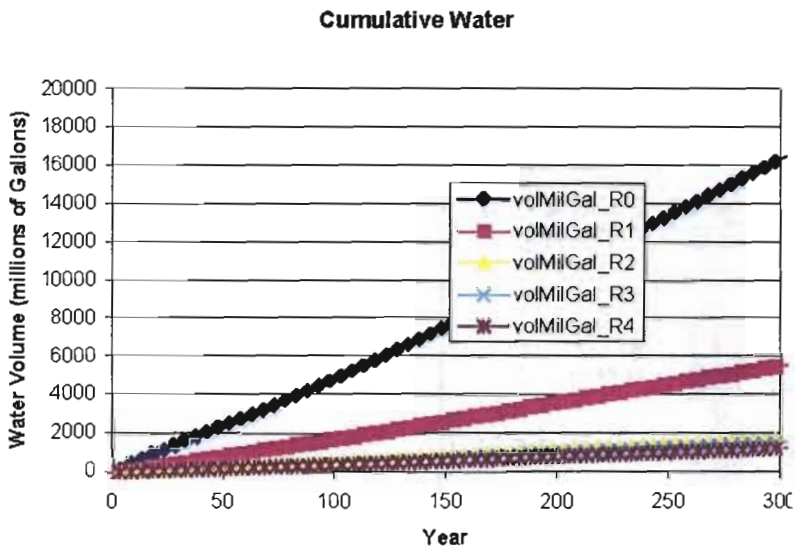
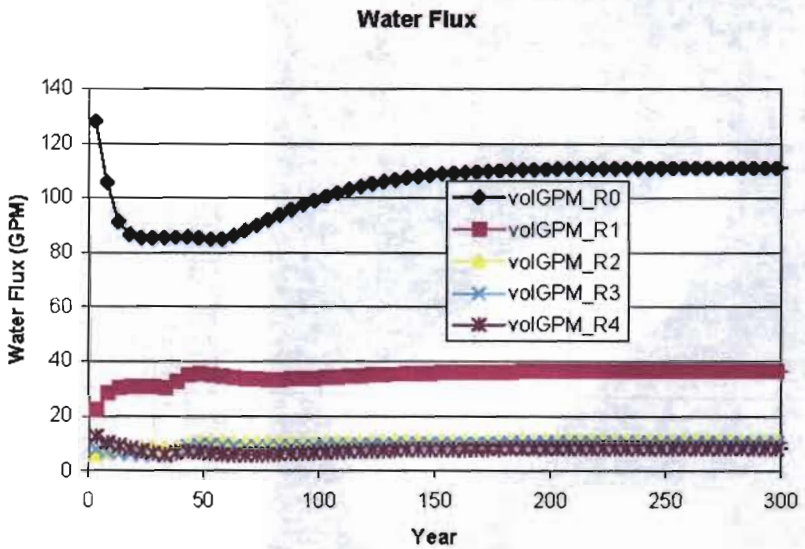
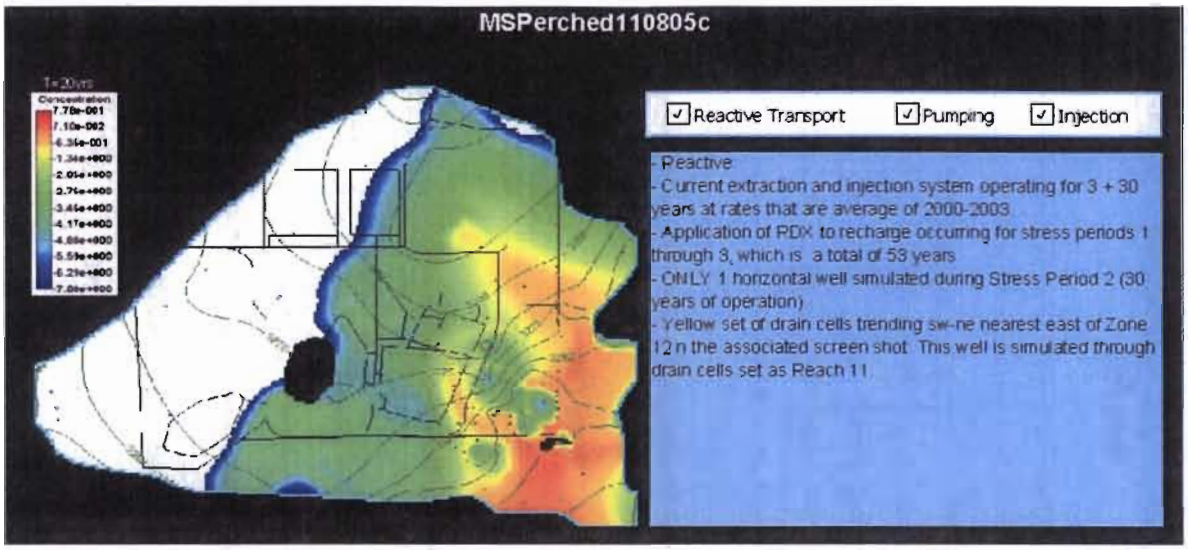










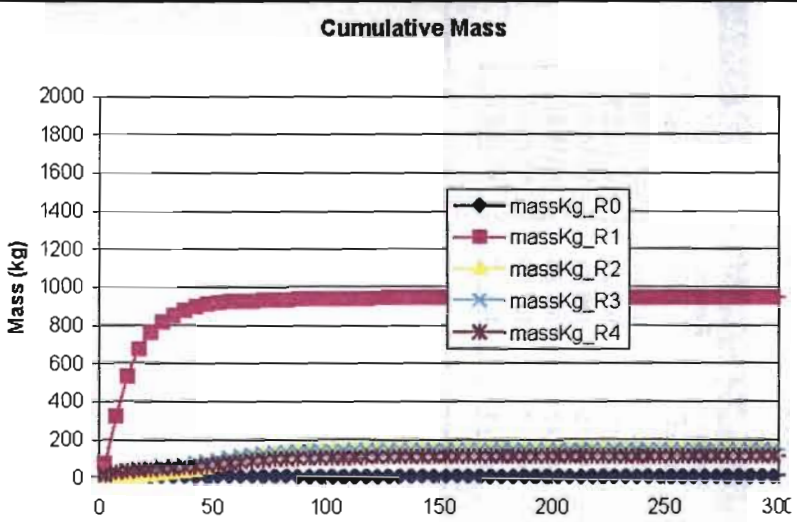
Cumulative Water Across GHB Reaches (millions of gallons)

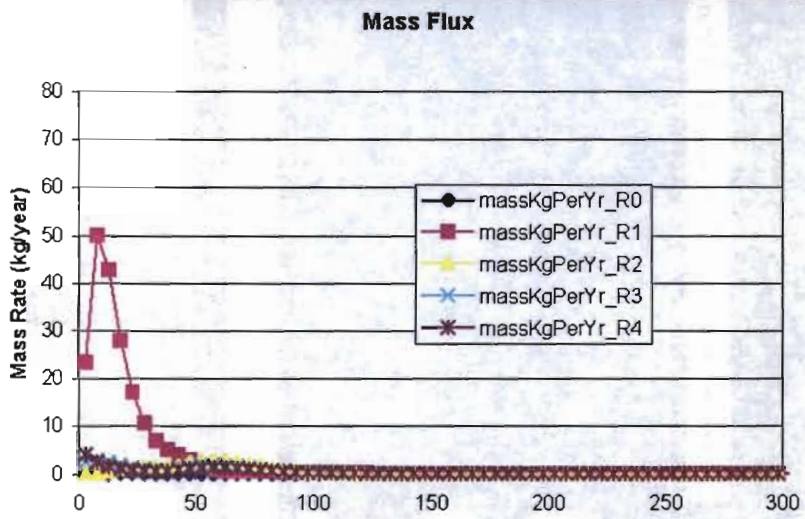
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1970.15	398.18	109.04	63.19	83.21	2623.77
50	3148.45	687.23	179.83	115.47	135.97	4266.96
100	6088.07	1630.17	461.37	386.99	351.19	8917.79
150	9009.21	2590.31	751.74	667.62	569.88	13588.76
200	11926.57	3549.81	1041.96	947.98	788.14	18254.46
250	14843.00	4509.11	1332.11	1228.25	1006.29	22918.76
300	17759.21	5468.35	1622.24	1508.50	1224.40	27582.71

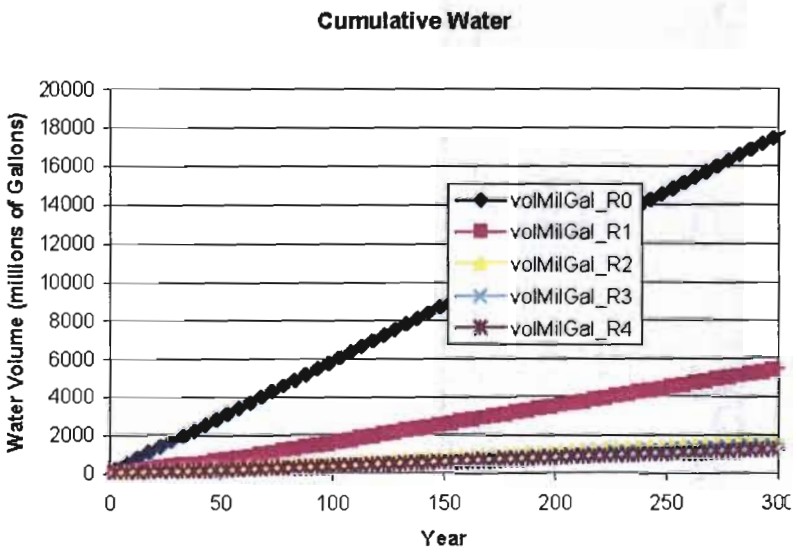
Cumulative Mass Across GHB Reaches (kg)

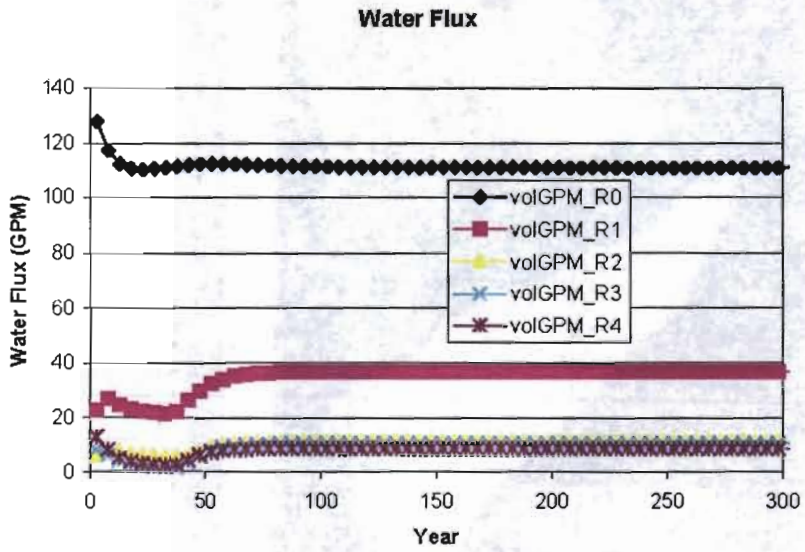
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.38	848.46	27.23	62.44	47.09	987.60
50	2.98	915.75	67.84	89.07	65.37	1141.01
100	3.22	936.64	138.01	137.12	101.24	1316.23
150	3.24	941.87	140.11	140.55	106.05	1331.82
200	3.24	942.94	140.47	141.49	106.88	1335.02
250	3.24	942.97	140.57	141.67	107.00	1335.45
300	3.24	942.98	140.59	141.71	107.02	1335.54

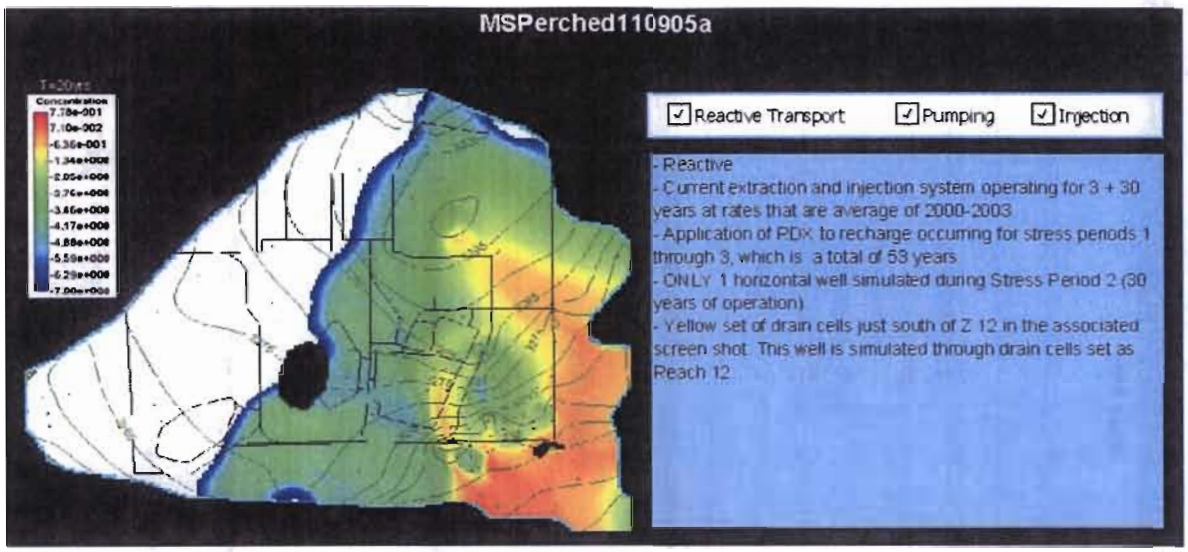
MSPerched110805c











Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1914.72	214.30	109.03	92.82	149.61	2480.47
50	3084.38	500.28	188.39	173.90	239.91	4186.87
100	6044.69	1463.07	477.96	456.34	467.01	8909.07
150	8972.35	2425.55	769.09	738.02	686.88	13591.88
200	11891.07	3385.43	1059.42	1018.54	905.33	18259.80
250	14807.85	4344.82	1349.60	1298.85	1123.52	22924.62
300	17724.16	5304.09	1639.74	1579.11	1341.65	27588.74

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.66	571.42	21.41	102.27	117.95	815.71
50	3.53	715.13	58.35	161.33	176.44	1114.78
100	3.90	741.75	117.49	200.65	215.26	1279.05
150	3.92	745.97	118.18	202.57	219.49	1290.13
200	3.92	746.77	118.44	203.35	220.22	1292.70
250	3.92	746.79	118.53	203.51	220.33	1293.08
300	3.92	746.80	118.55	203.54	220.35	1293.16

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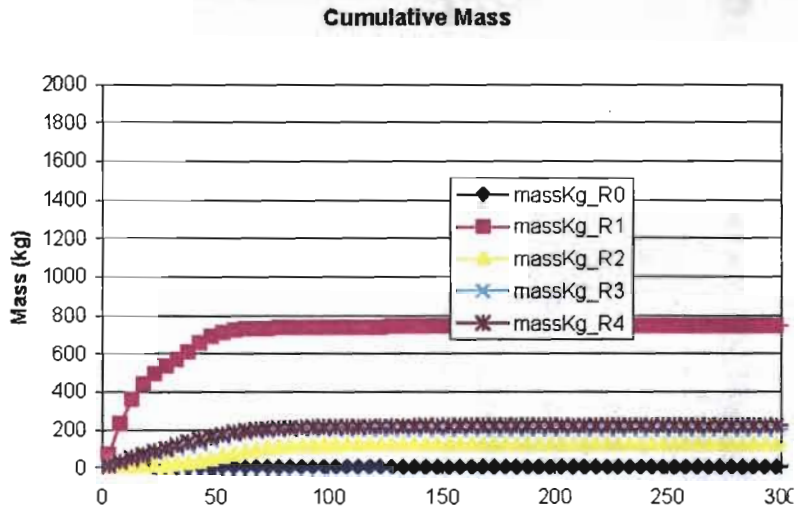

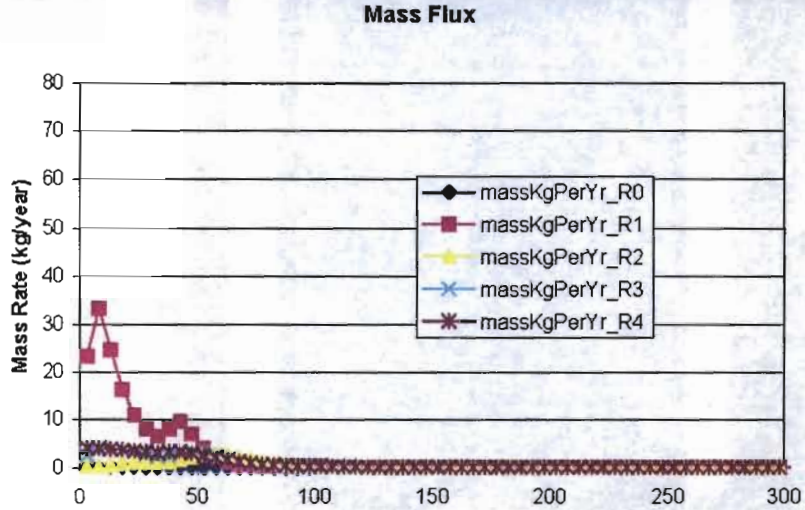

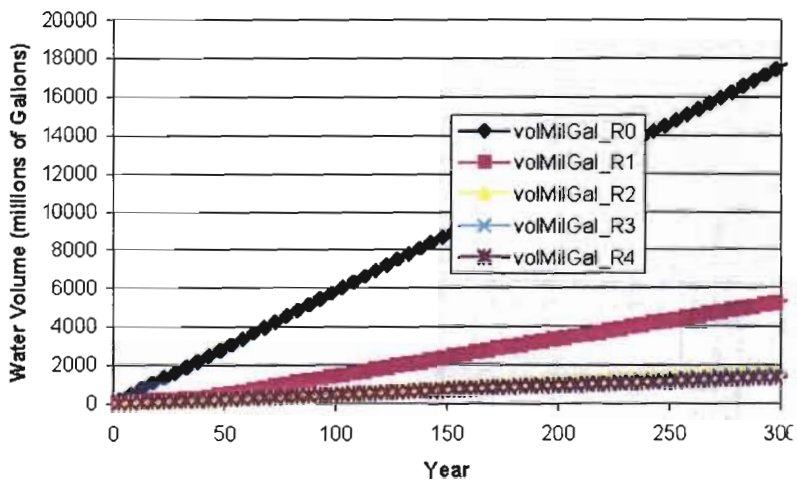

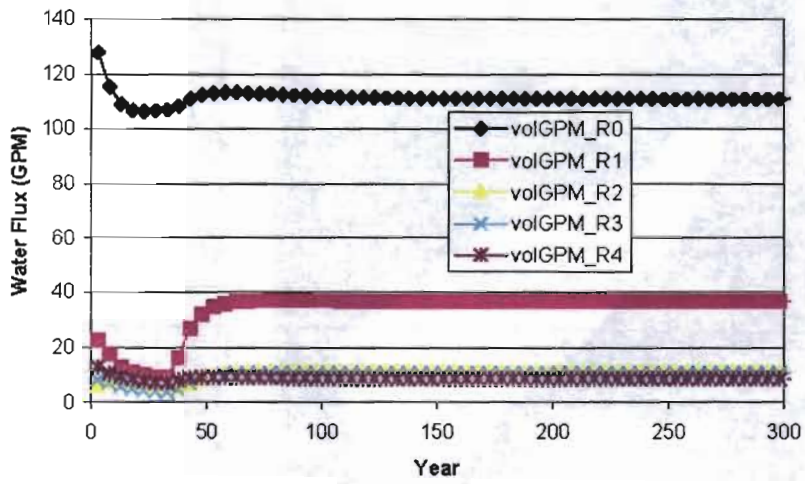

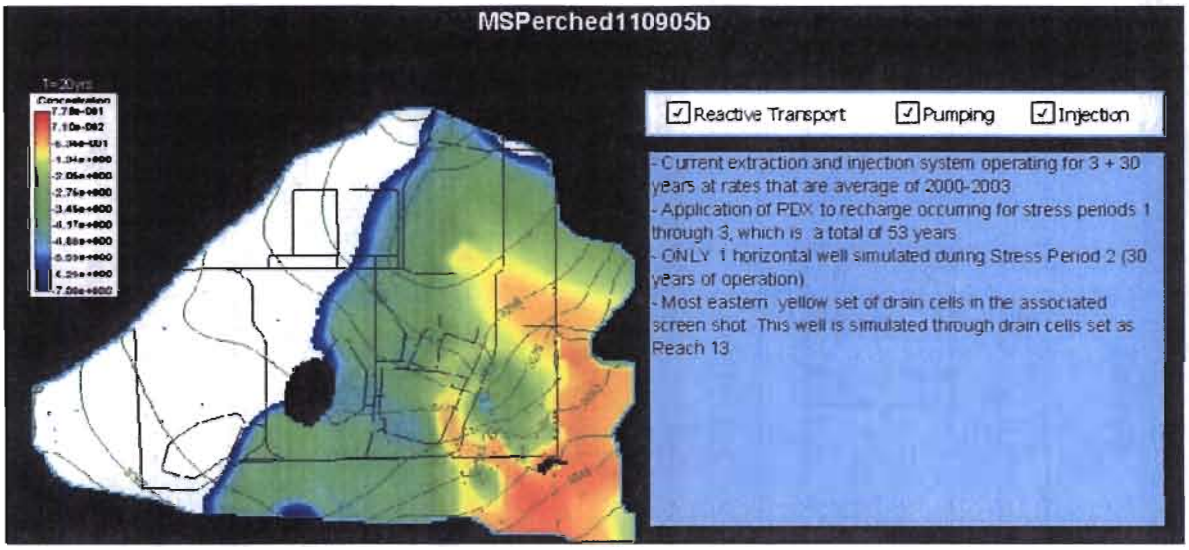

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2004.82	509.99	135.37	105.53	111.74	2867.46
50	3233.87	892.83	239.71	207.13	203.77	4777.30
100	6241.23	1880.88	538.17	500.16	439.21	9599.65
150	9177.75	2845.96	830.12	782.94	660.23	14296.99
200	12098.06	3806.28	1120.58	1063.64	878.87	18967.43
250	15015.17	4765.73	1410.78	1343.98	1097.10	23632.77
300	17931.56	5725.03	1700.93	1624.25	1315.24	28297.01

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.56	1069.29	48.31	120.23	66.26	1306.66
50	3.38	1192.04	125.99	197.02	114.48	1632.90
100	3.74	1227.47	194.72	230.10	150.13	1806.16
150	3.76	1232.22	195.29	231.50	154.15	1816.92
200	3.76	1232.95	195.53	232.22	154.85	1819.30
250	3.76	1232.97	195.61	232.37	154.96	1819.66
300	3.76	1232.98	195.62	232.40	154.97	1819.73

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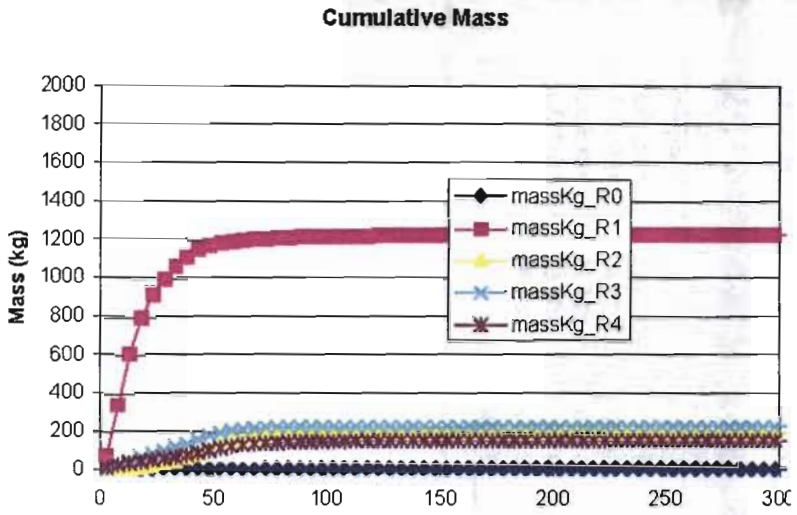

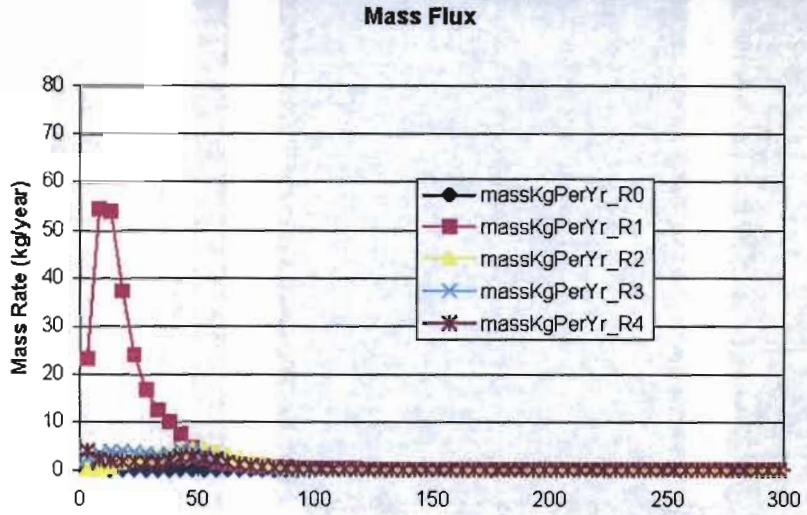

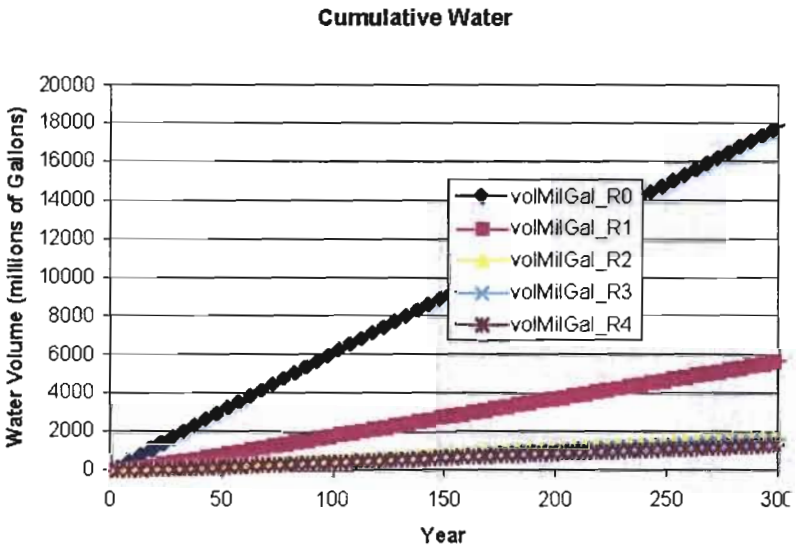

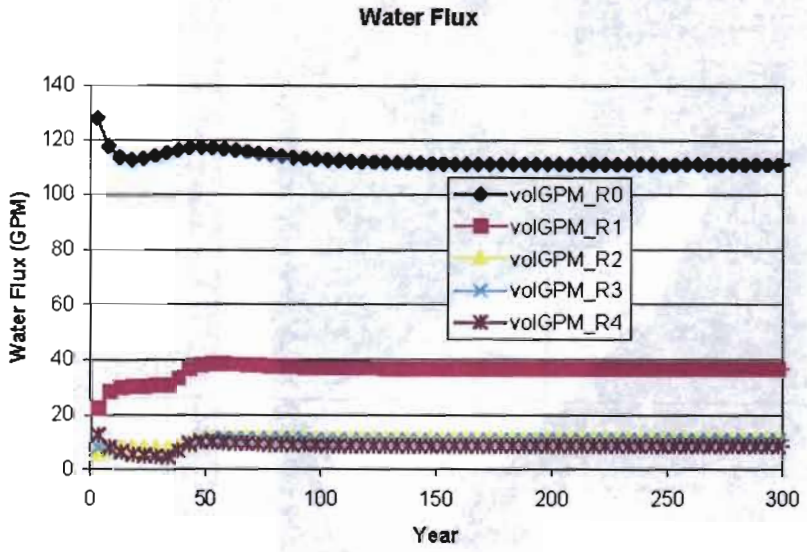

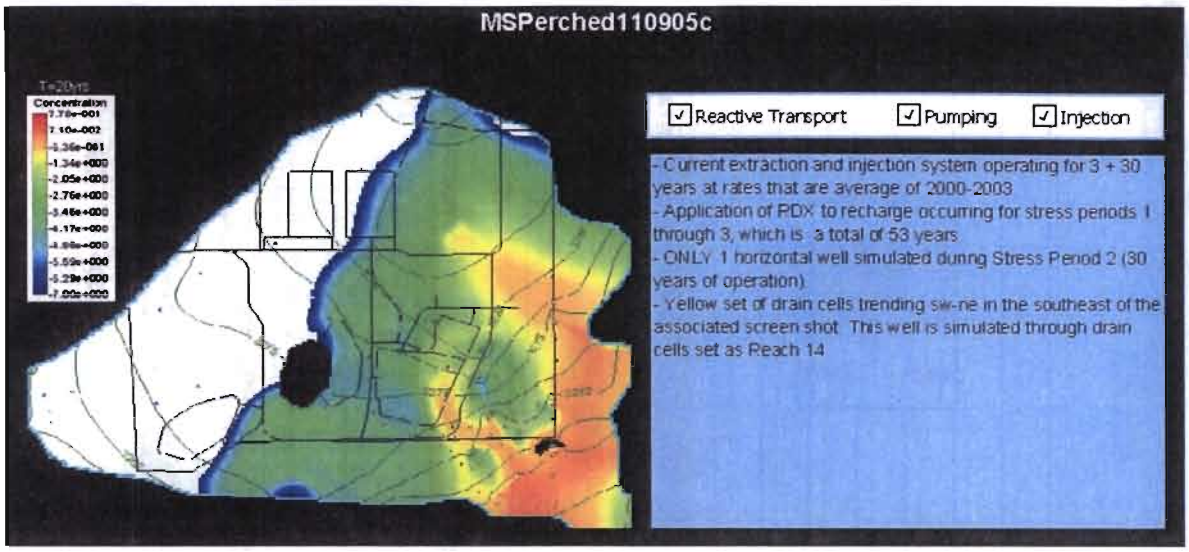

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2004.38	370.22	114.05	105.46	160.01	2754.12
50	3238.21	747.86	213.55	210.19	265.75	4675.55
100	6255.00	1741.28	513.87	505.94	504.55	9520.63
150	9193.89	2707.13	806.05	789.05	725.95	14222.06
200	12114.65	3667.57	1096.56	1069.81	944.65	18893.24
250	15031.86	4627.06	1386.77	1350.16	1162.89	23558.74
300	17948.31	5586.35	1676.92	1630.43	1381.04	28223.06

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.74	572.20	22.29	120.10	130.19	847.53
50	3.70	662.34	75.51	200.50	201.13	1143.18
100	4.12	695.50	134.14	236.26	239.35	1309.37
150	4.14	700.16	134.67	237.88	243.48	1320.34
200	4.14	700.88	134.91	238.61	244.19	1322.75
250	4.14	700.91	134.99	238.76	244.30	1323.10
300	4.14	700.91	135.01	238.80	244.31	1323.17

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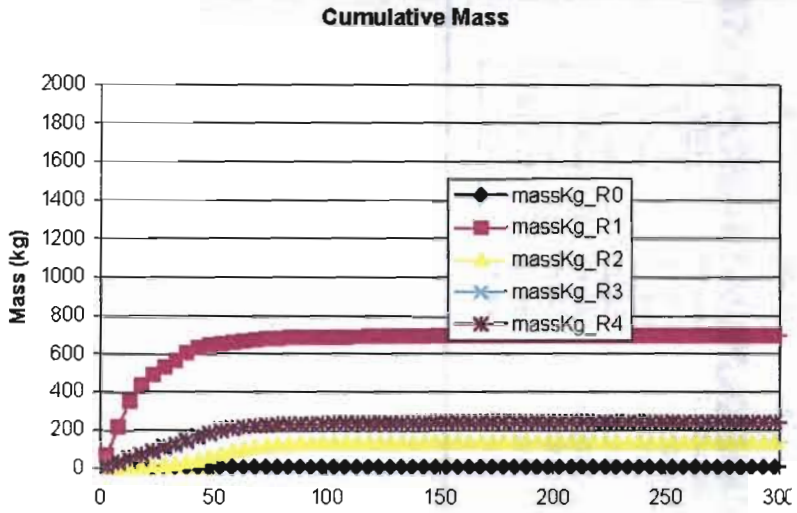

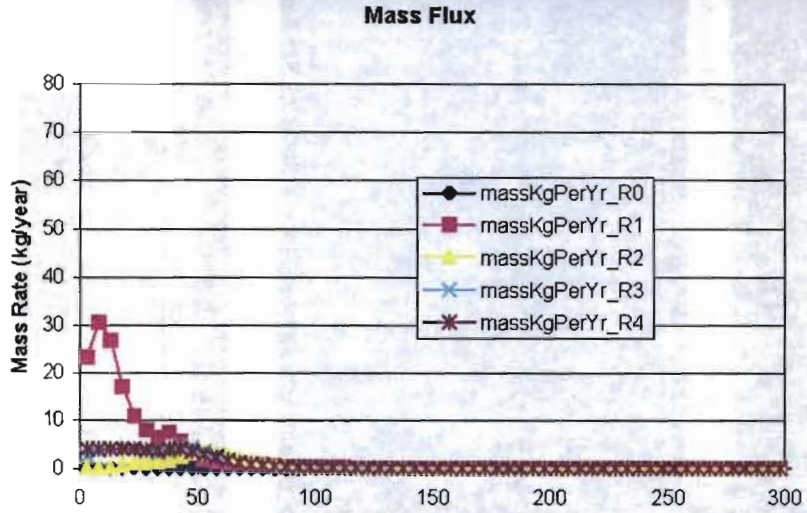

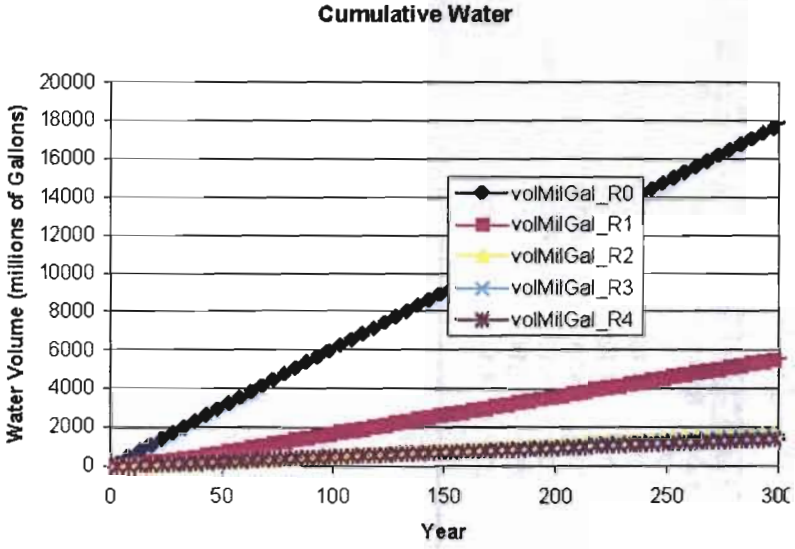

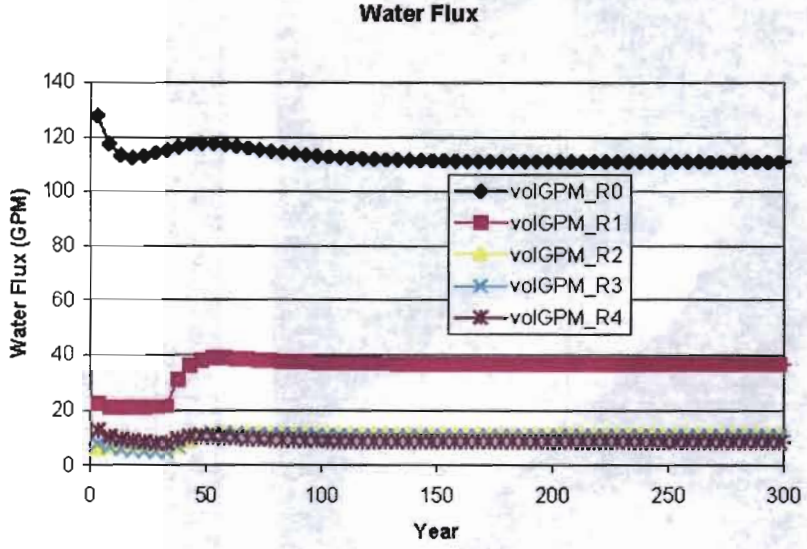

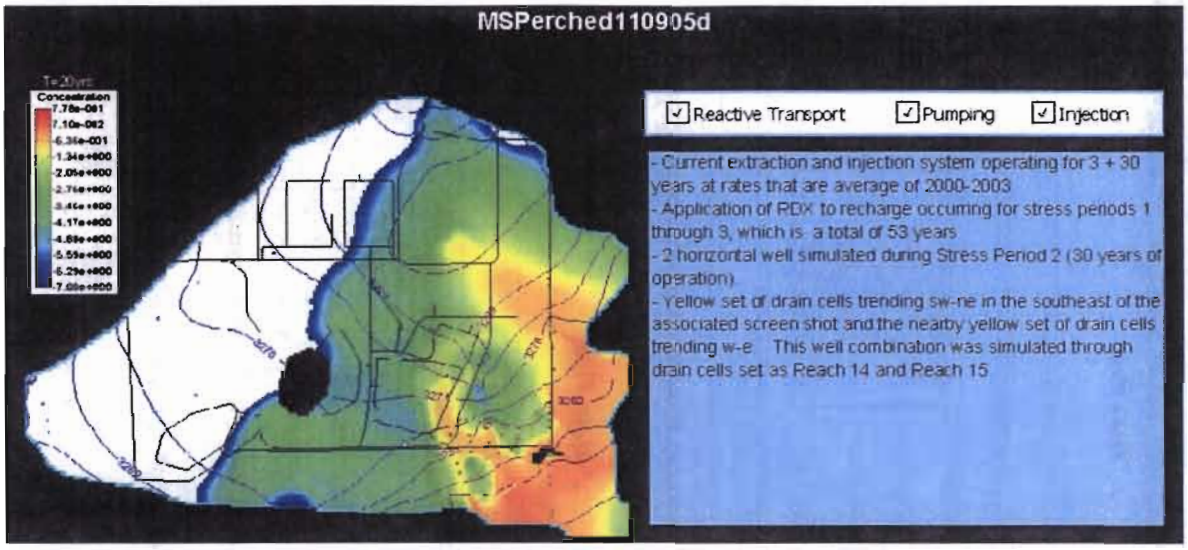

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1975.75	207.35	110.82	101.62	158.19	2553.72
50	3197.50	562.95	204.78	200.66	260.85	4426.74
100	6204.59	1550.68	503.04	493.89	497.47	9249.68
150	9141.53	2515.94	795.04	776.75	718.59	13947.85
200	12061.94	3476.29	1085.52	1057.47	937.25	18618.47
250	14979.08	4435.75	1375.72	1337.81	1155.49	23283.85
300	17895.50	5395.05	1665.87	1618.08	1373.63	27948.14

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.72	401.97	20.11	114.76	128.10	667.67
50	3.67	489.38	67.74	189.88	196.57	947.24
100	4.07	523.36	125.73	226.29	234.90	1114.36
150	4.10	527.95	126.27	227.96	239.05	1125.33
200	4.10	528.67	126.51	228.70	239.76	1127.75
250	4.10	528.70	126.59	228.85	239.87	1128.11
300	4.10	528.70	126.61	228.88	239.88	1128.18

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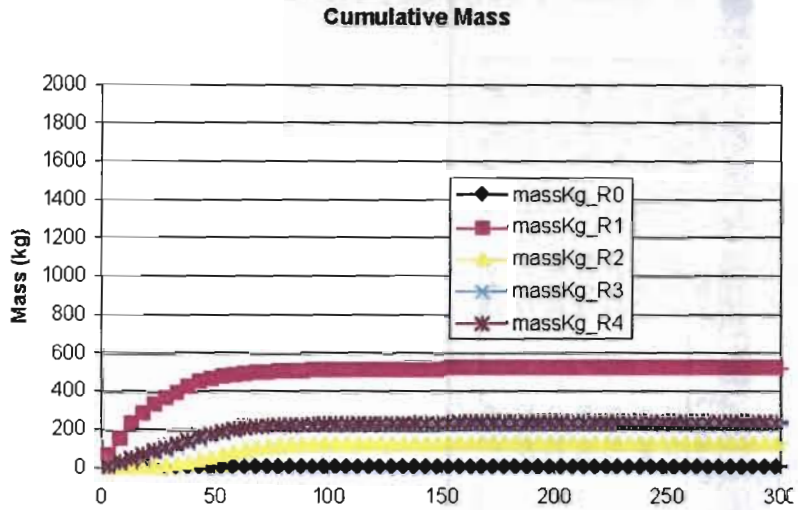

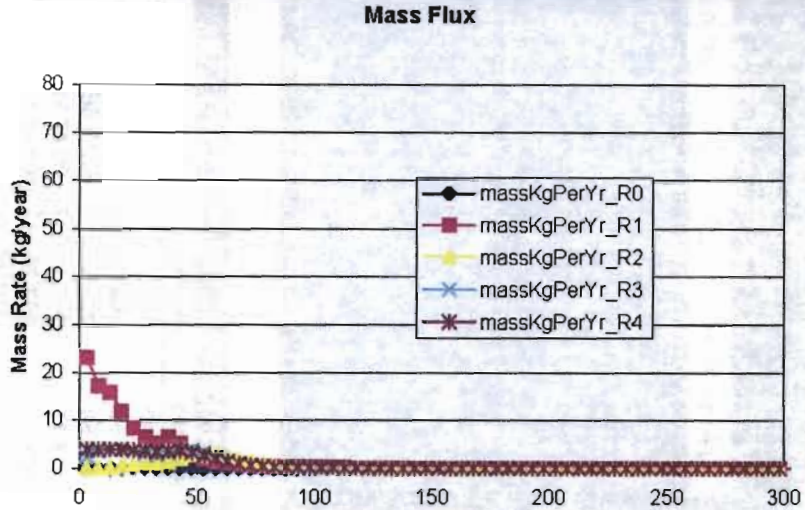

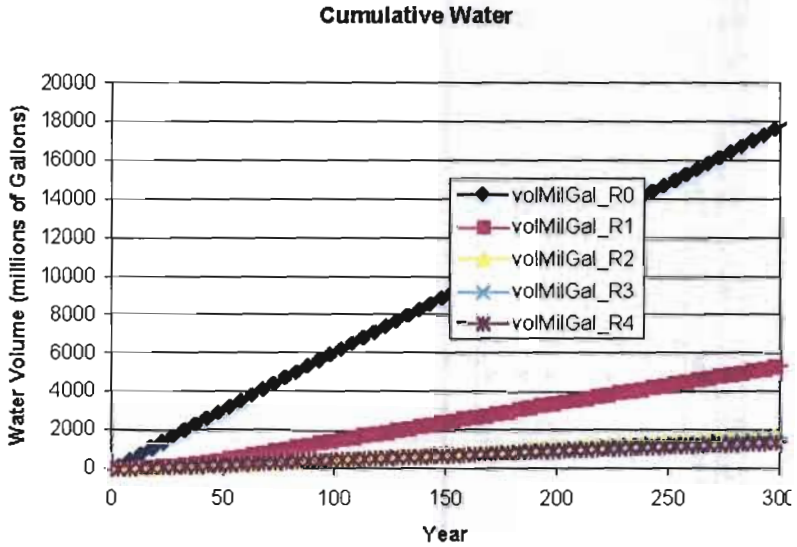

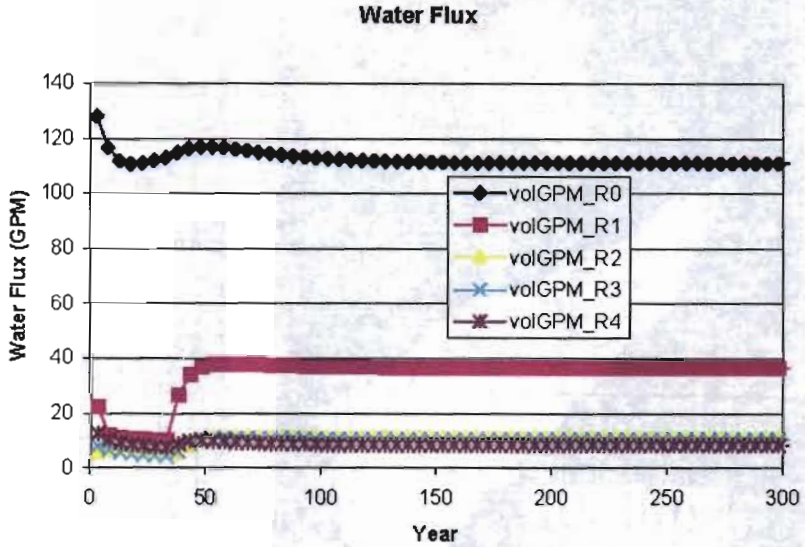

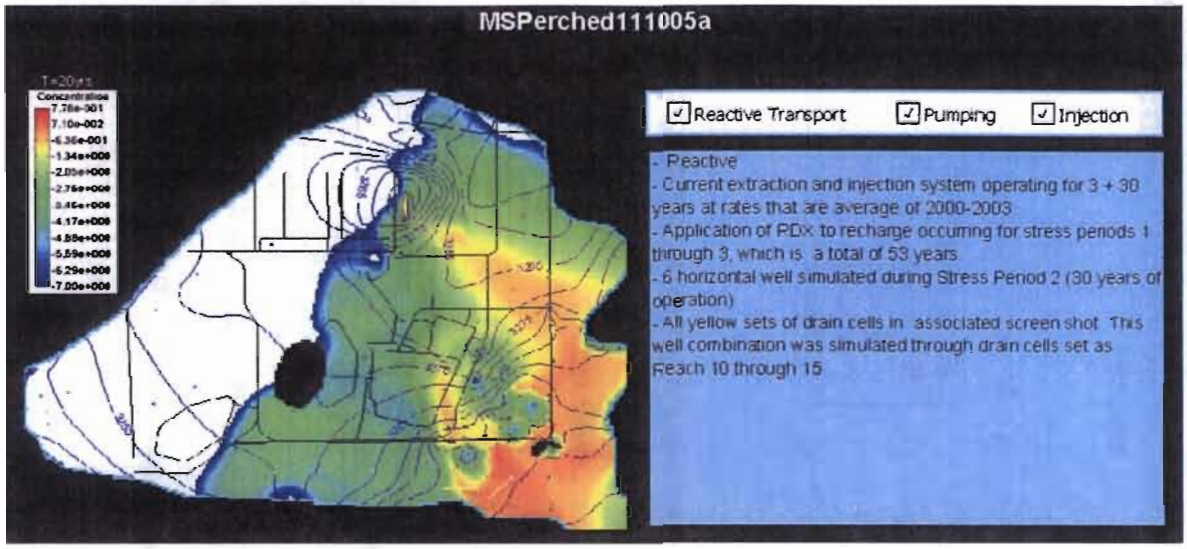

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1514.14	121.42	87.27	52.96	69.18	1844.98
50	2325.84	294.35	131.37	79.23	92.67	2923.46
100	4654.21	1094.75	370.15	286.51	226.37	6632.00
150	7403.19	2008.47	646.54	547.14	421.53	11026.86
200	10285.27	2958.37	933.83	823.43	635.24	15636.13
250	13195.07	3915.87	1223.43	1102.95	852.56	20289.88
300	16110.08	4874.80	1513.47	1383.06	1070.52	24951.93

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.80	286.48	9.11	51.28	35.24	383.91
50	1.96	340.26	21.64	62.41	42.54	468.81
100	1.99	371.61	63.55	94.21	61.00	592.36
150	1.99	375.58	65.31	97.65	64.86	605.38
200	2.01	376.48	65.60	98.44	65.53	608.07
250	2.03	376.50	65.68	98.59	65.62	608.42
300	2.03	376.50	65.70	98.62	65.63	608.49

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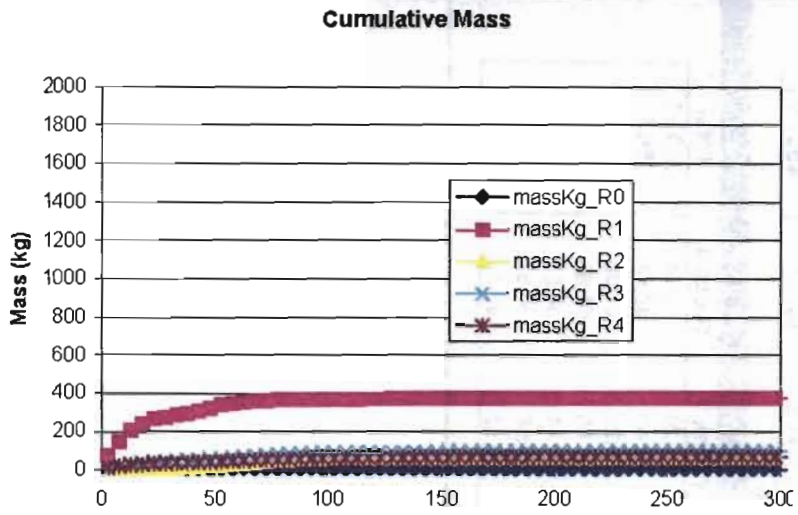

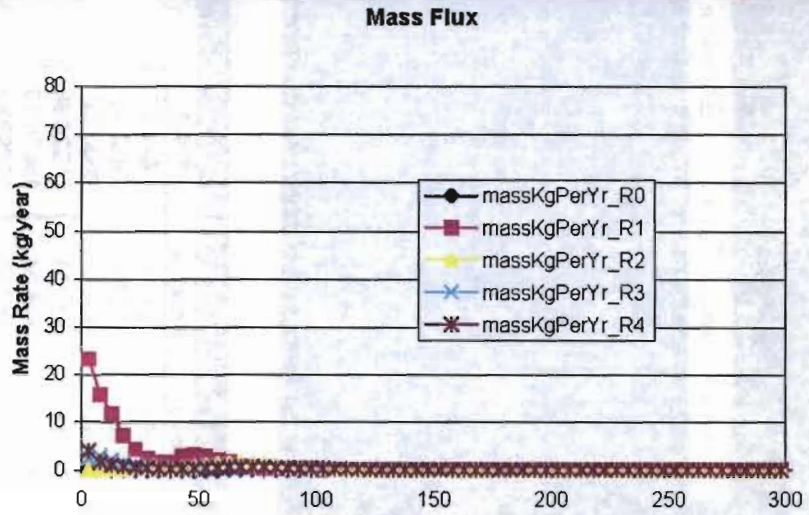

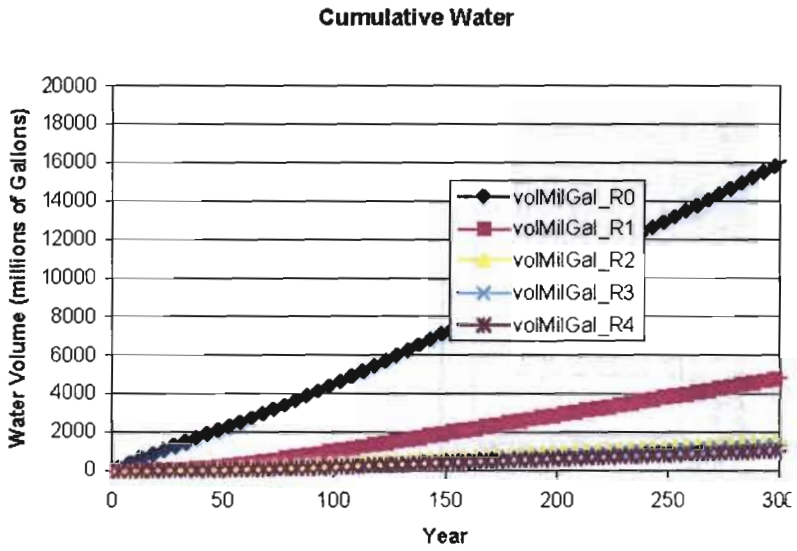

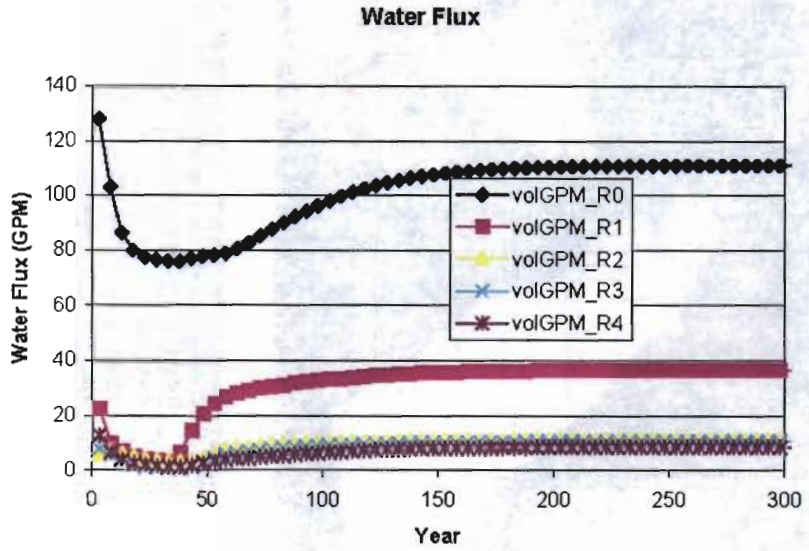

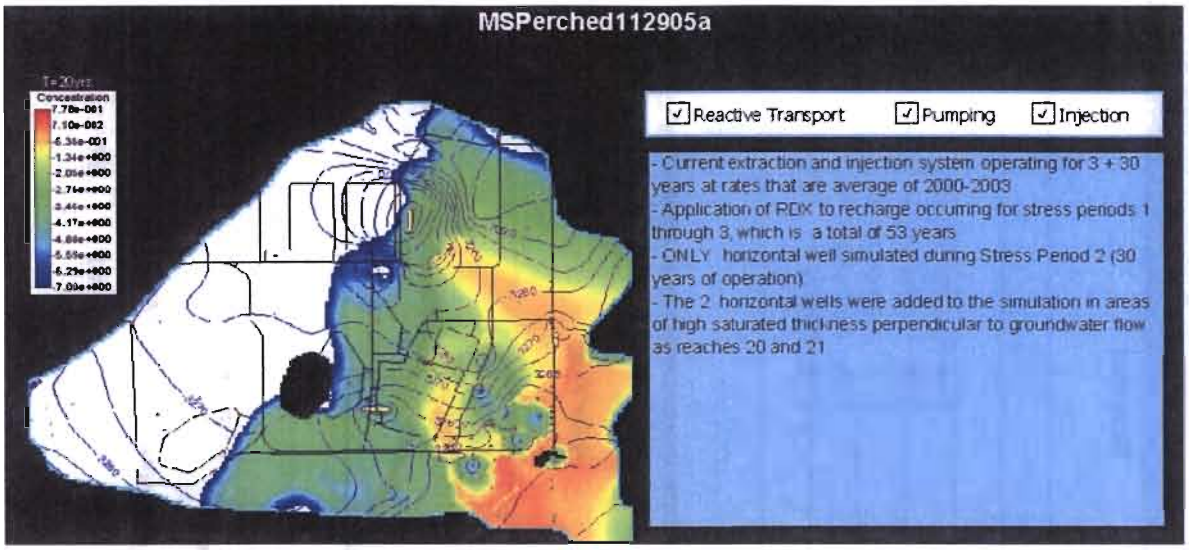

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1424.07	112.26	87.14	52.74	65.63	1741.83
50	2127.52	224.67	125.55	70.61	80.59	2628.94
100	4248.45	928.57	336.11	238.82	179.83	5931.79
150	6925.30	1819.85	605.58	489.79	364.58	10205.10
200	9791.80	2765.43	891.56	764.26	576.29	14789.34
250	12698.66	3722.14	1180.92	1043.44	793.25	19438.41
300	15613.16	4680.92	1470.92	1323.50	1011.15	24099.65

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.41	285.08	9.04	51.09	33.79	380.42
50	1.49	327.19	19.15	59.23	38.76	445.81
100	1.50	359.60	54.51	83.17	50.91	549.69
150	1.50	363.88	56.60	87.39	54.49	563.86
200	1.50	364.98	56.90	88.16	55.15	566.69
250	1.50	365.01	56.98	88.32	55.23	567.04
300	1.50	365.02	57.00	88.35	55.24	567.11

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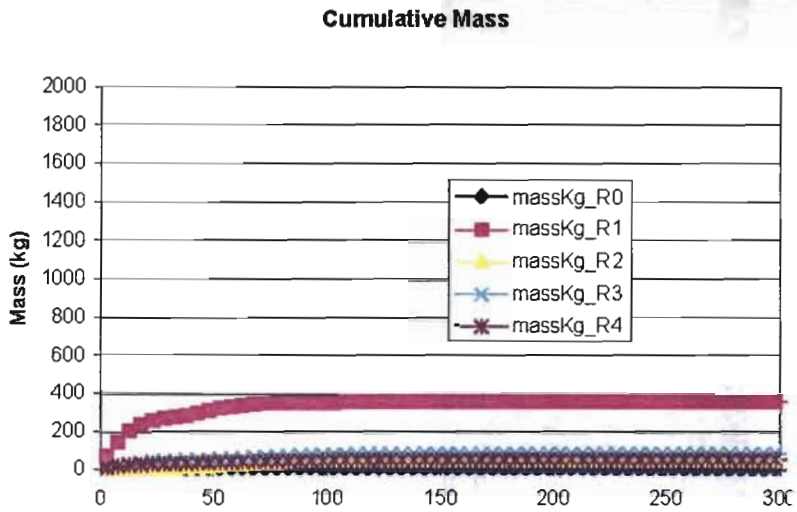

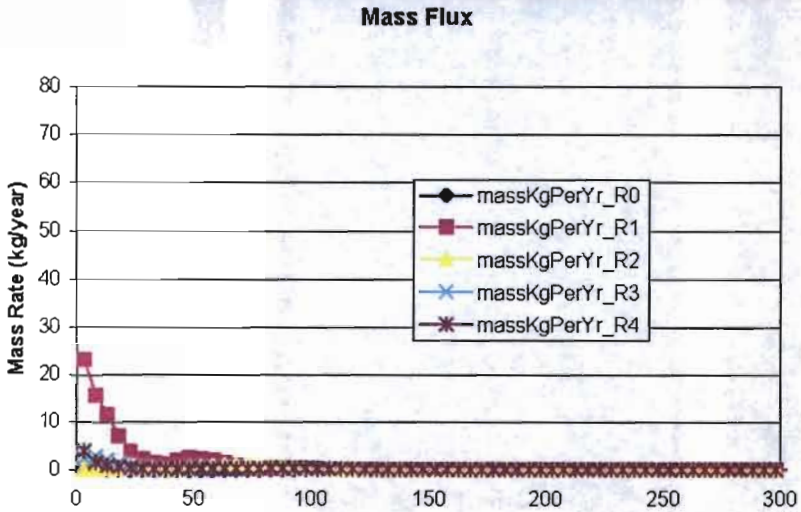

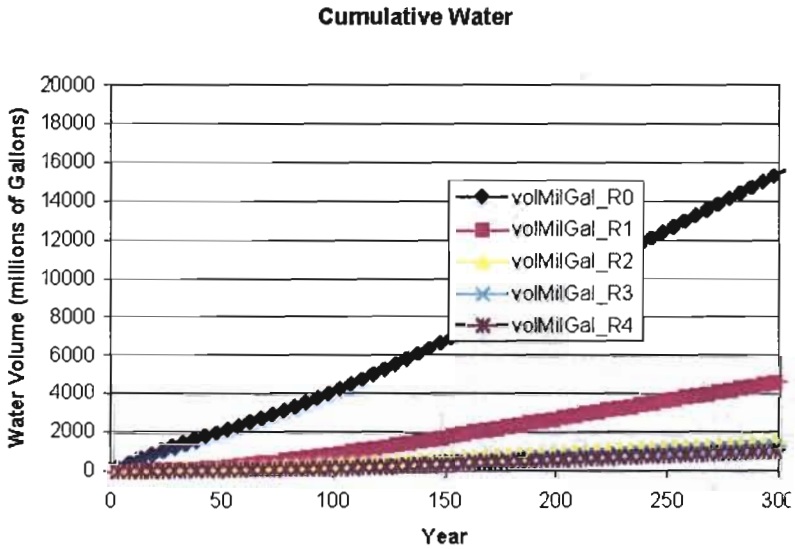

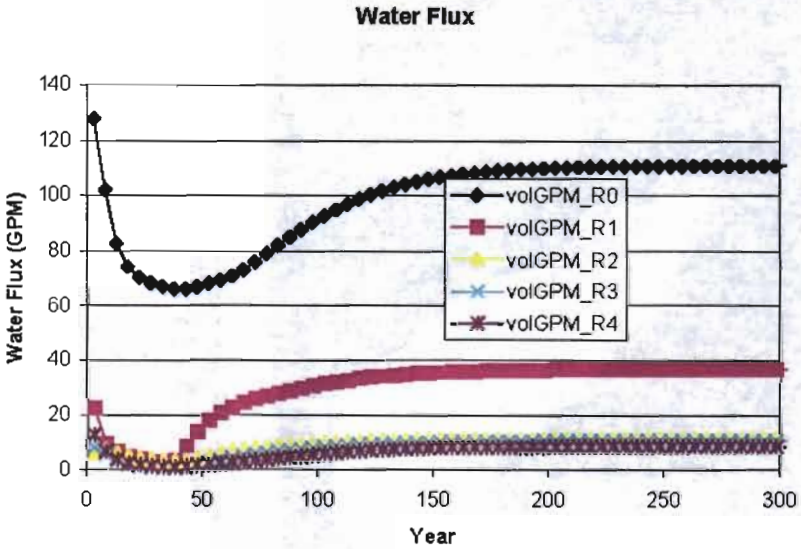

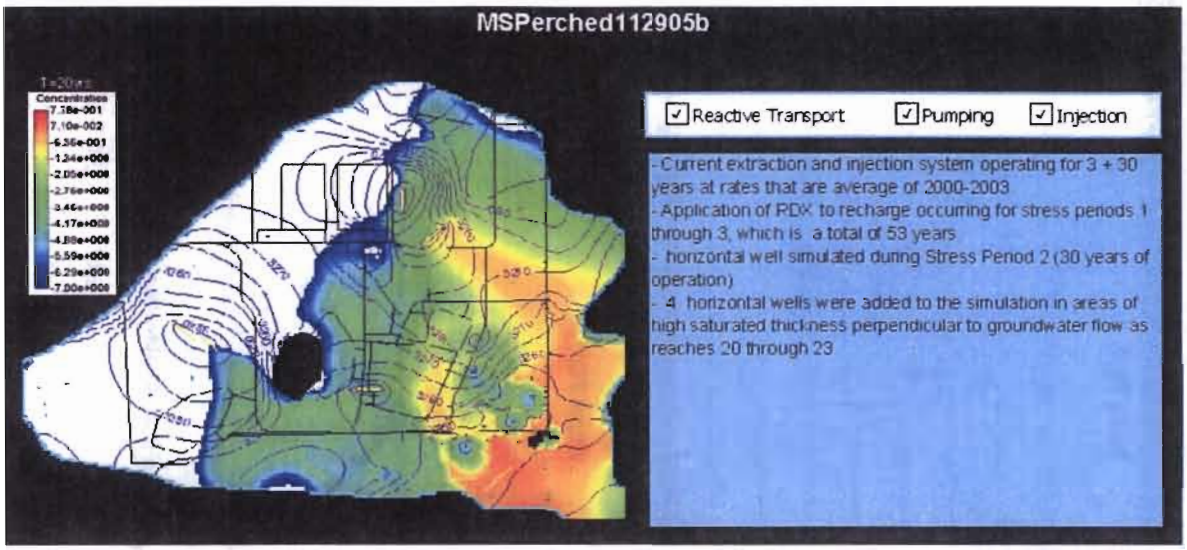

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	922.21	123.06	90.06	61.18	80.16	1276.67
50	1049.42	207.97	126.27	75.87	94.07	1553.60
100	2062.52	831.91	320.28	223.94	180.59	3619.24
150	4456.62	1679.64	578.69	460.01	351.85	7526.80
200	7275.43	2614.49	861.57	730.27	559.27	12041.02
250	10174.07	3569.13	1150.31	1008.60	775.31	16677.42
300	13087.09	4527.53	1440.19	1288.49	993.04	21336.34

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.43	294.25	8.14	54.58	40.09	398.49
50	1.53	333.07	17.37	62.40	45.06	459.42
100	1.54	369.90	52.22	85.01	56.49	565.16
150	1.54	374.32	54.88	89.92	60.15	580.80
200	1.54	375.66	55.19	90.76	60.84	583.99
250	1.54	375.70	55.28	90.93	60.93	584.39
300	1.54	375.71	55.30	90.96	60.94	584.46

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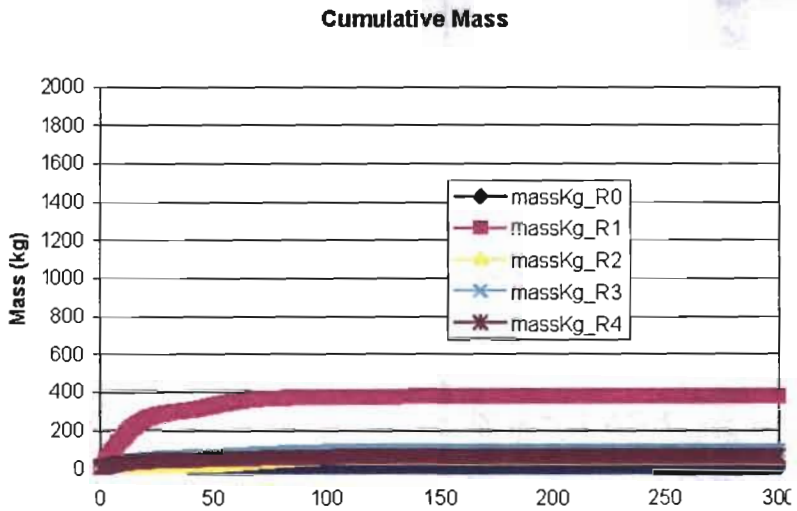
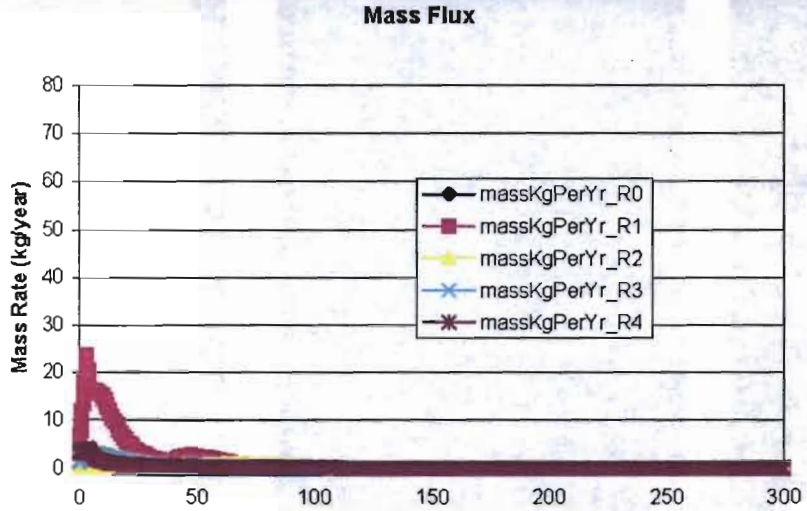
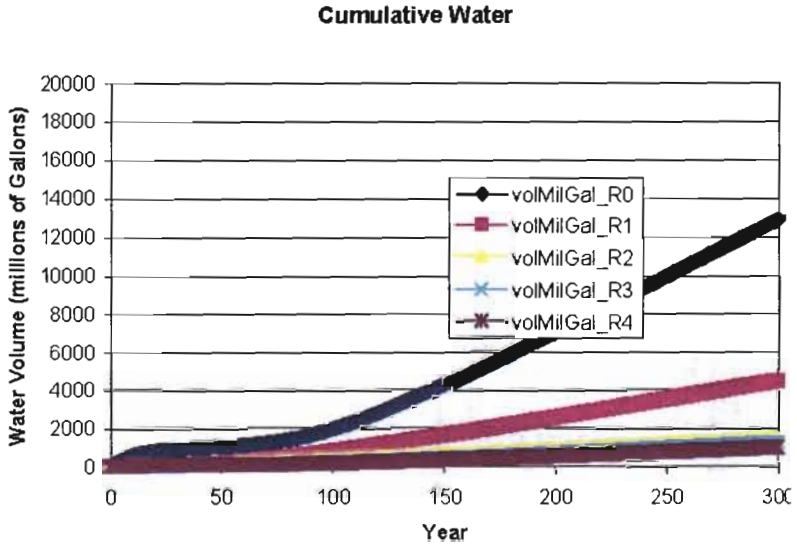
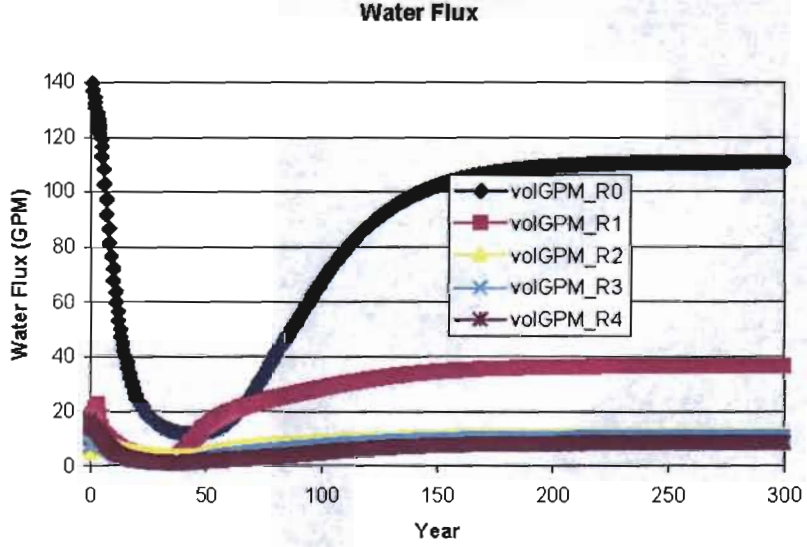
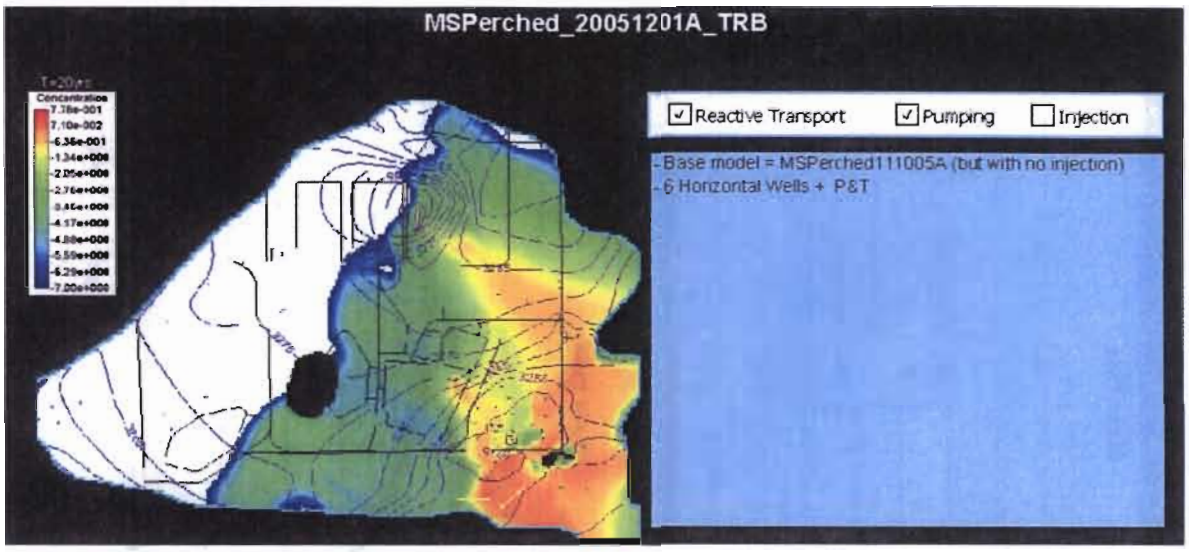








RUN22_MSPerched_20051201a_TRB



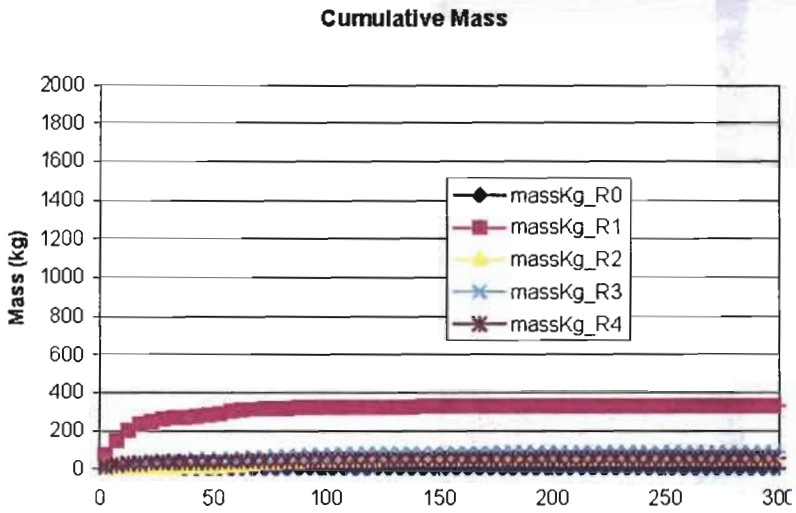
Cumulative Water Across GHB Reaches (millions of gallons)

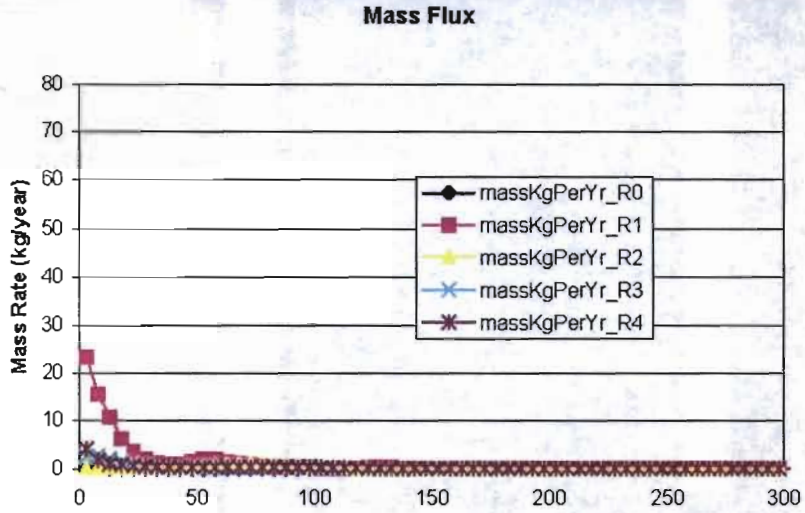
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1496.72	109.32	85.27	50.82	64.17	1806.30
50	2269.22	203.30	116.94	59.38	74.17	2723.02
100	4511.74	920.69	324.66	228.16	180.07	6165.32
150	7231.13	1823.48	597.55	484.01	370.33	10506.49
200	10106.81	2771.55	884.28	759.53	583.20	15105.36
250	13015.40	3728.73	1173.78	1038.91	800.36	19757.18
300	15930.20	4687.59	1463.80	1319.00	1018.30	24418.90

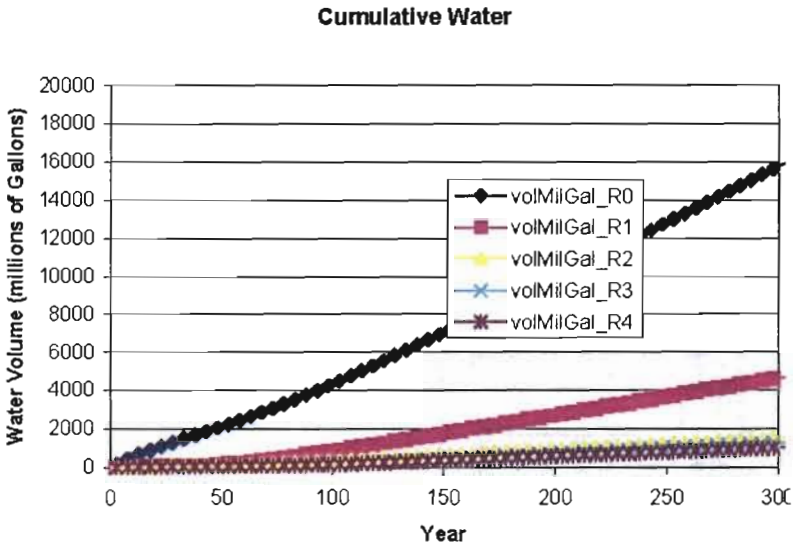
Cumulative Mass Across GHB Reaches (kg)

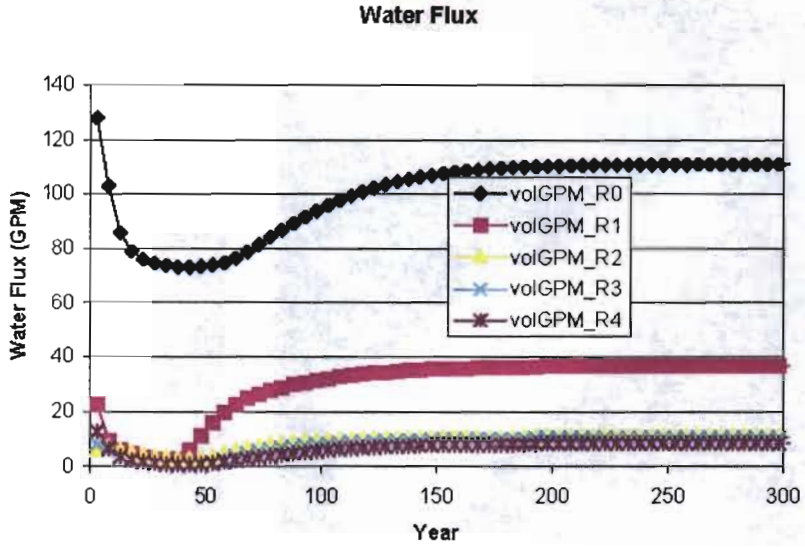
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.64	265.75	8.17	48.76	32.64	356.96
50	1.75	289.99	15.41	53.30	35.79	396.24
100	1.77	321.27	46.46	77.15	46.10	492.74
150	1.77	326.50	51.67	83.89	49.98	513.81
200	1.79	327.57	52.38	84.87	50.59	517.20
250	1.80	327.59	52.47	85.02	50.67	517.56
300	1.81	327.60	52.49	85.05	50.68	517.63

MSPerched_20051201A_TRB

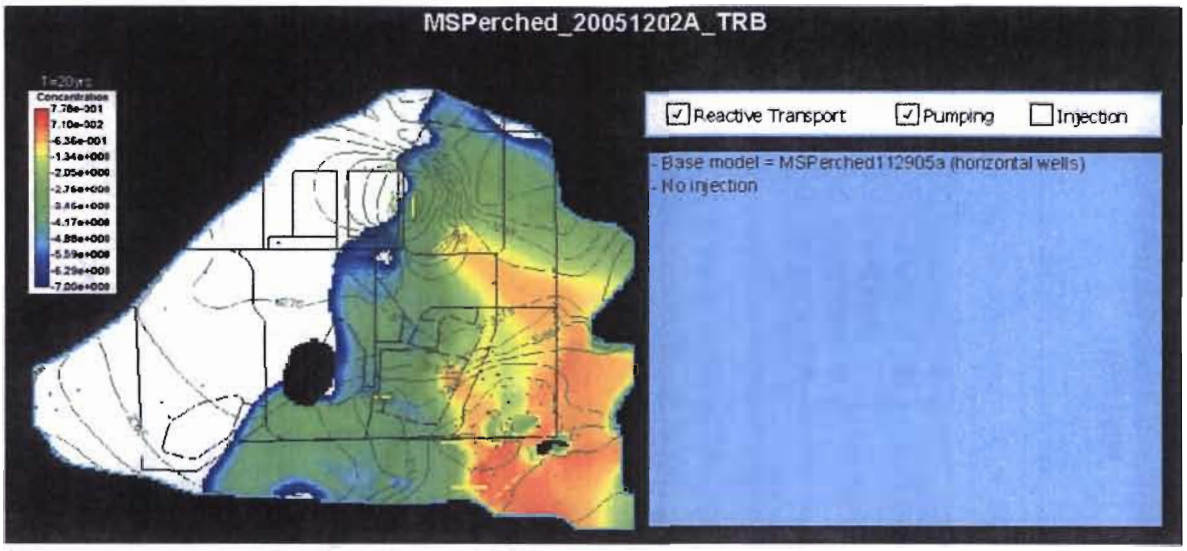








RUN23_MSPerched_20051202a_TRB



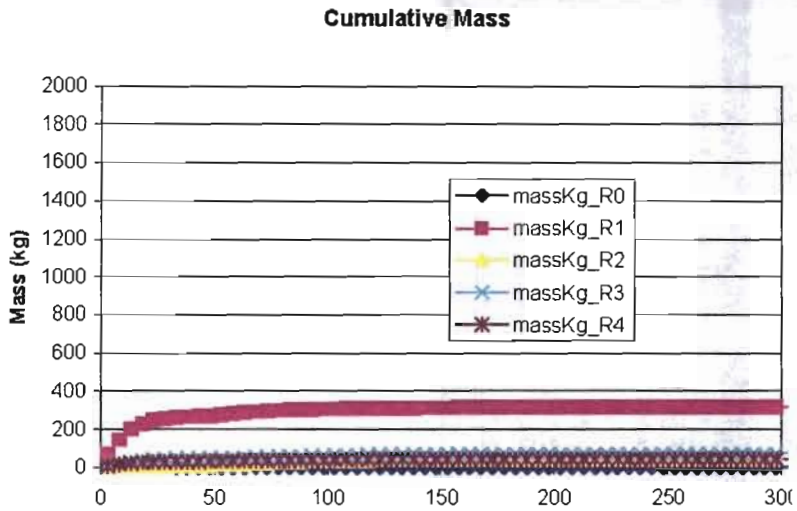
Cumulative Water Across GHB Reaches (millions of gallons)

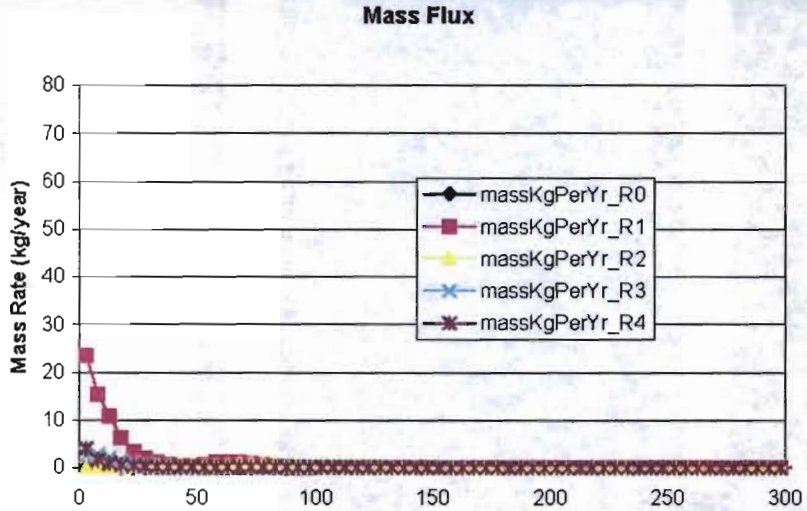
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1419.60	102.15	85.22	50.71	61.53	1719.22
50	2104.86	140.78	114.16	55.85	68.48	2484.13
100	4152.45	739.99	286.39	179.85	142.64	5501.32
150	6799.77	1618.64	551.71	425.28	322.07	9717.46
200	9659.60	2562.26	837.08	698.92	532.89	14290.75
250	12565.20	3518.62	1126.34	977.96	749.69	18937.80
300	15479.47	4477.34	1416.31	1257.99	967.56	23598.68

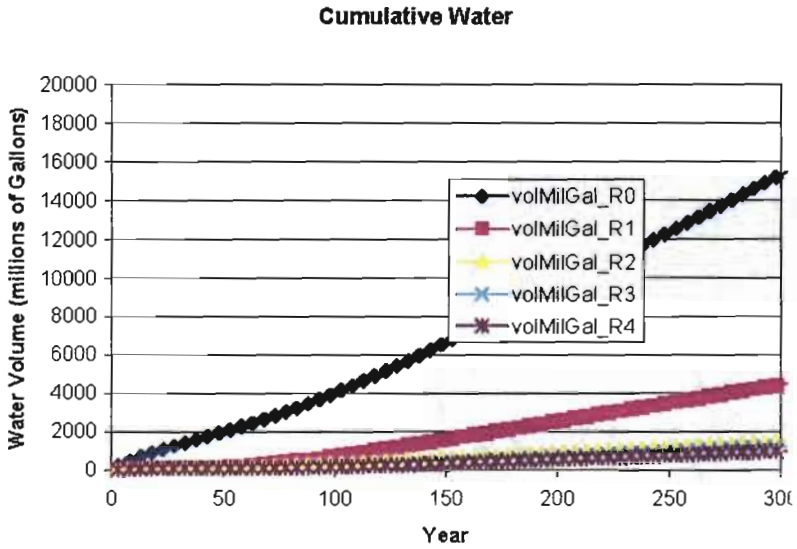
Cumulative Mass Across GHB Reaches (kg)

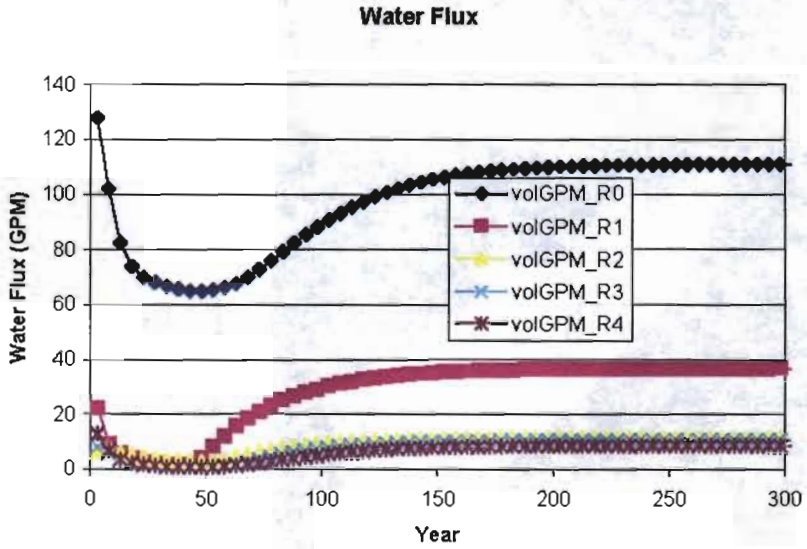
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.34	265.03	8.15	48.66	31.61	354.79
50	1.40	277.08	14.42	52.25	33.97	379.12
100	1.41	308.51	38.31	65.44	39.72	453.40
150	1.41	315.28	43.51	72.76	43.00	475.96
200	1.41	316.66	44.36	73.78	43.60	479.80
250	1.41	316.68	44.46	73.94	43.67	480.17
300	1.41	316.69	44.48	73.97	43.68	480.24

MSPerched_20051202A_TRB

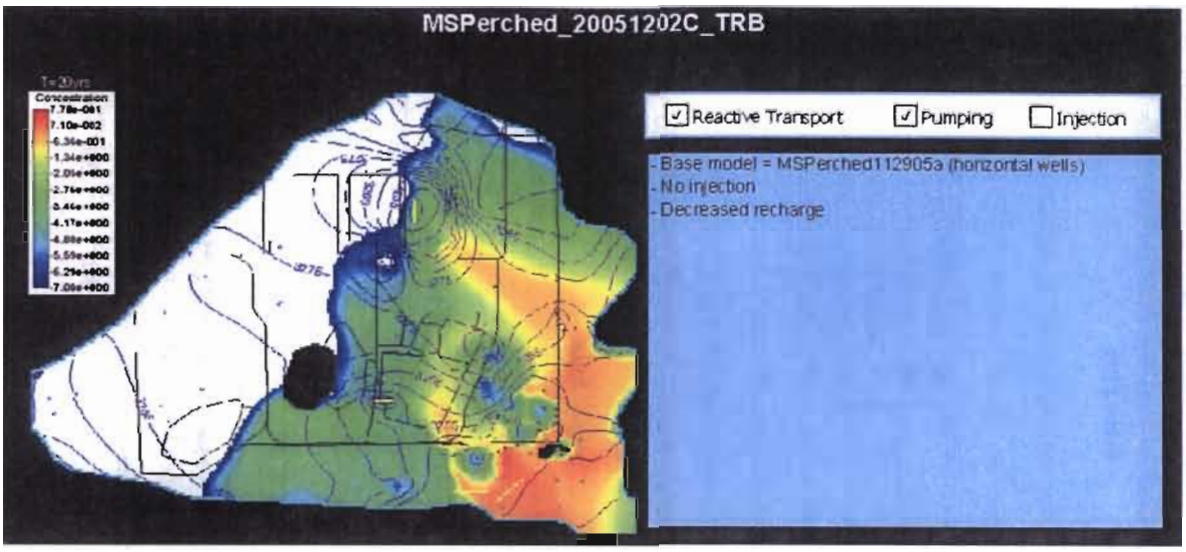








RUN24_MSPerched_20051202c_TRB



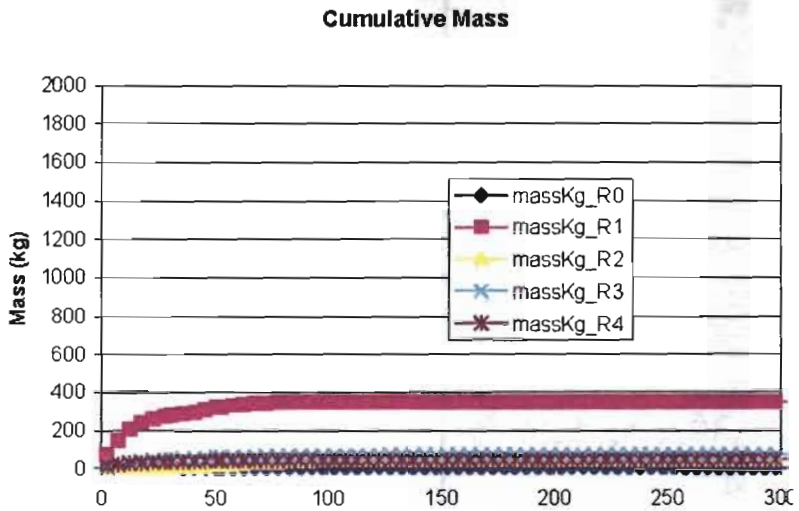
Cumulative Water Across GHB Reaches (millions of gallons)

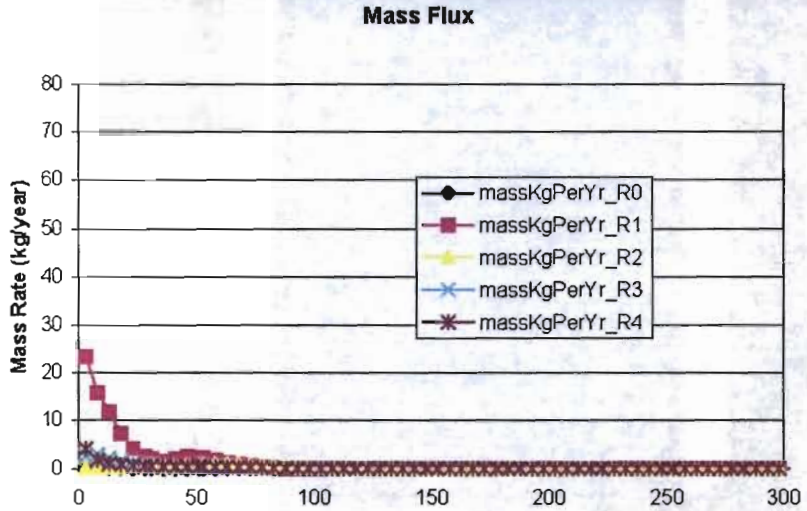
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1052.07	108.56	83.74	51.88	63.60	1359.86
50	1457.97	194.52	124.44	67.84	77.17	1921.93
100	2295.55	616.20	283.86	147.64	112.03	3455.28
150	2996.01	1008.99	433.07	222.45	143.50	4804.03
200	3719.58	1417.97	587.27	304.66	179.43	6208.91
250	4471.24	1843.12	746.18	392.95	218.43	7671.92
300	5162.79	2233.63	891.37	475.12	254.75	9017.65

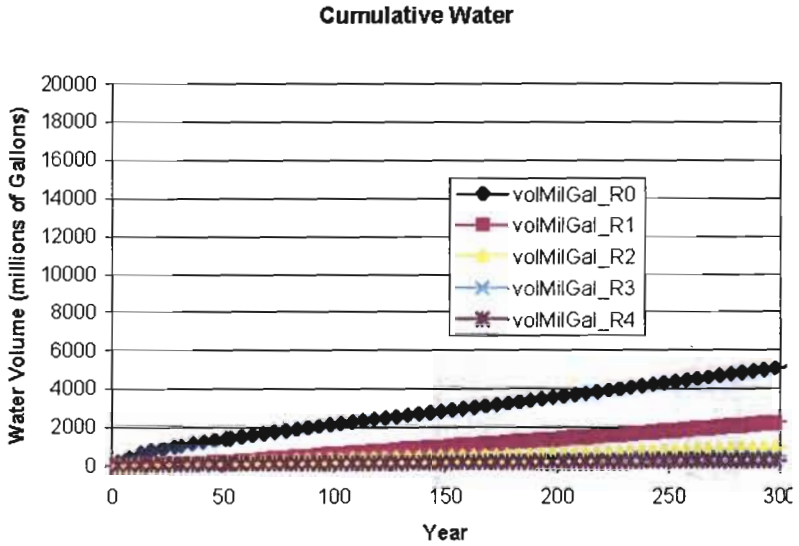
Cumulative Mass Across GHB Reaches (kg)

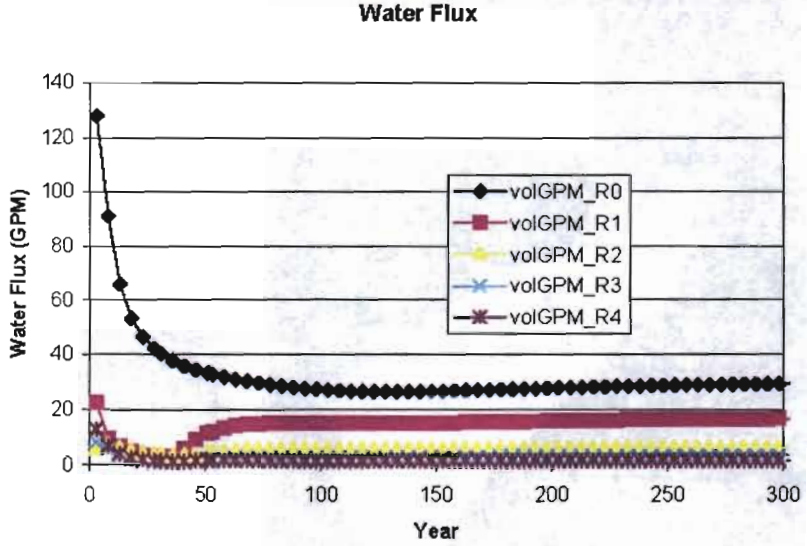
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.32	282.23	8.22	50.28	32.87	374.92
50	1.41	324.48	18.70	58.58	37.67	440.84
100	1.41	349.06	45.68	69.79	42.72	508.67
150	1.41	349.77	47.41	71.51	43.43	513.53
200	1.41	349.87	47.60	71.75	43.52	514.15
250	1.41	349.90	47.63	71.79	43.53	514.28
300	1.41	349.91	47.64	71.80	43.54	514.30

MSPerched_20051202C_TRB

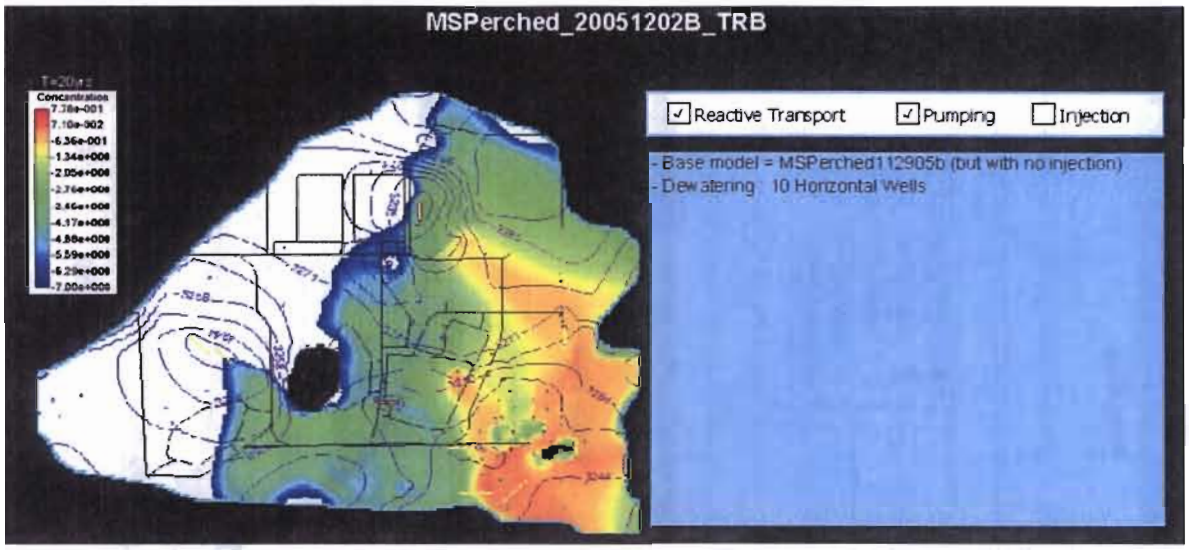








RUN25_MSPerched_20051202b_TRB



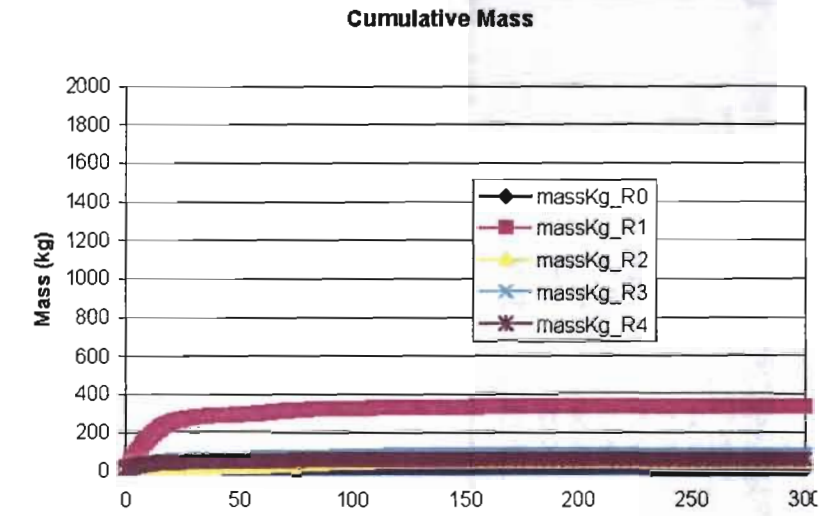
Cumulative Water Across GHB Reaches (millions of gallons)

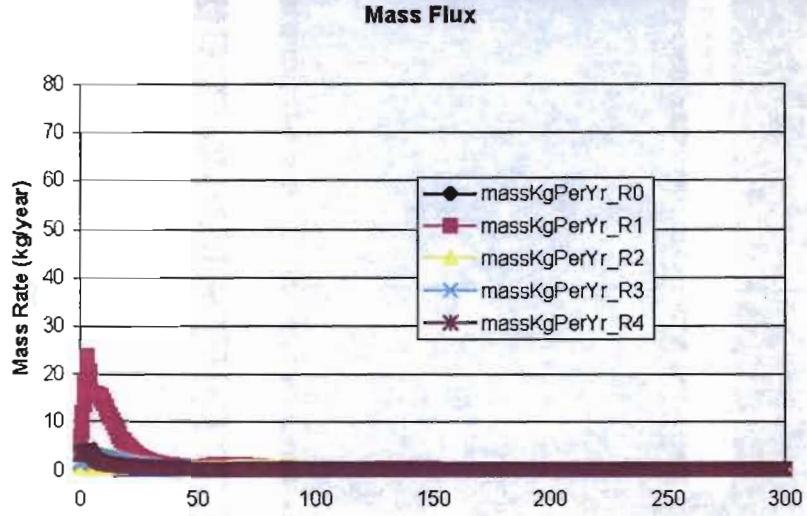
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	920.75	114.01	88.36	59.32	76.48	1258.92
50	1041.34	137.83	117.73	64.54	83.50	1444.94
100	1990.46	640.15	270.39	166.10	145.30	3212.39
150	4342.40	1471.50	523.56	395.32	310.48	7043.27
200	7151.68	2403.71	805.64	664.49	516.76	11542.28
250	10048.54	3357.88	1094.24	942.63	732.59	16175.89
300	12961.25	4316.19	1384.09	1222.49	950.29	20834.31

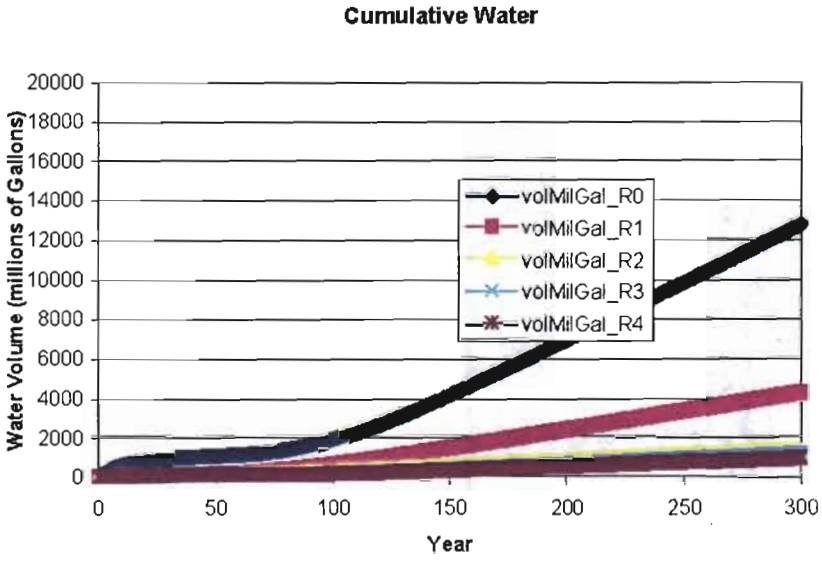
Cumulative Mass Across GHB Reaches (kg)

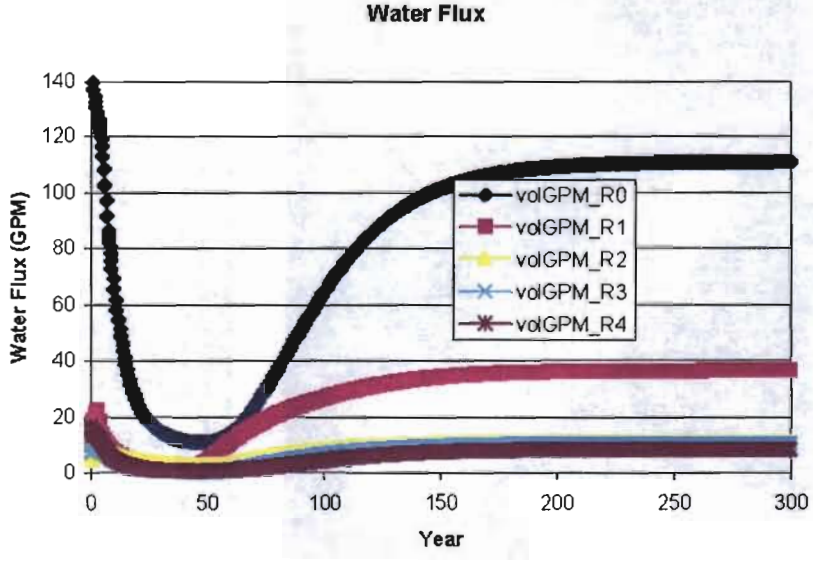
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.36	275.50	7.34	52.34	38.14	374.68
50	1.44	287.20	13.70	56.52	40.74	399.60
100	1.45	318.28	35.79	67.30	45.88	468.70
150	1.45	325.42	41.47	74.91	49.03	492.29
200	1.45	327.22	42.42	76.04	49.65	496.78
250	1.45	327.26	42.54	76.22	49.73	497.20
300	1.45	327.26	42.56	76.25	49.74	497.27

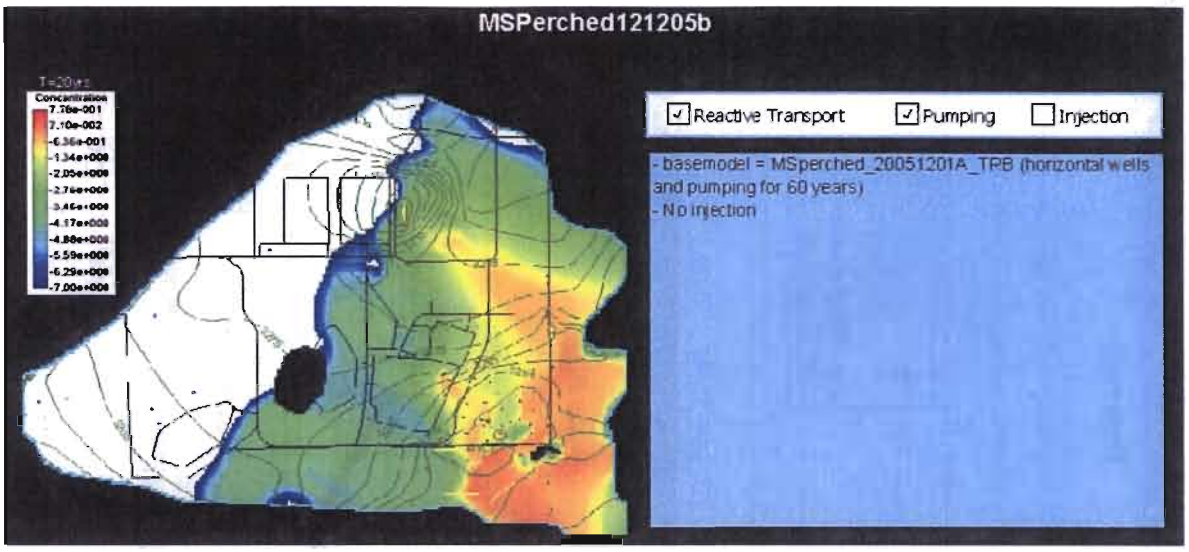
MSPerched_20051202B_TRB











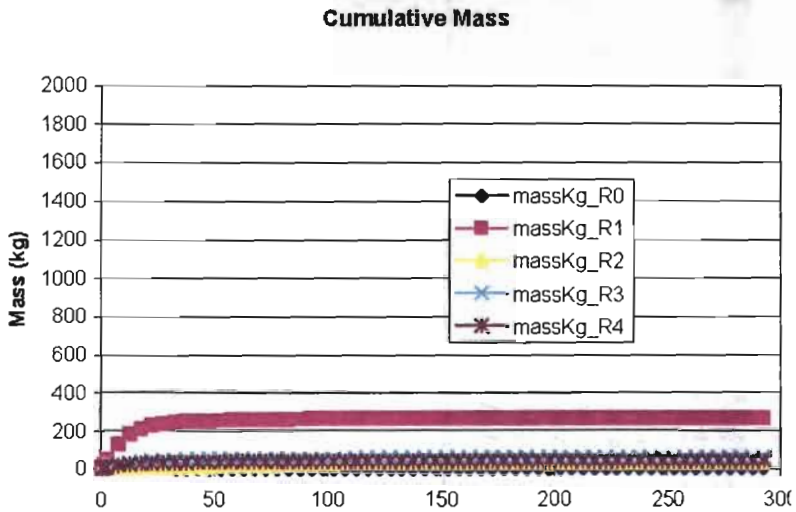
Cumulative Water Across GHB Reaches (millions of gallons)

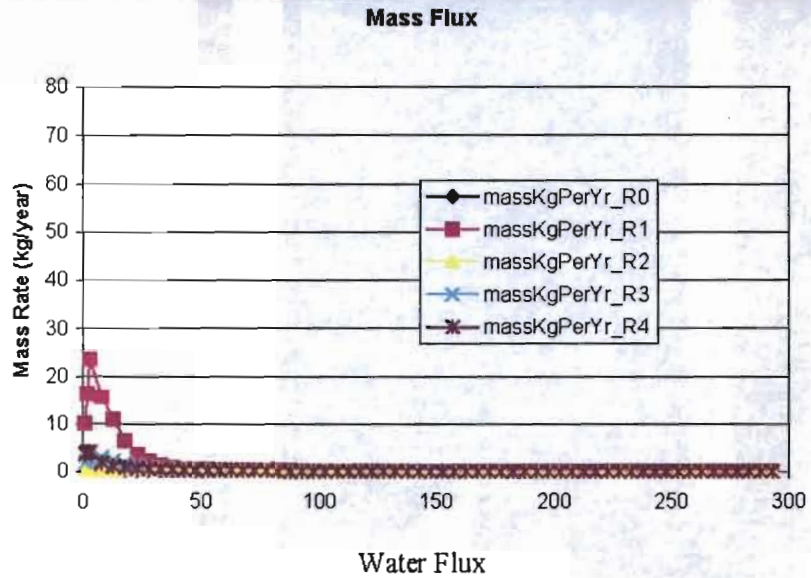
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1505.23	105.93	84.84	50.53	65.29	1811.82
50	2260.79	123.48	113.51	55.40	72.54	2625.72
100	4134.35	418.71	209.21	95.24	99.96	4957.48
150	6540.62	1213.44	447.29	301.60	236.92	8739.88
200	9330.35	2136.80	726.46	566.51	437.85	13197.97
250	12221.78	3089.26	1014.53	843.90	652.82	17822.29
300	15133.37	4047.26	1304.28	1123.63	870.36	22478.90

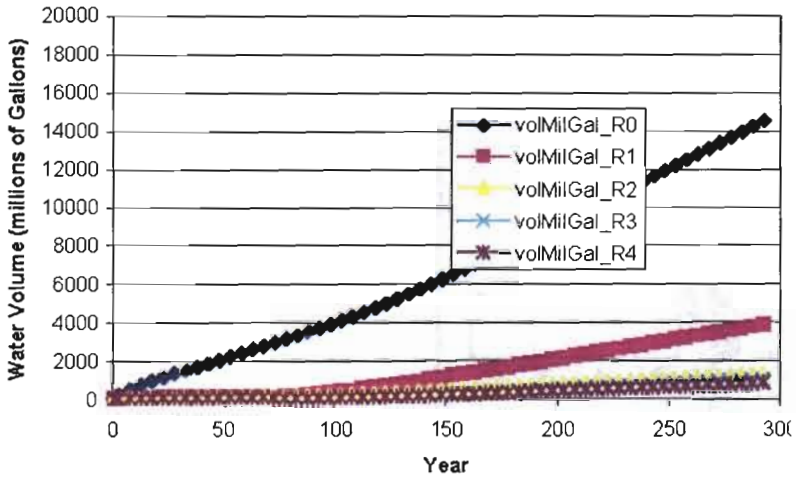
Cumulative Mass Across GHB Reaches (kg)

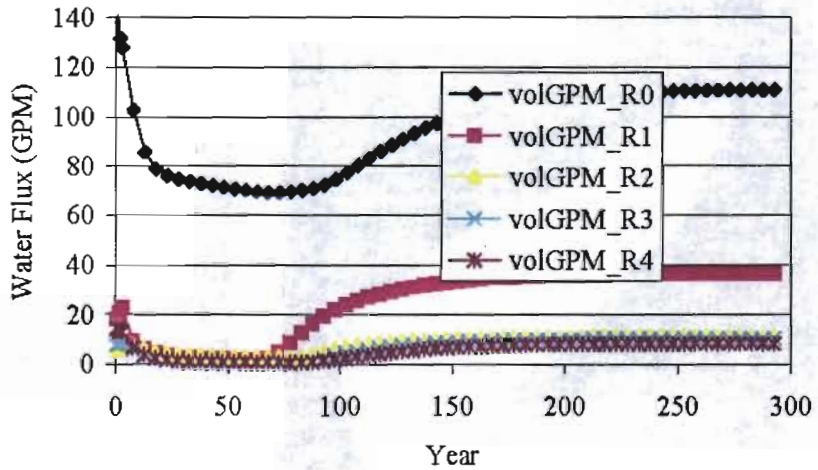
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1.64	245.96	8.14	47.52	31.95	335.22
50	1.75	255.20	14.32	51.07	34.54	356.86
100	1.76	263.47	26.18	53.38	36.74	381.52
150	1.76	265.12	30.48	57.26	38.54	393.15
200	1.77	265.53	31.22	58.18	38.98	395.69
250	1.79	265.54	31.31	58.31	39.03	395.99
300	1.80	265.55	31.32	58.33	39.04	396.03

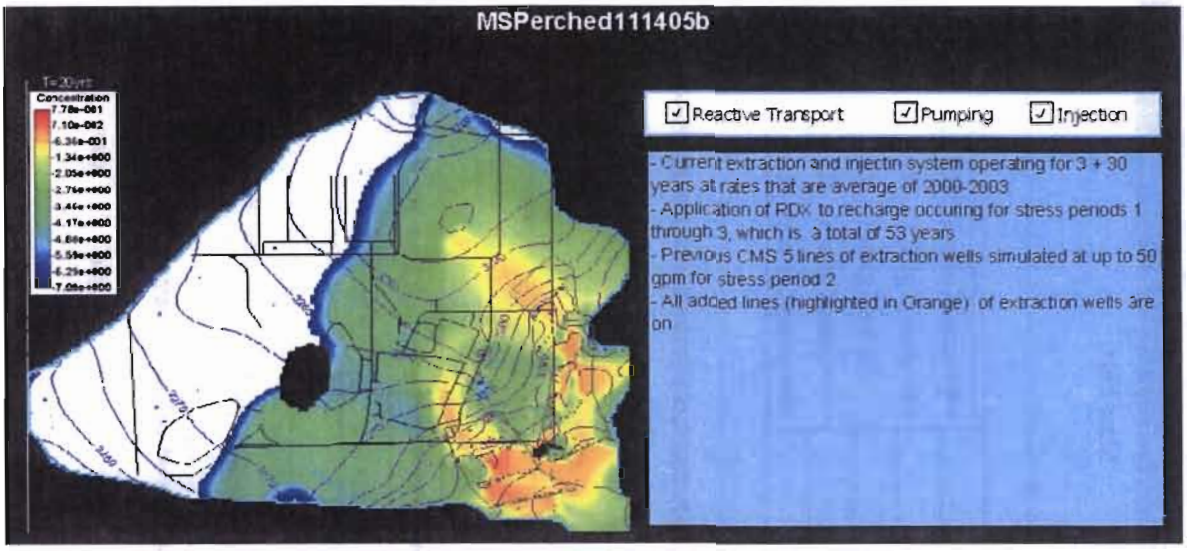
MSPerched121205b











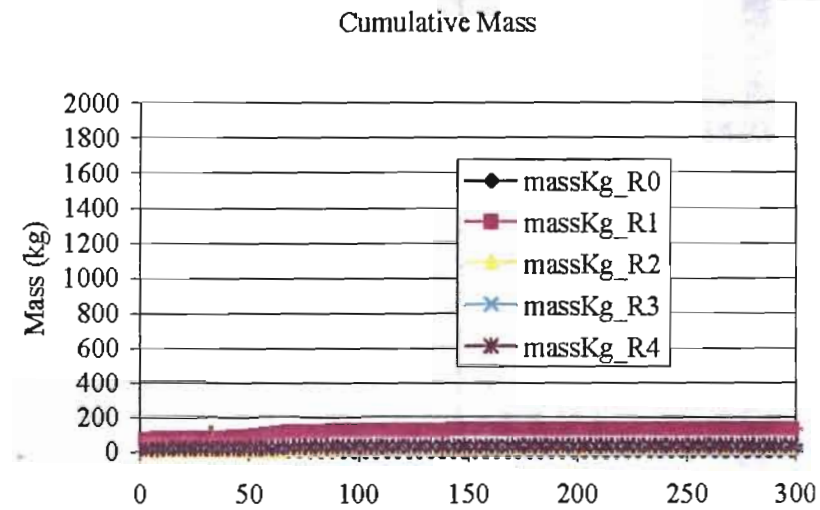
Cumulative Water Across GHB Reaches (millions of gallons)

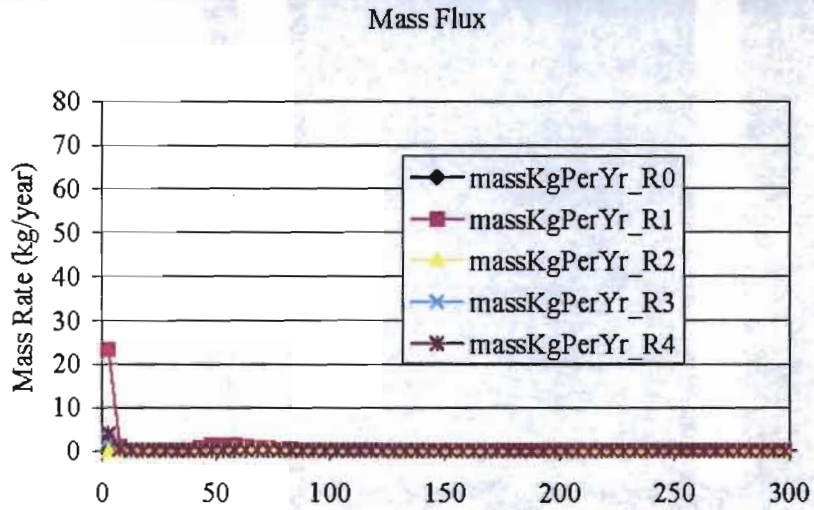
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1906.23	84.15	45.00	15.28	32.34	2083.00
50	3048.66	300.78	84.30	46.39	57.95	3538.08
100	5945.04	1215.83	354.97	303.58	257.22	8076.64
150	8854.83	2172.20	644.14	582.55	474.02	12727.75
200	11769.68	3131.04	934.15	862.62	691.95	17389.45
250	14685.55	4090.20	1224.26	1142.83	910.02	22052.87
300	17601.64	5049.41	1514.39	1423.07	1128.12	26716.63

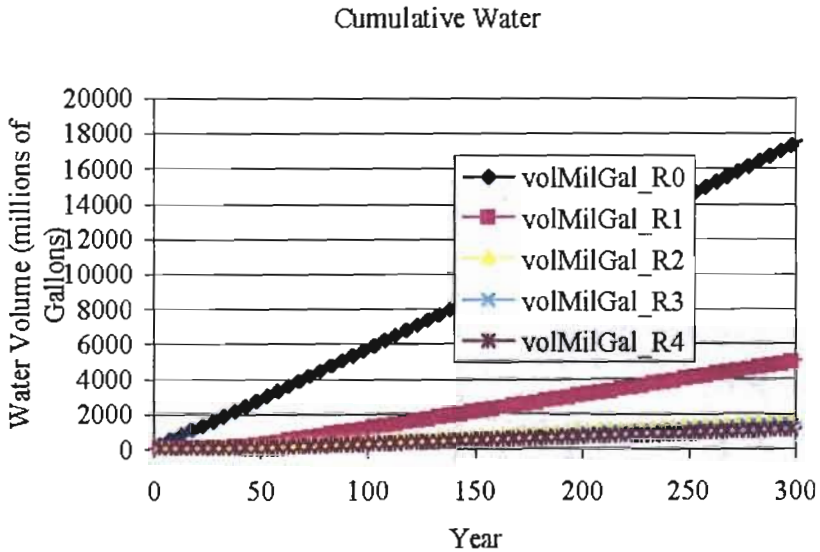
Cumulative Mass Across GHB Reaches (kg)

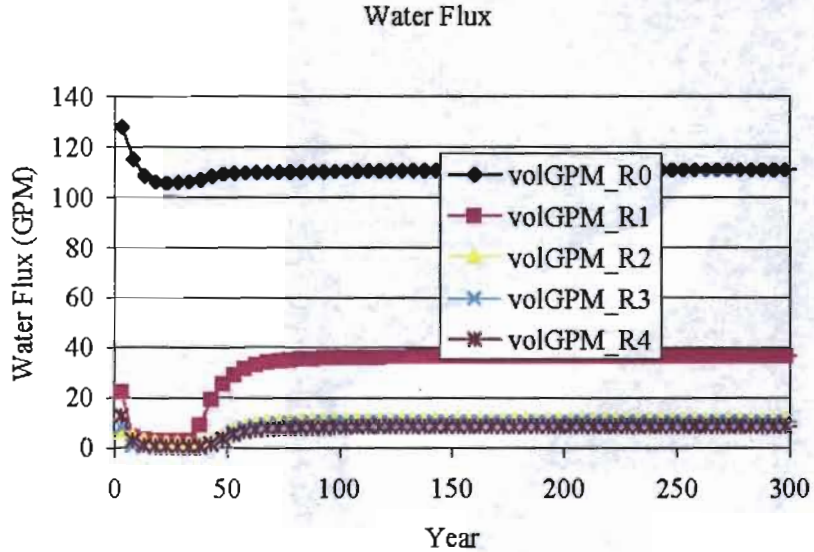
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.69	76.62	0.16	10.30	17.01	104.79
50	0.75	94.40	1.62	12.59	18.90	128.27
100	0.80	120.88	15.25	17.76	27.68	182.38
150	0.81	125.49	15.55	18.40	29.44	189.69
200	0.82	126.31	15.79	18.92	29.91	191.74
250	0.82	126.33	15.86	19.06	30.00	192.07
300	0.82	126.34	15.88	19.10	30.02	192.14

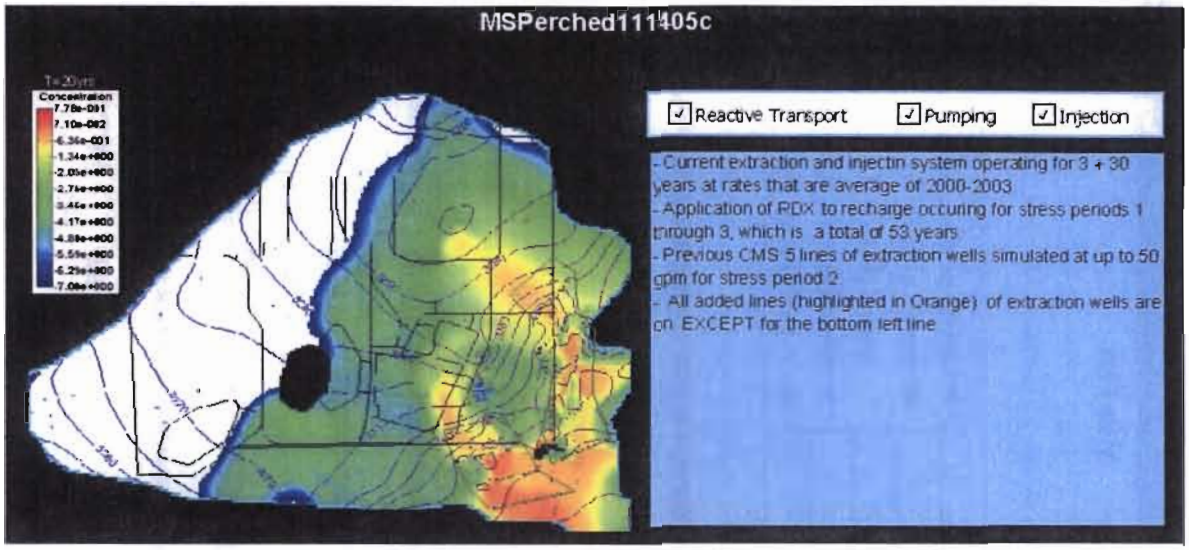
MSPerched111405b











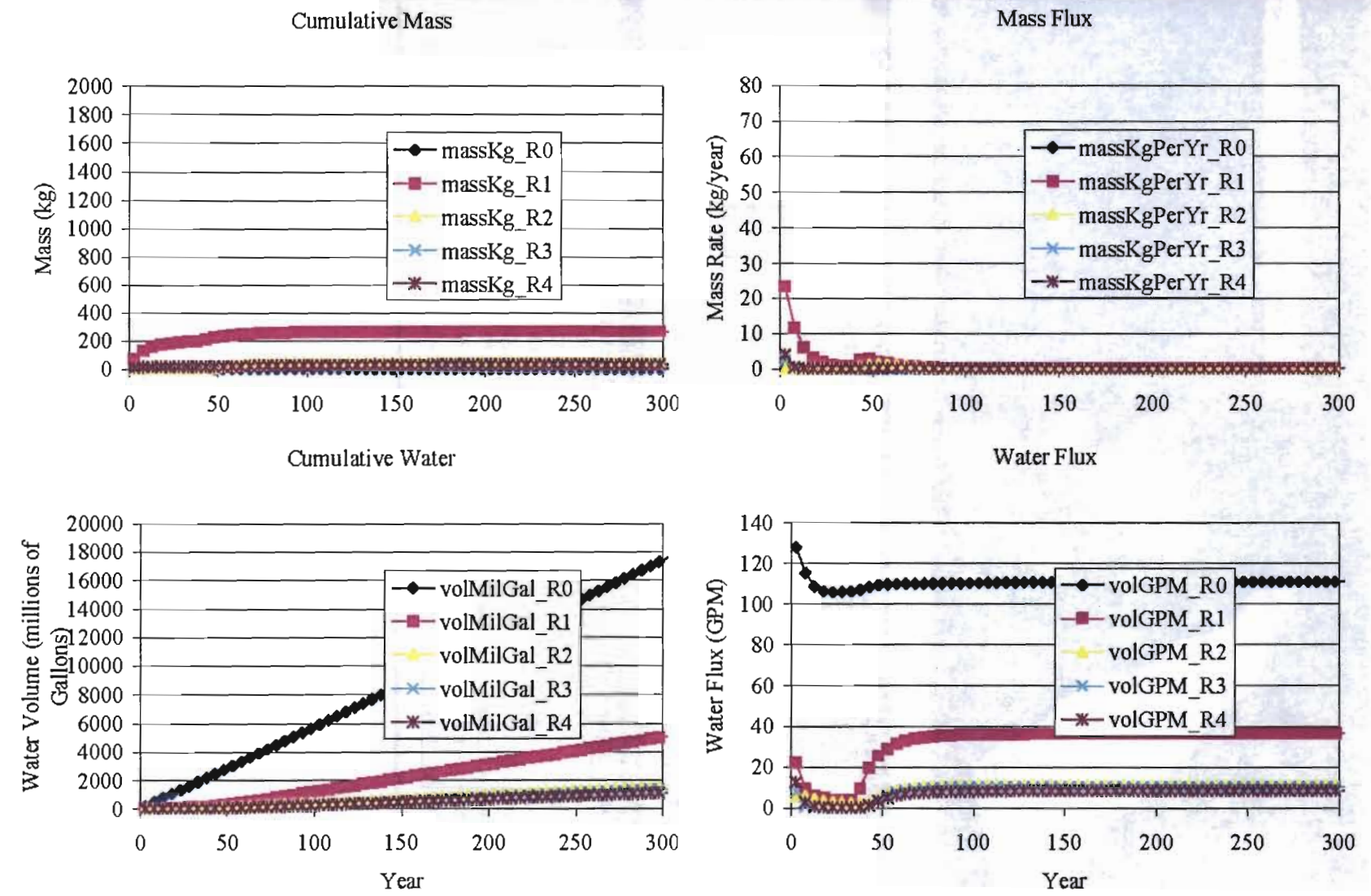
Cumulative Water Across GHB Reaches (millions of gallons)

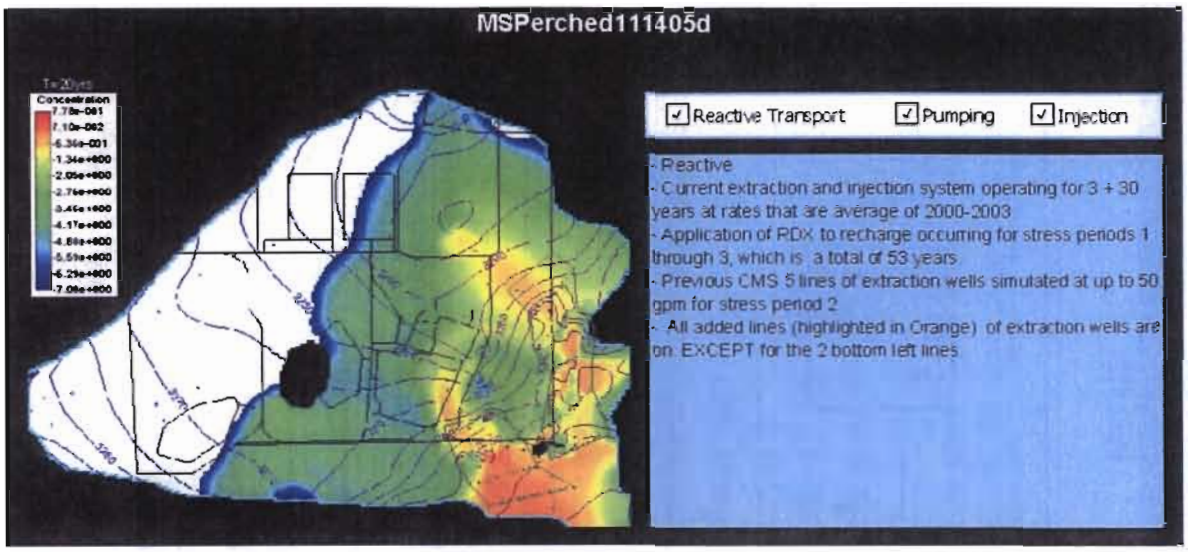
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1906.24	118.05	67.11	17.63	32.34	2141.37
50	3048.69	339.51	112.37	49.93	57.96	3608.45
100	5945.13	1254.93	383.34	307.33	257.28	8148.01
150	8854.94	2211.31	672.51	586.30	474.09	12799.15
200	11769.80	3170.16	962.52	866.37	692.02	17460.86
250	14685.66	4129.31	1252.63	1146.58	910.09	22124.27
300	17601.73	5088.52	1542.75	1426.82	1128.19	26788.01

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.69	191.67	4.07	11.18	17.01	224.62
50	0.75	231.85	17.62	14.12	18.90	283.25
100	0.80	259.37	40.27	19.66	27.68	347.79
150	0.81	263.98	40.58	20.30	29.45	355.11
200	0.82	264.80	40.82	20.82	29.91	357.16
250	0.82	264.82	40.89	20.96	30.01	357.49
300	0.82	264.82	40.90	21.00	30.02	357.56

MSPerched111405c





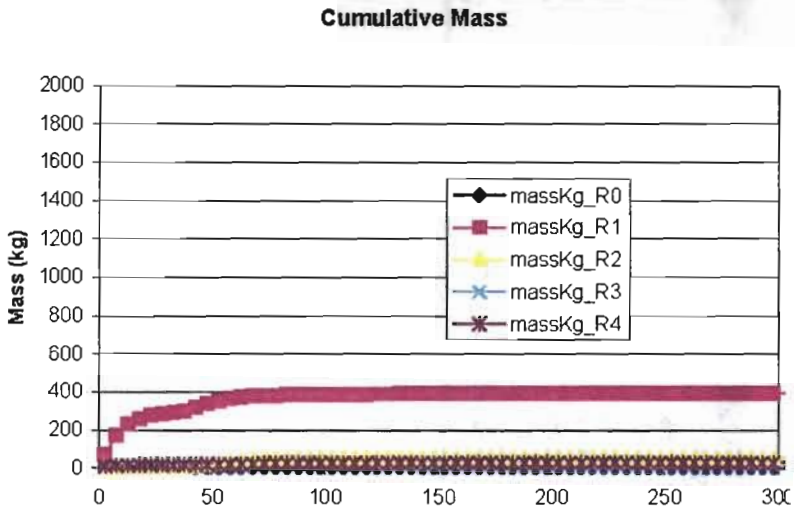
Cumulative Water Across GHB Reaches (millions of gallons)

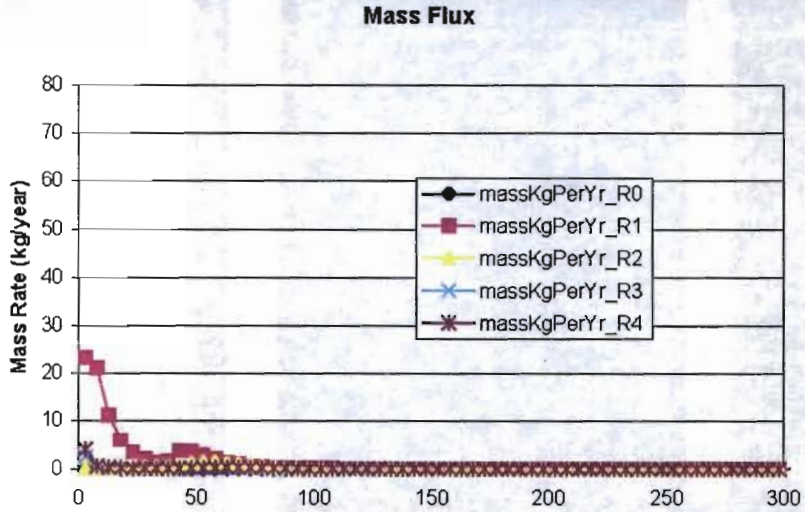
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1907.63	150.82	72.48	18.58	32.34	2181.84
50	3050.72	377.56	119.66	51.55	58.03	3657.52
100	5947.67	1293.59	390.93	309.24	257.51	8198.94
150	8857.60	2250.00	680.12	588.22	474.34	12850.28
200	11772.48	3208.85	970.13	868.30	692.27	17512.03
250	14688.35	4168.01	1260.24	1148.51	910.34	22175.45
300	17604.44	5127.22	1550.36	1428.75	1128.44	26839.21

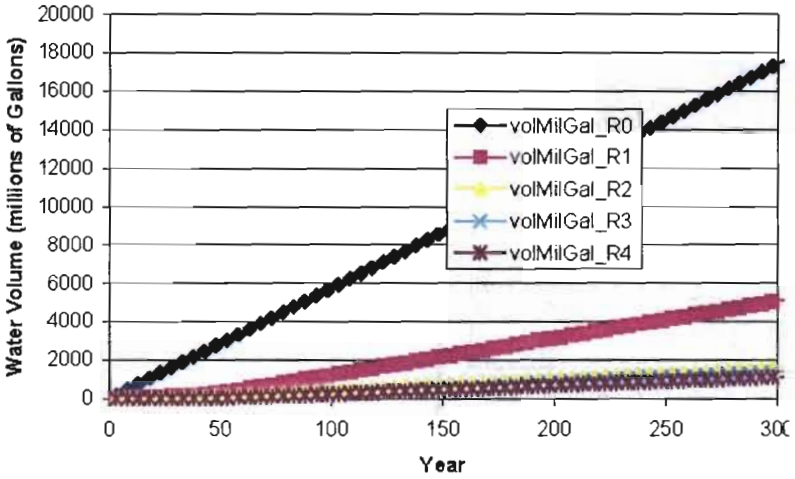
Cumulative Mass Across GHB Reaches (kg)

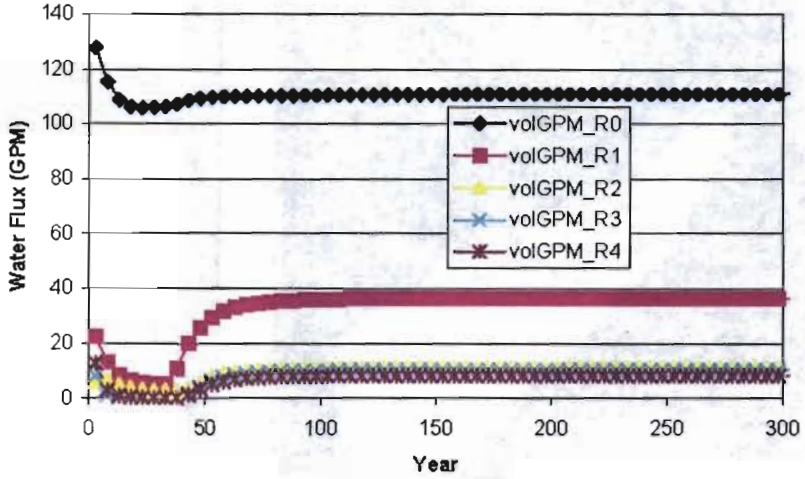
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.69	297.02	6.97	11.56	17.01	333.25
50	0.75	358.08	23.60	14.80	18.91	416.14
100	0.80	390.88	51.16	20.53	27.70	491.07
150	0.81	395.49	51.47	21.17	29.46	498.40
200	0.82	396.31	51.71	21.69	29.93	500.46
250	0.82	396.33	51.78	21.83	30.03	500.79
300	0.82	396.34	51.80	21.87	30.04	500.86

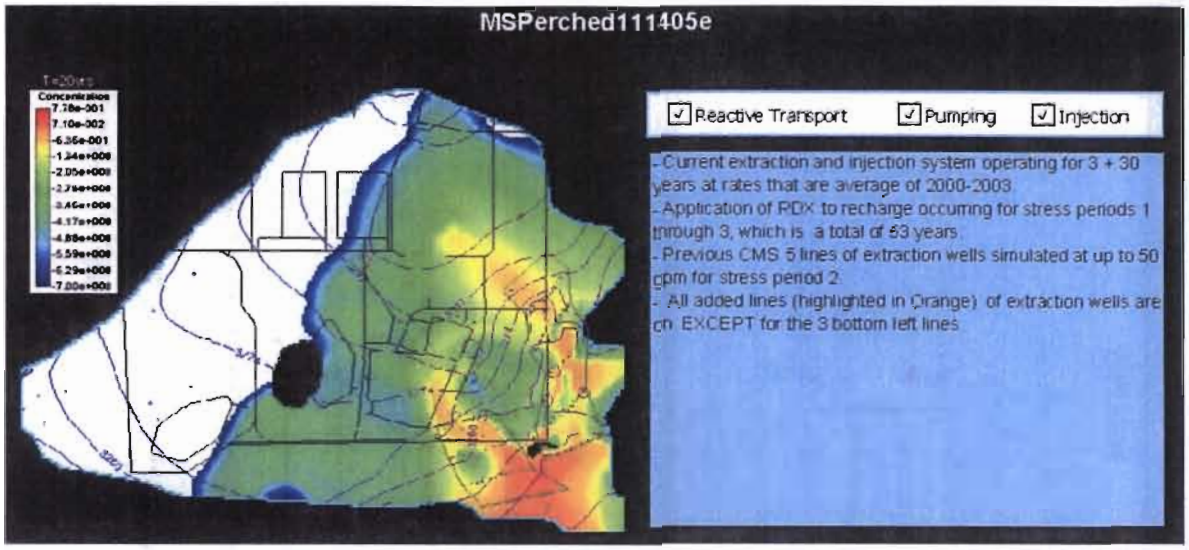
MSPerched111405d











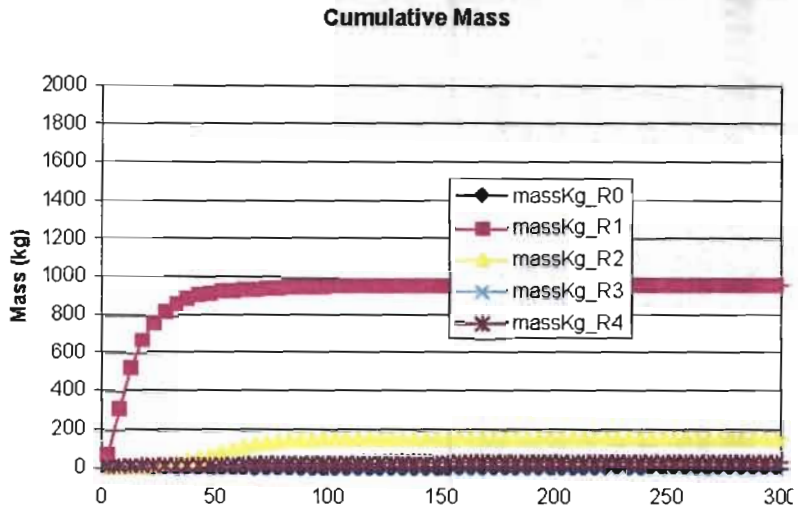
Cumulative Water Across GHB Reaches (millions of gallons)

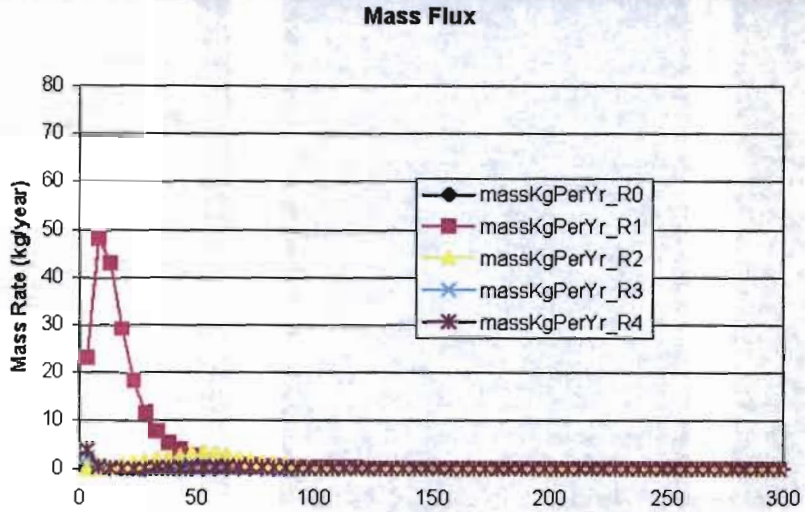
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1963.99	427.10	97.96	23.48	32.34	2544.88
50	3142.42	740.89	172.67	74.93	63.00	4193.91
100	6070.47	1679.35	452.87	342.86	270.06	8815.61
150	8987.01	2637.86	742.72	622.74	487.82	13478.15
200	11903.09	3597.04	1032.83	902.96	705.90	18141.82
250	14819.18	4556.25	1322.96	1183.20	924.00	22805.58
300	17735.30	5515.47	1613.09	1463.43	1142.10	27469.40

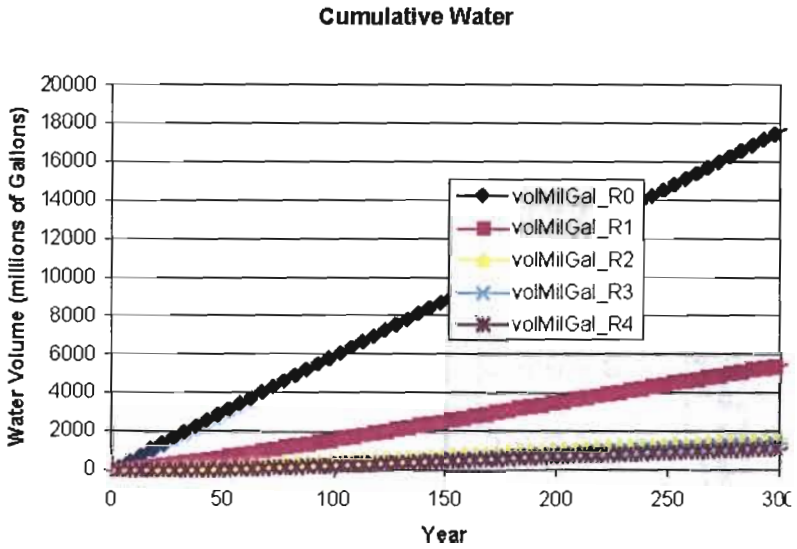
Cumulative Mass Across GHB Reaches (kg)

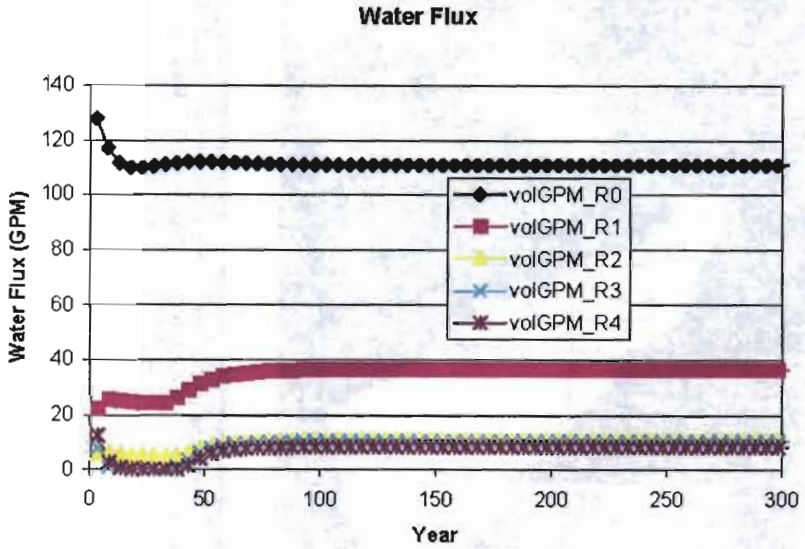
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.72	865.68	30.80	13.28	17.02	927.49
50	0.78	933.24	86.35	24.04	19.33	1063.74
100	0.84	959.88	151.90	34.46	28.65	1175.73
150	0.85	964.94	152.42	35.04	30.42	1183.67
200	0.85	965.88	152.66	35.57	30.93	1185.89
250	0.85	965.91	152.73	35.72	31.03	1186.25
300	0.85	965.91	152.75	35.76	31.05	1186.33

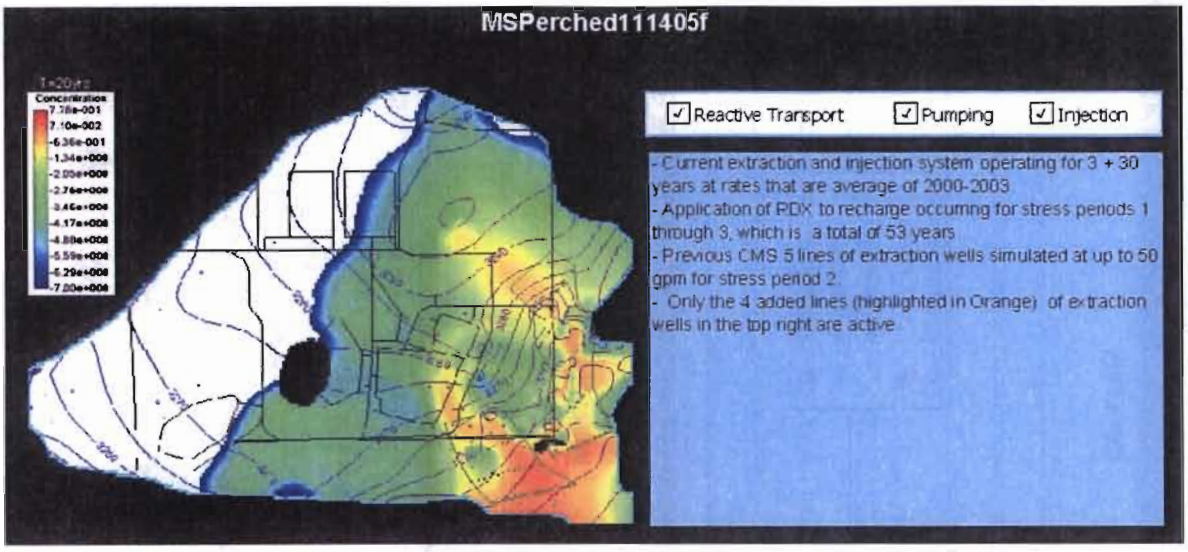
MSPerched111405e











Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1964.21	442.84	111.08	49.87	32.35	2600.34
50	3142.78	759.25	188.38	103.74	63.05	4257.21
100	6071.03	1698.04	468.77	371.85	270.20	8879.88
150	8987.61	2656.57	758.62	651.74	487.97	13542.51
200	11903.71	3615.75	1048.74	931.96	706.05	18206.21
250	14819.81	4574.96	1338.86	1212.19	924.15	22869.97
300	17735.92	5534.19	1628.99	1492.43	1142.25	27533.78

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.72	918.29	32.59	44.41	17.02	1013.01
50	0.78	993.07	85.50	66.76	19.33	1165.46
100	0.84	1020.35	150.78	78.63	28.66	1279.26
150	0.85	1025.41	151.32	79.21	30.44	1287.22
200	0.85	1026.35	151.56	79.74	30.94	1289.45
250	0.85	1026.38	151.64	79.89	31.05	1289.81
300	0.85	1026.38	151.65	79.93	31.07	1289.89

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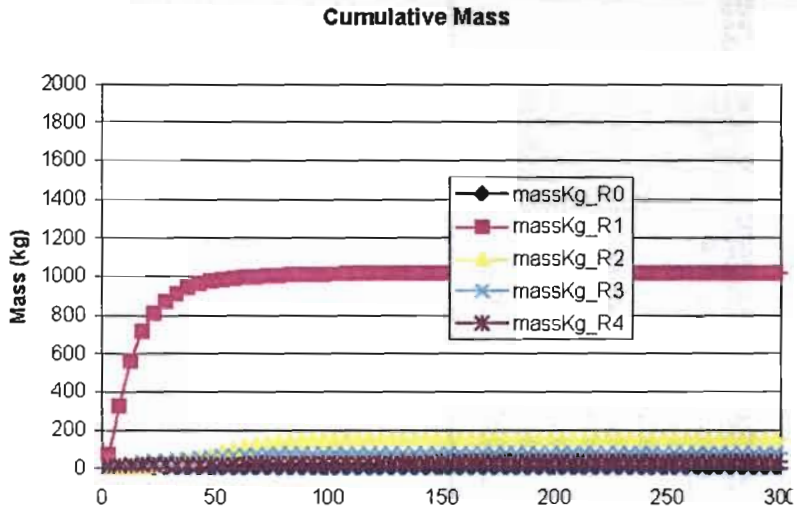

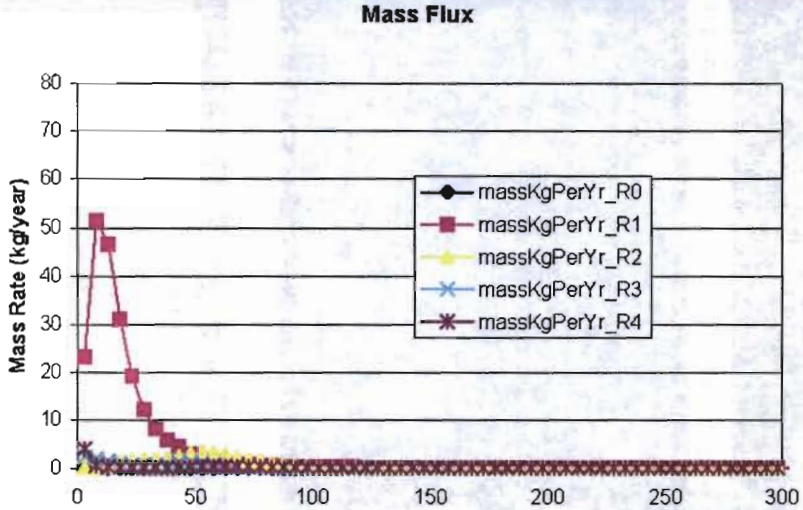

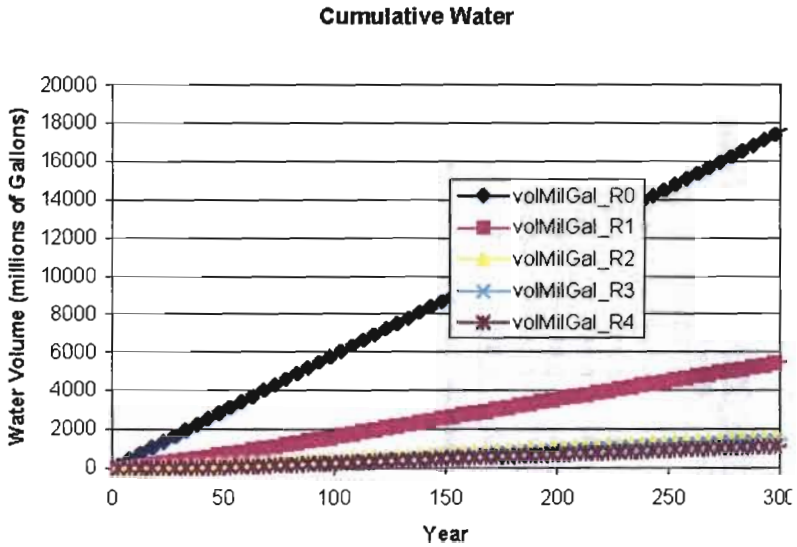

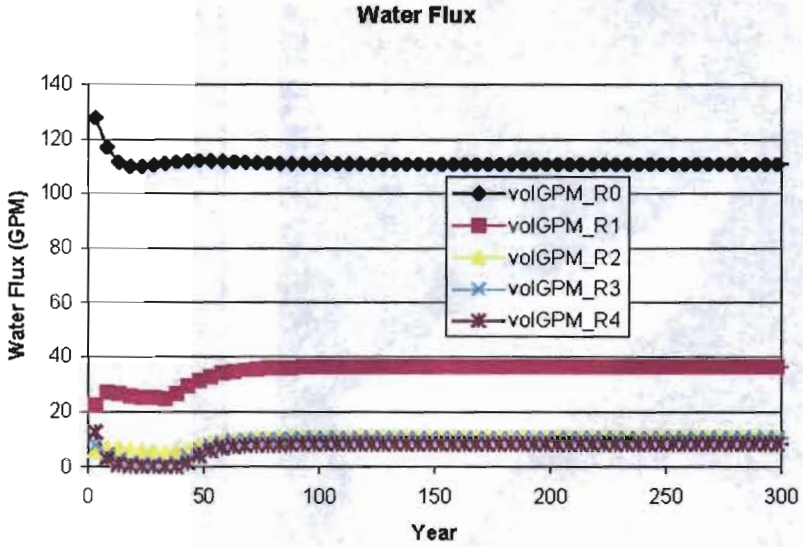

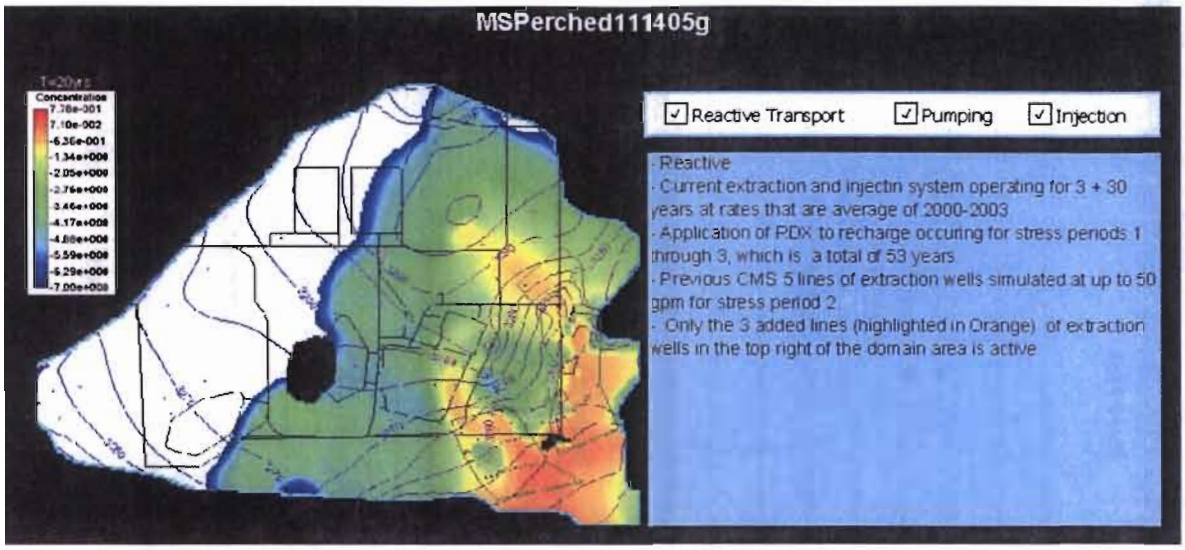

Cumulative Water Across GHB Reaches (millions of gallons)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1966.60	466.37	122.12	72.84	42.57	2670.49
50	3147.79	794.16	205.90	135.64	78.02	4361.51
100	6079.77	1736.92	488.02	405.82	286.83	8997.36
150	8997.31	2695.78	777.98	685.86	504.75	13661.69
200	11913.66	3655.01	1068.11	966.10	722.86	18325.75
250	14829.79	4614.24	1358.24	1246.34	940.96	22989.56
300	17745.91	5573.46	1648.37	1526.58	1159.06	27653.39

Cumulative Mass Across GHB Reaches (kg)

Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.72	983.75	38.40	78.03	21.09	1121.99
50	0.78	1075.46	96.82	115.61	25.92	1314.60
100	0.84	1104.91	164.40	137.52	39.62	1447.29
150	0.85	1110.00	165.18	138.11	41.42	1455.56
200	0.86	1110.97	165.42	138.64	41.93	1457.83
250	0.86	1111.00	165.50	138.80	42.04	1458.19
300	0.86	1111.01	165.51	138.84	42.06	1458.28

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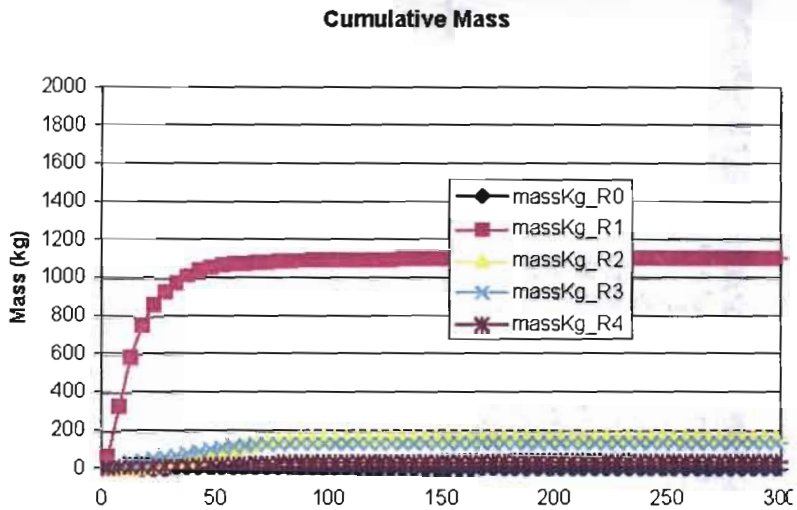
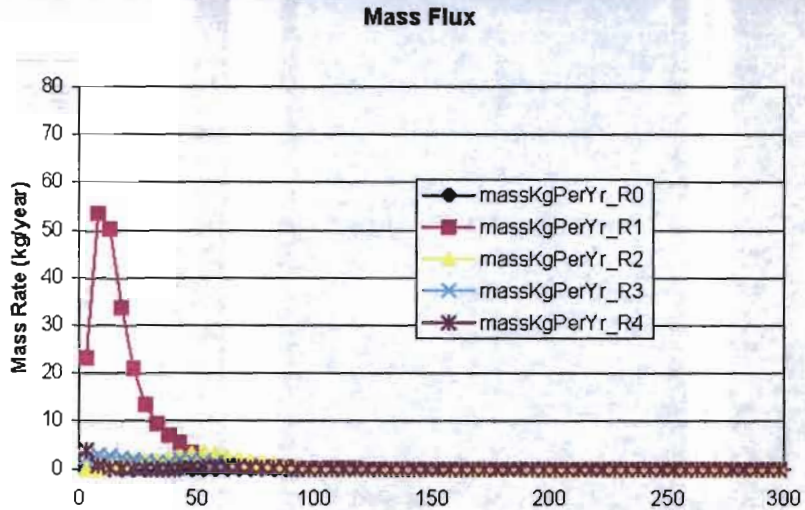
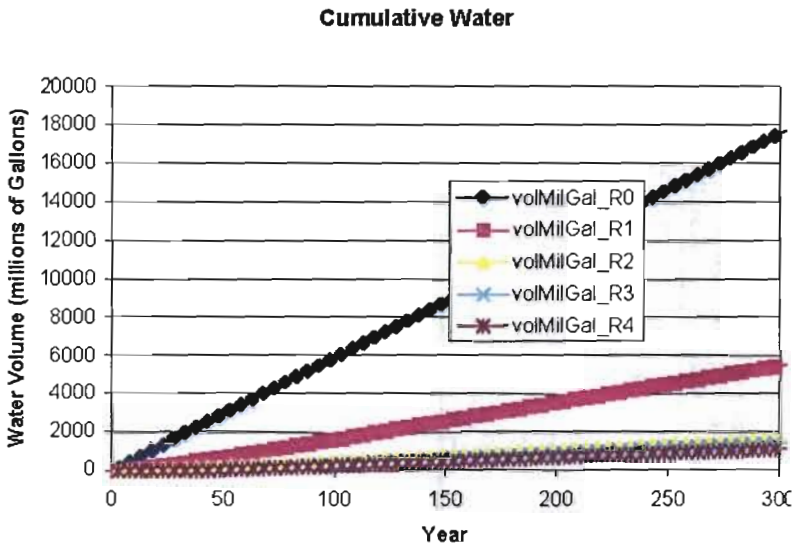
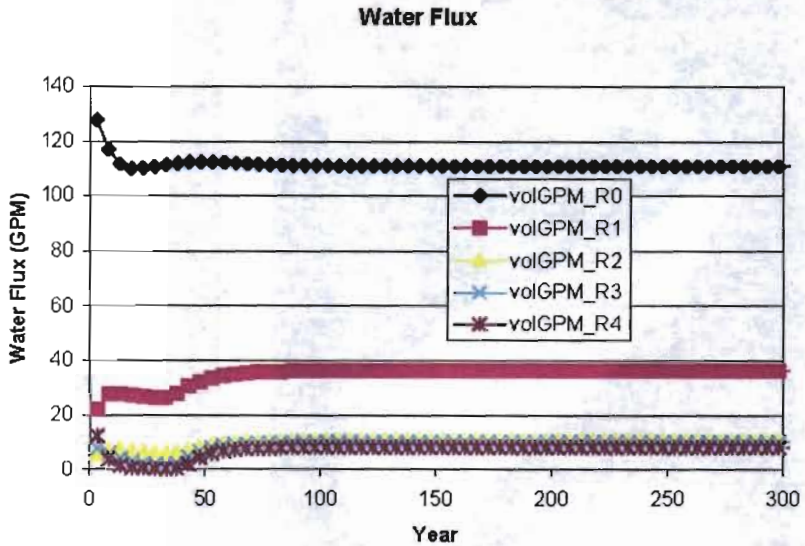
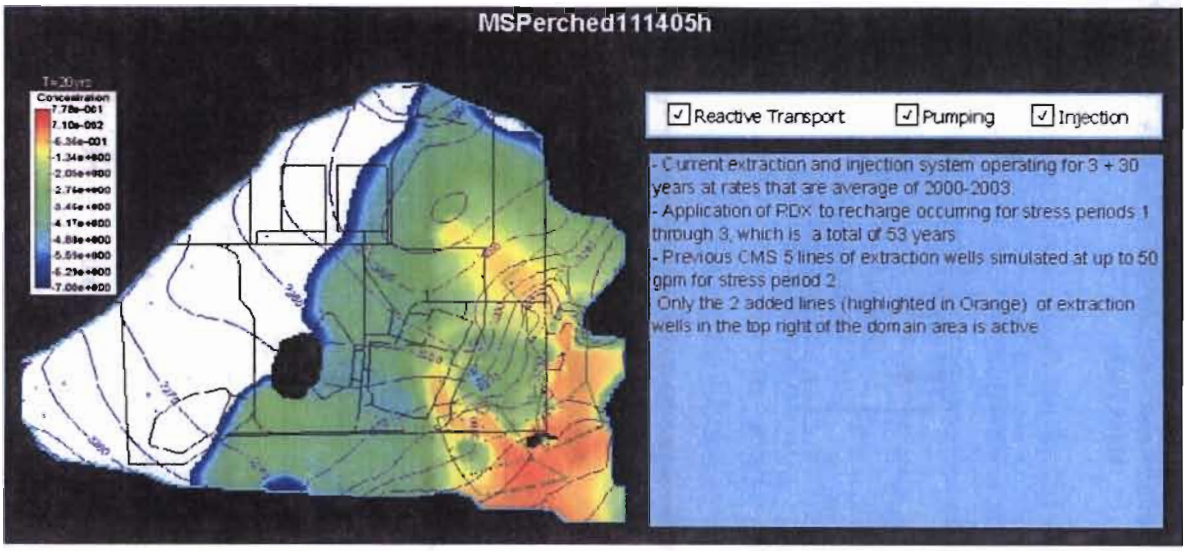










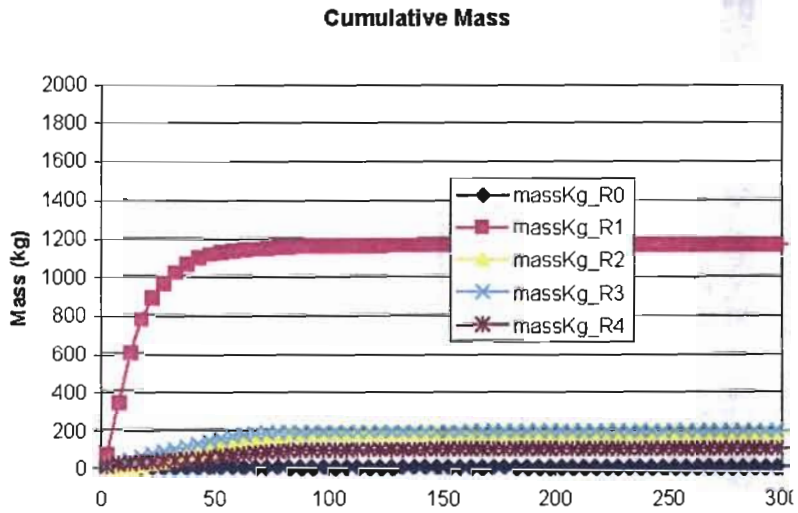
Cumulative Water Across GHB Reaches (millions of gallons)

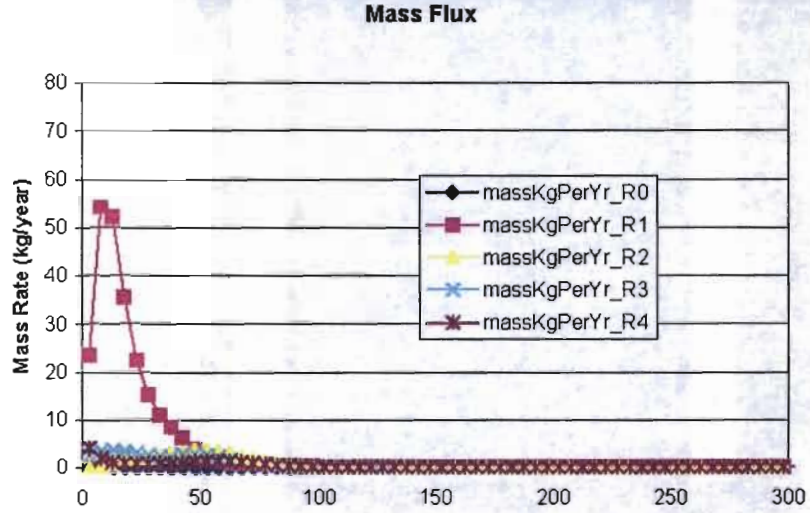
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1970.08	483.57	128.36	89.31	71.29	2742.61
50	3156.97	828.95	219.96	166.79	121.81	4494.48
100	6098.97	1781.54	506.07	442.11	335.31	9163.99
150	9019.17	2741.34	796.33	722.56	553.68	13833.08
200	11936.20	3700.76	1086.52	1002.88	771.89	18498.25
250	14852.53	4660.04	1376.66	1283.14	990.02	23162.39
300	17768.72	5619.27	1666.80	1563.39	1208.14	27826.31

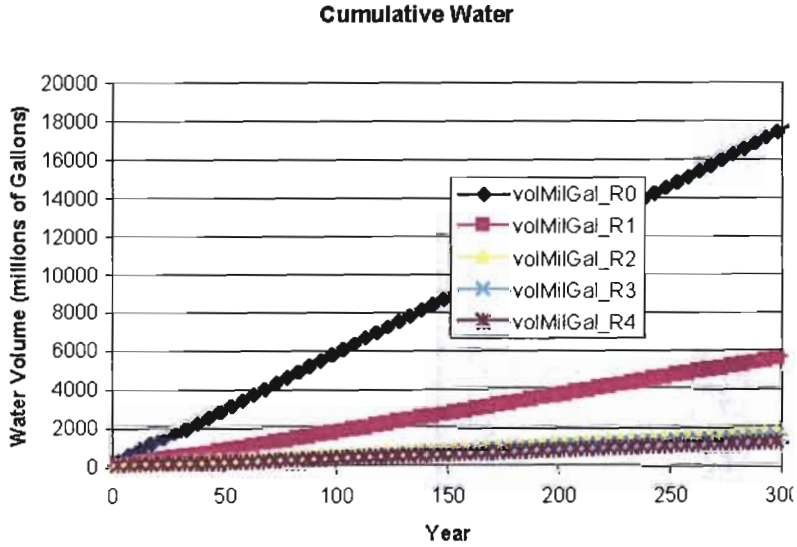
Cumulative Mass Across GHB Reaches (kg)

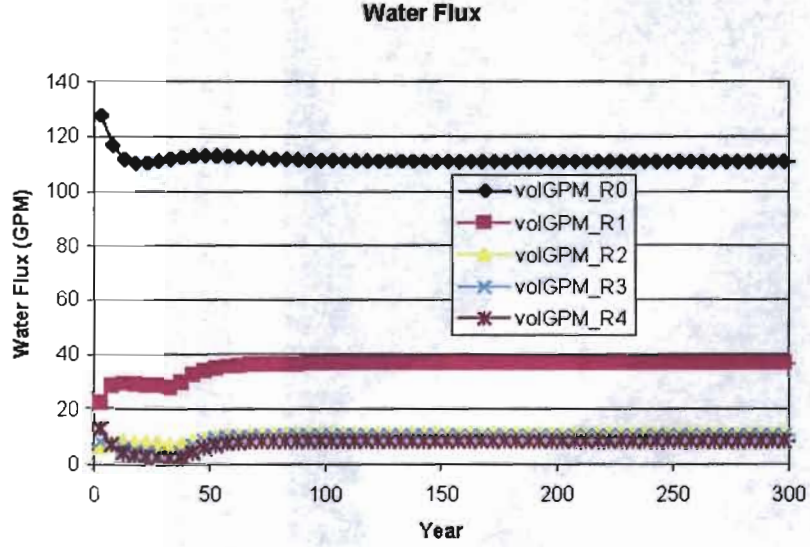
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.72	1021.80	42.62	98.99	38.52	1202.65
50	0.79	1126.95	108.01	152.70	58.47	1446.92
100	0.85	1158.61	176.48	188.80	92.27	1617.01
150	0.86	1163.81	177.33	189.54	94.59	1626.13
200	0.86	1164.91	177.56	190.08	95.14	1628.55
250	0.86	1164.94	177.64	190.25	95.26	1628.95
300	0.86	1164.95	177.66	190.29	95.28	1629.04

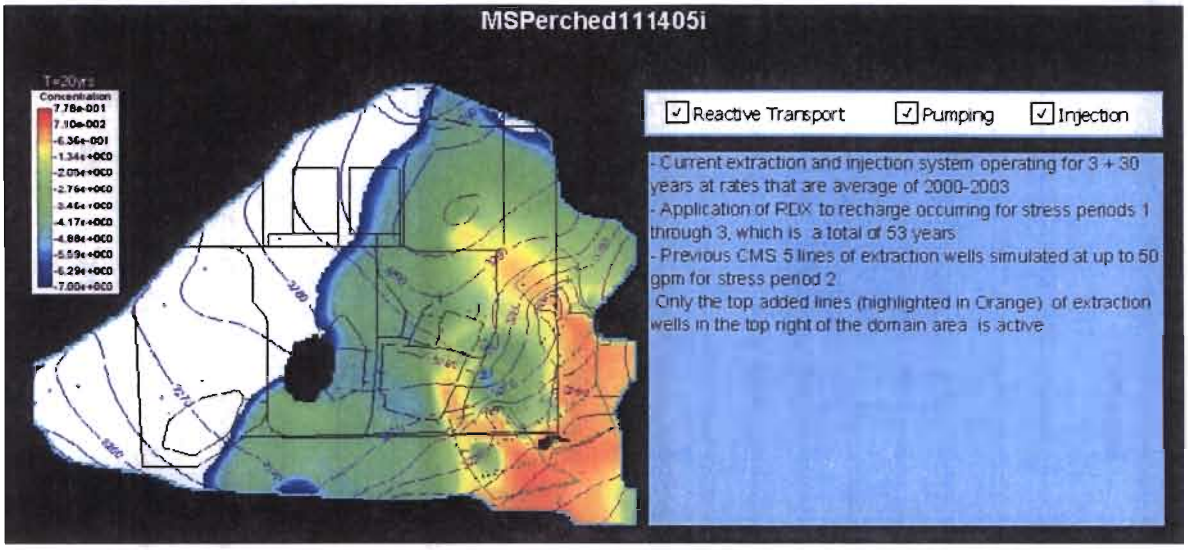
MSPerched111405h











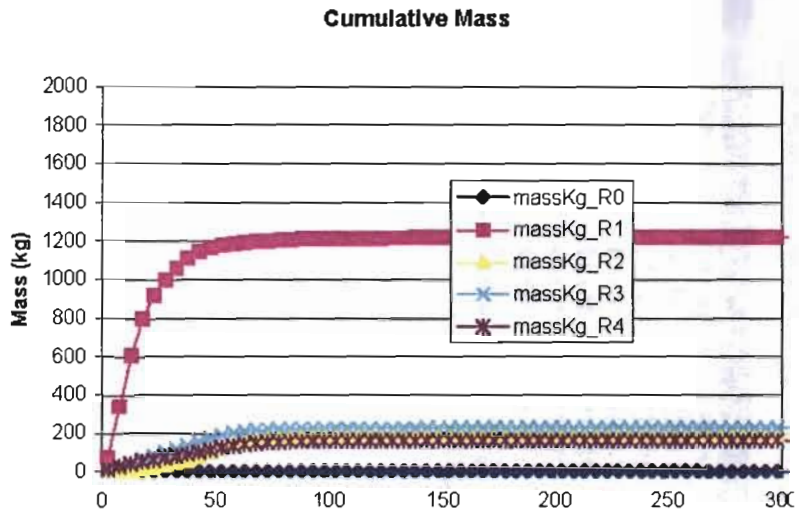
Cumulative Water Across GHB Reaches (millions of gallons)

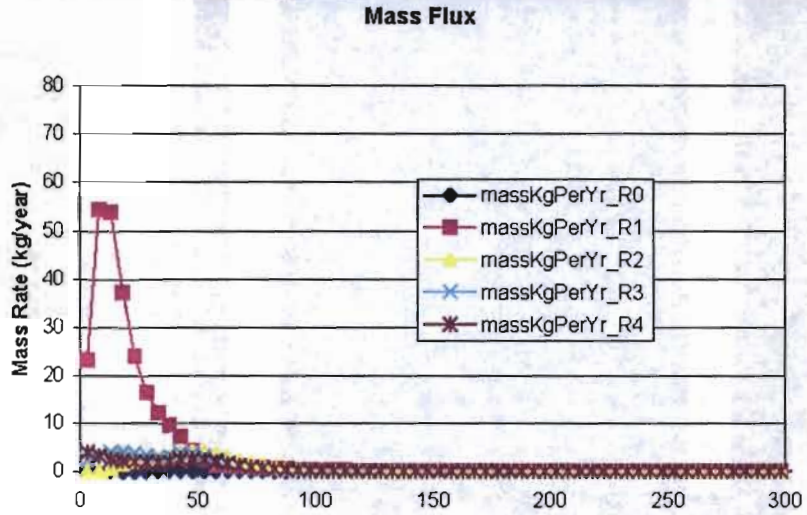
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1976.43	505.53	135.13	106.71	110.60	2834.40
50	3174.39	873.90	235.74	200.53	179.98	4664.56
100	6135.15	1840.38	527.07	482.80	400.57	9385.97
150	9060.03	2801.76	817.84	763.95	619.71	14063.29
200	11978.03	3761.44	1108.11	1044.38	838.05	18730.01
250	14894.62	4720.78	1398.27	1324.67	1056.22	23394.55
300	17810.88	5680.04	1688.41	1604.92	1274.34	28058.60

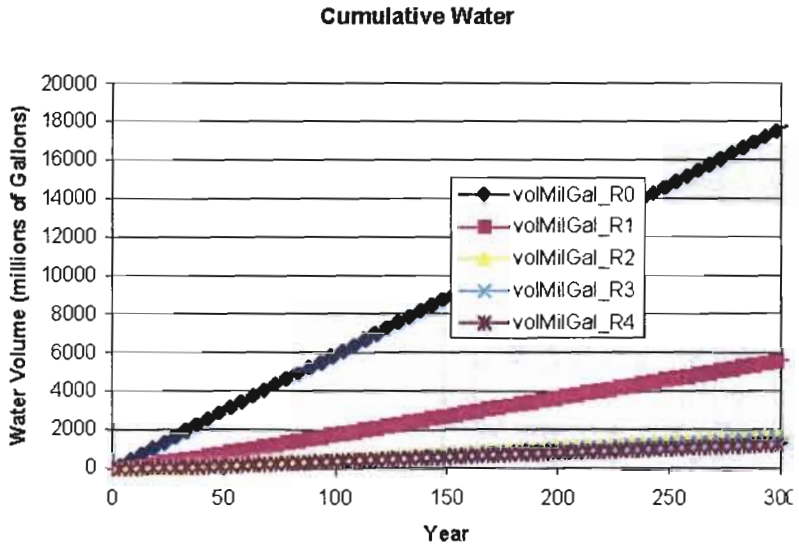
Cumulative Mass Across GHB Reaches (kg)

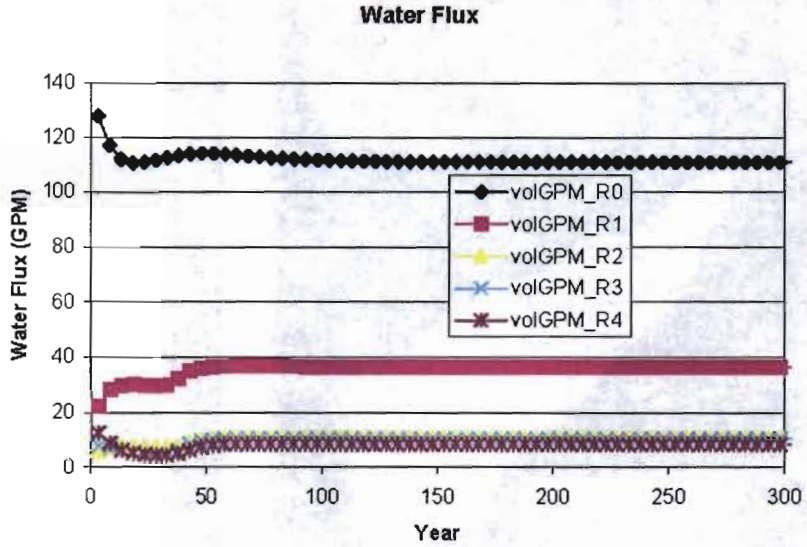
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.73	1066.33	47.81	121.90	80.25	1317.02
50	0.80	1184.95	121.76	194.24	125.65	1627.40
100	0.87	1219.17	190.97	232.07	161.18	1804.27
150	0.88	1224.01	191.75	232.75	163.19	1812.58
200	0.89	1224.86	191.96	233.25	163.69	1814.65
250	0.89	1224.88	192.03	233.40	163.79	1814.99
300	0.89	1224.89	192.04	233.43	163.81	1815.06

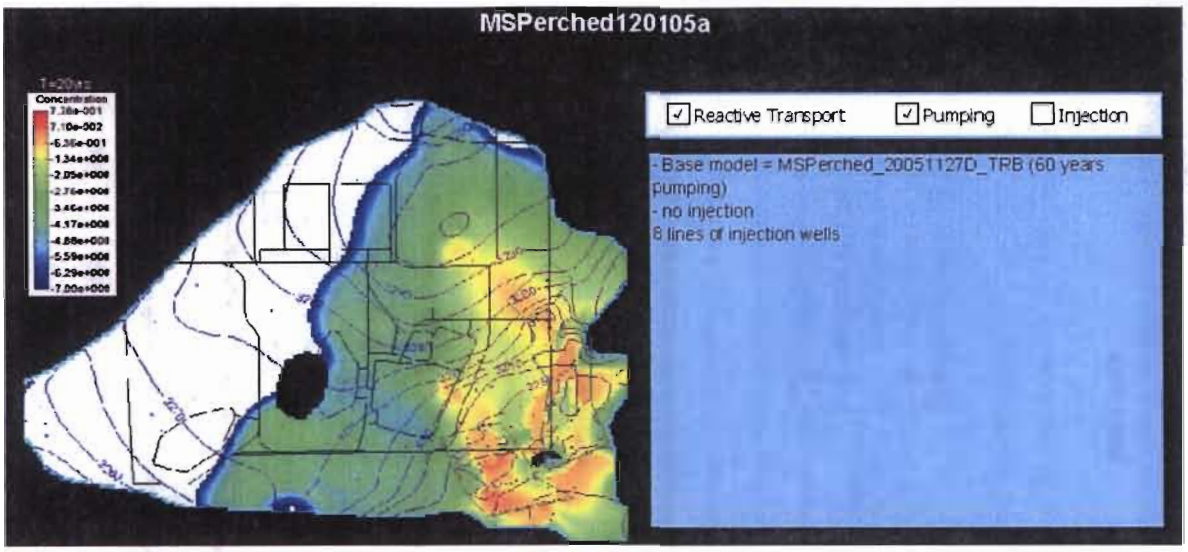
MSPerched111405i











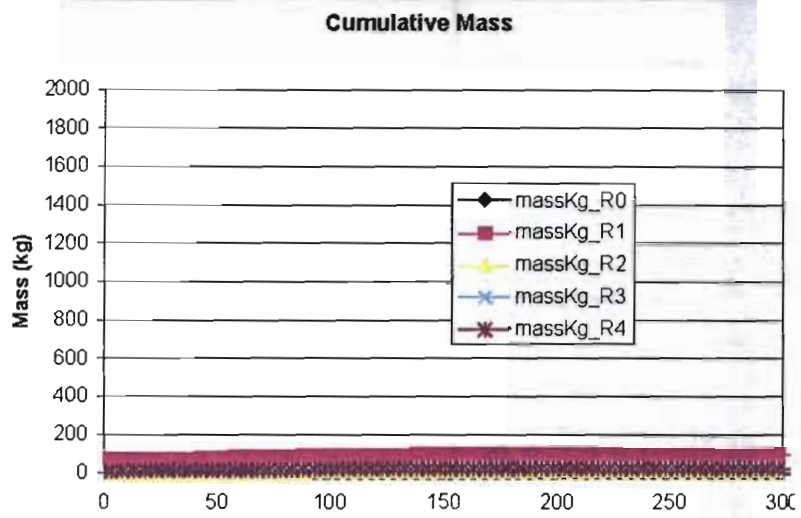
Cumulative Water Across GHB Reaches (millions of gallons)

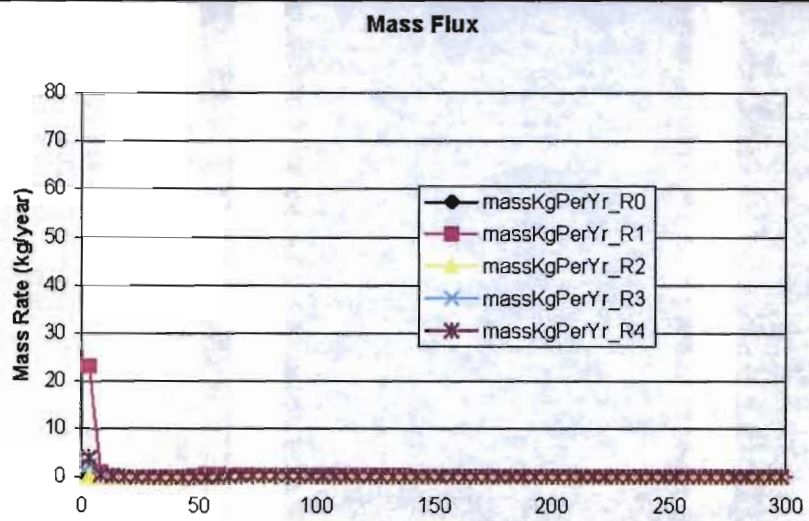
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1869.54	69.50	44.95	15.23	32.26	2031.47
50	2936.40	178.55	66.22	19.38	38.20	3238.75
100	5712.17	997.41	299.13	230.05	199.49	7438.25
150	8592.49	1943.79	585.10	504.67	411.69	12037.74
200	11501.64	2901.01	874.62	784.06	628.88	16690.21
250	14416.48	3859.89	1164.64	1064.16	846.82	21351.99
300	17332.39	4819.05	1454.75	1344.37	1064.90	26015.47

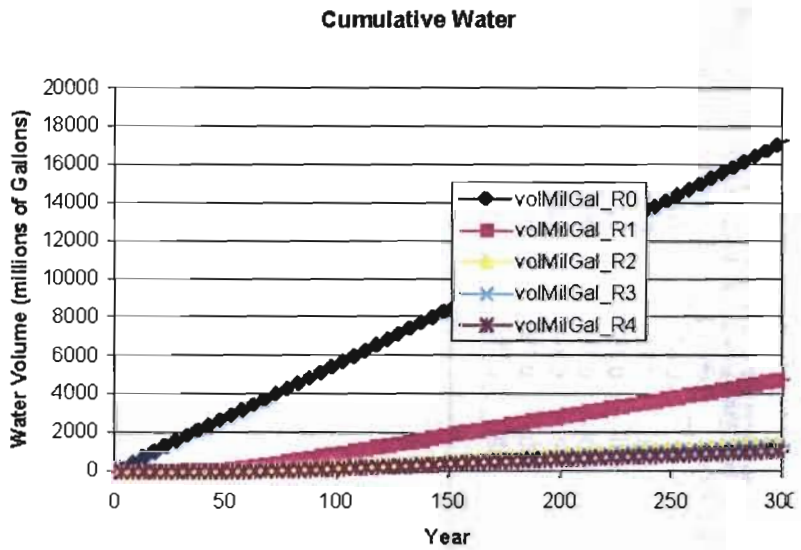
Cumulative Mass Across GHB Reaches (kg)

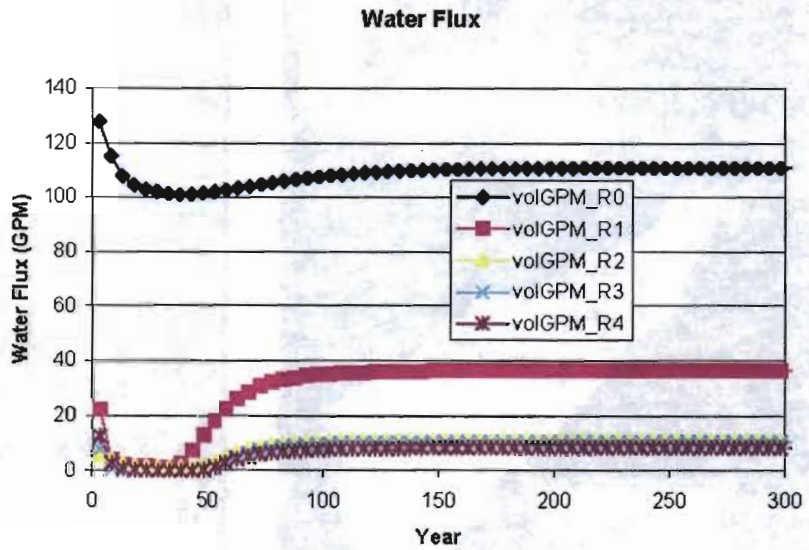
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	0.67	76.24	0.16	10.29	17.00	104.36
50	0.72	81.25	0.51	10.75	17.50	110.73
100	0.75	92.34	10.60	18.98	23.67	146.34
150	0.76	98.02	12.91	21.37	25.75	158.80
200	0.76	98.82	13.38	21.97	26.15	161.08
250	0.76	98.84	13.45	22.10	26.23	161.38
300	0.76	98.84	13.47	22.13	26.24	161.44

MSPerched120105a

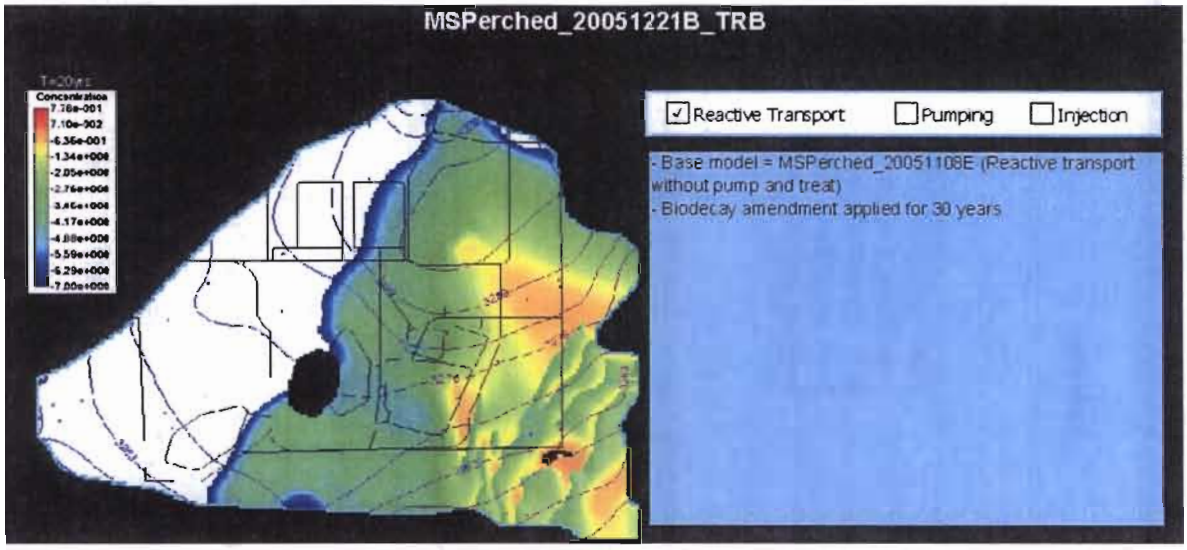








RUN36_MSPerched_20051221B_TRB



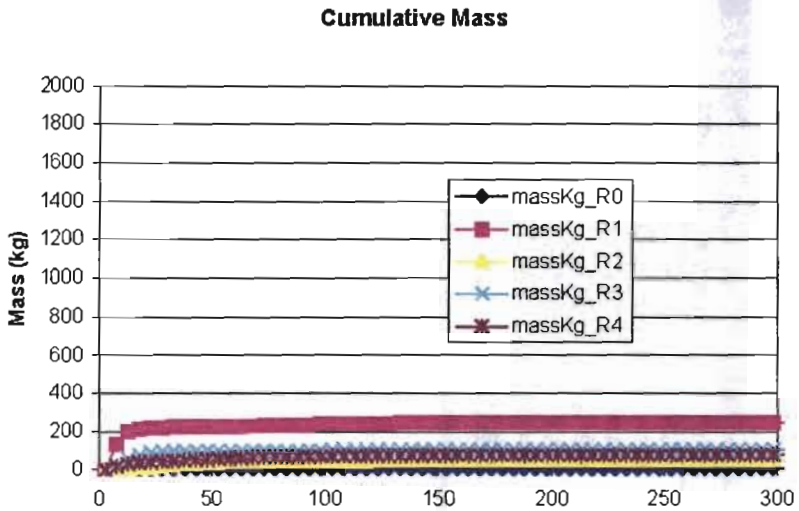
Cumulative Water Across GHB Reaches (millions of gallons)

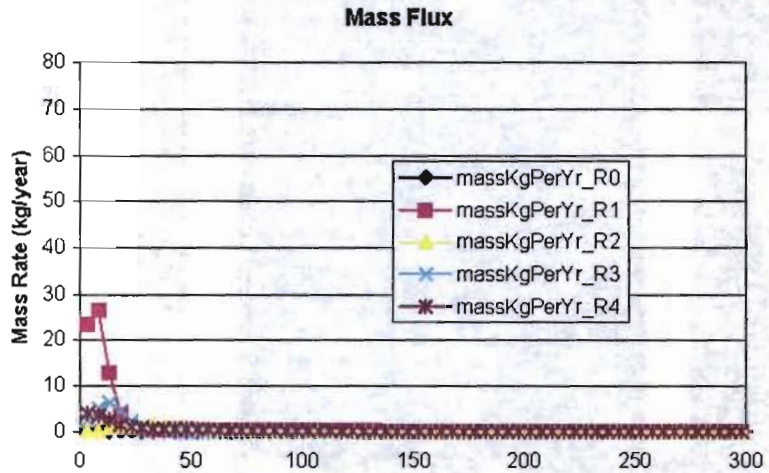
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1802.81	582.73	169.06	181.78	189.26	2925.63
50	2999.69	979.95	282.76	305.21	318.67	4886.28
100	5991.90	1974.86	585.72	606.67	569.27	9728.42
150	8901.82	2939.84	875.22	890.18	792.94	14400.00
200	11894.03	3904.83	1166.96	1174.44	1009.87	19150.13
250	14811.43	4862.34	1458.70	1451.22	1226.81	23810.49
300	17654.03	5819.84	1750.44	1735.48	1451.22	28411.01

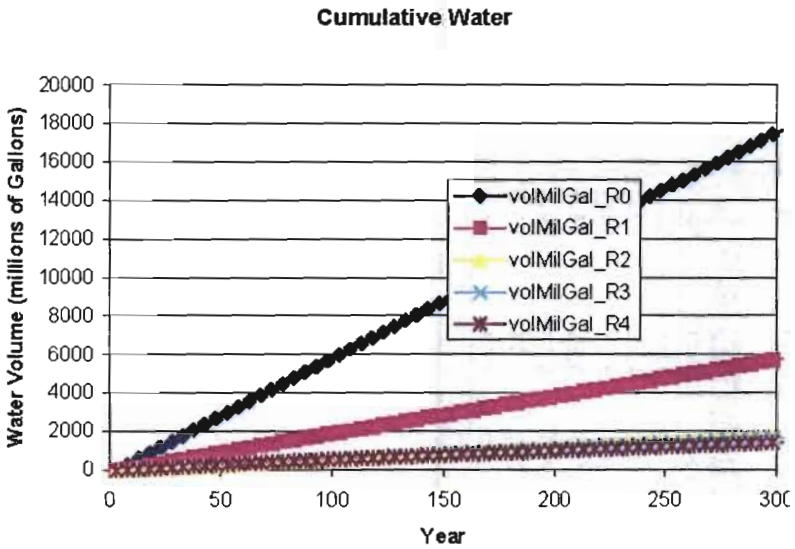
Cumulative Mass Across GHB Reaches (kg)

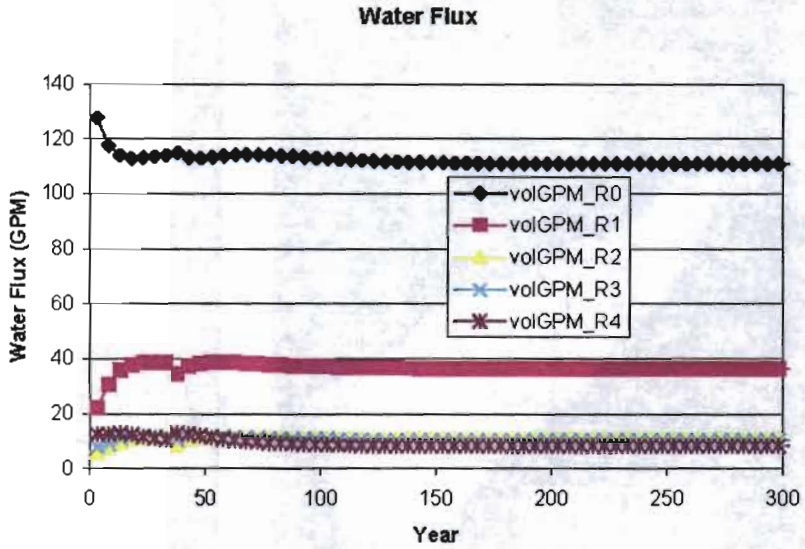
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	3.03	224.49	27.14	100.96	47.13	402.74
50	4.59	227.18	42.90	103.57	57.73	435.97
100	5.11	240.02	49.41	104.90	70.65	470.08
150	5.13	246.56	50.21	108.00	75.58	485.48
200	5.13	247.30	50.70	108.93	76.29	488.35
250	5.13	247.32	50.79	109.08	76.38	488.71
300	5.13	247.33	50.81	109.11	76.40	488.77

MSPerched_20051221B_TRB

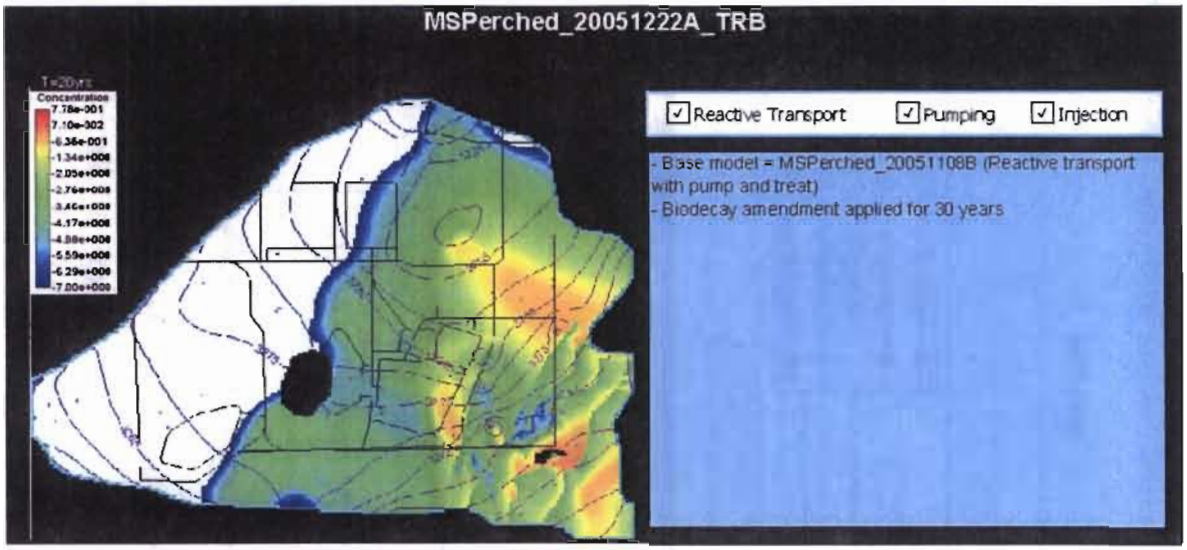








RUN37_MSPerched_20051222a_TRB



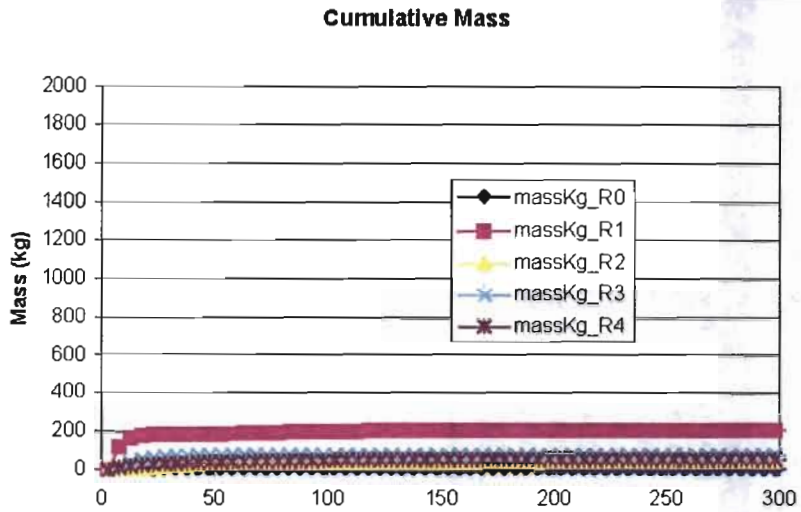
Cumulative Water Across GHB Reaches (millions of gallons)

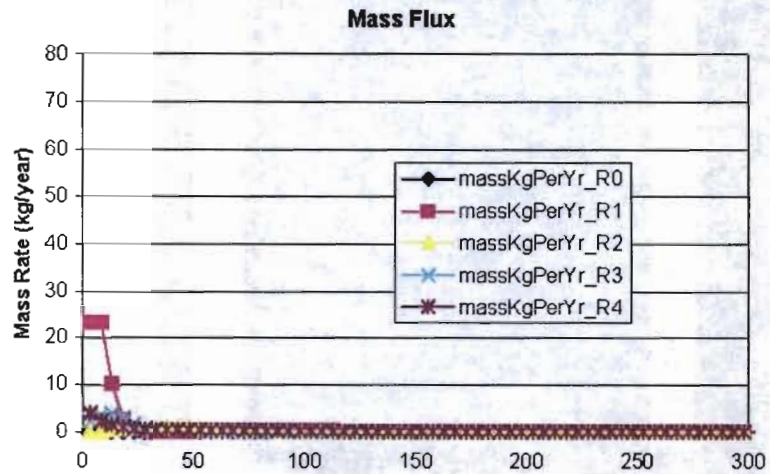
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1810.29	488.48	130.16	106.97	141.38	2677.28
50	3044.57	890.18	240.87	219.18	249.10	4643.91
100	6066.70	1885.09	542.34	516.90	489.23	9500.26
150	8976.62	2850.08	837.82	800.42	710.65	14175.58
200	11894.03	3807.58	1122.08	1077.19	927.58	18828.47
250	14811.43	4772.57	1413.82	1361.45	1144.52	23503.79
300	17728.83	5730.08	1705.56	1638.23	1368.94	28171.64

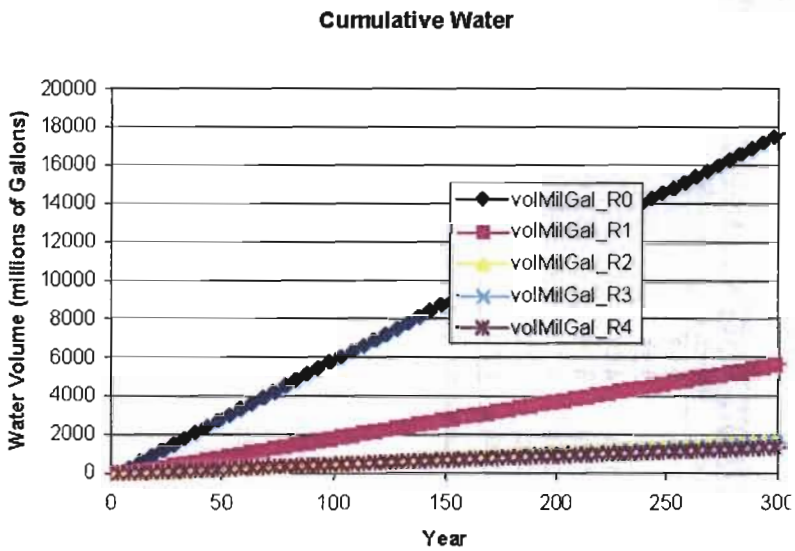
Cumulative Mass Across GHB Reaches (kg)

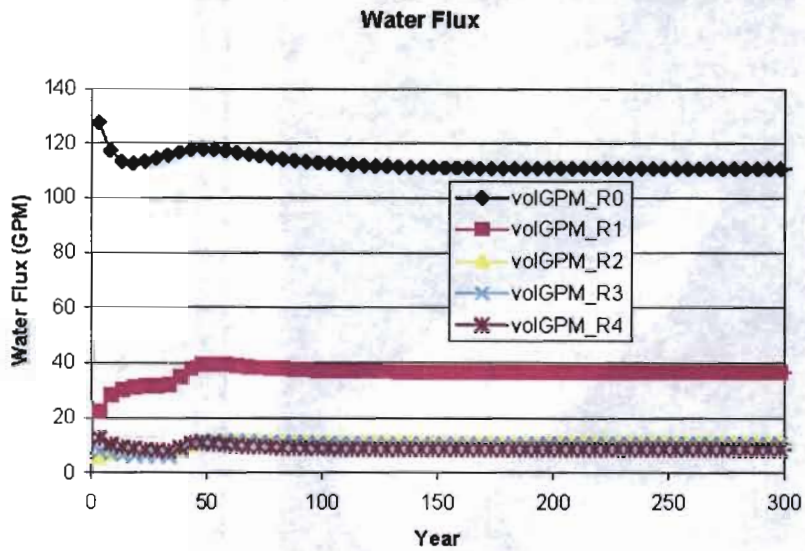
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	2.68	187.79	17.62	74.29	33.48	315.86
50	3.65	189.81	33.99	79.67	40.71	347.83
100	4.07	202.61	42.82	80.97	50.10	380.57
150	4.09	207.17	43.04	82.24	53.99	390.53
200	4.10	207.89	43.28	82.96	54.70	392.93
250	4.10	207.91	43.36	83.11	54.81	393.29
300	4.10	207.92	43.37	83.15	54.83	393.37

MSPerched_20051222A_TRB

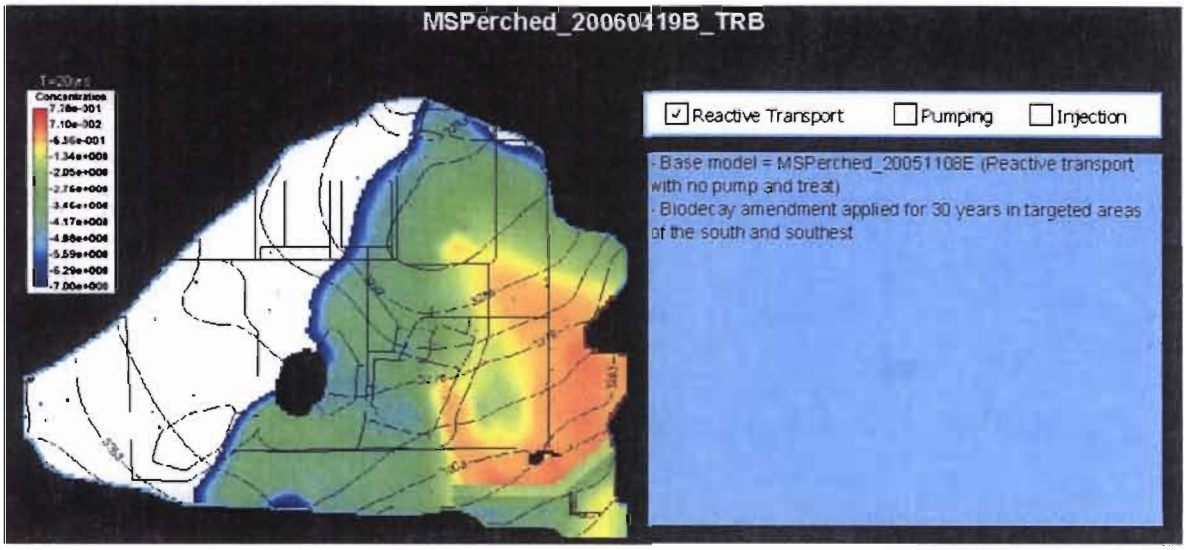








RUN38_MSPerched_20060419B_TRB



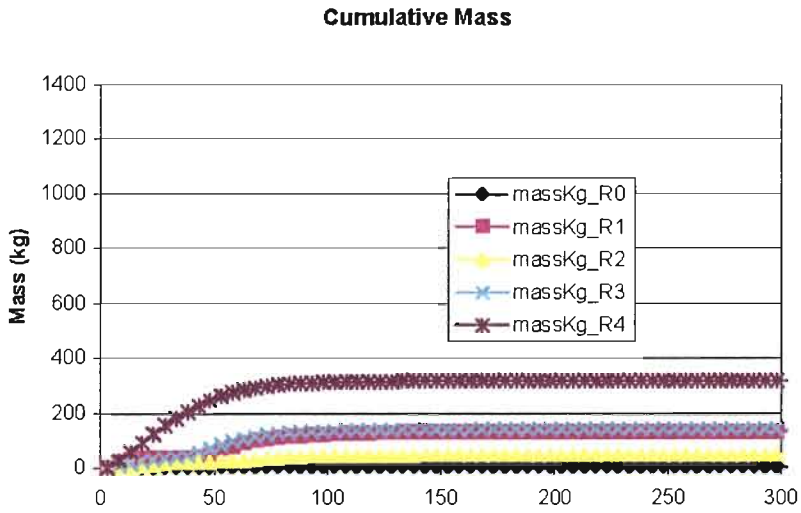
Cumulative Water Across GHB Reaches (millions of gallons)

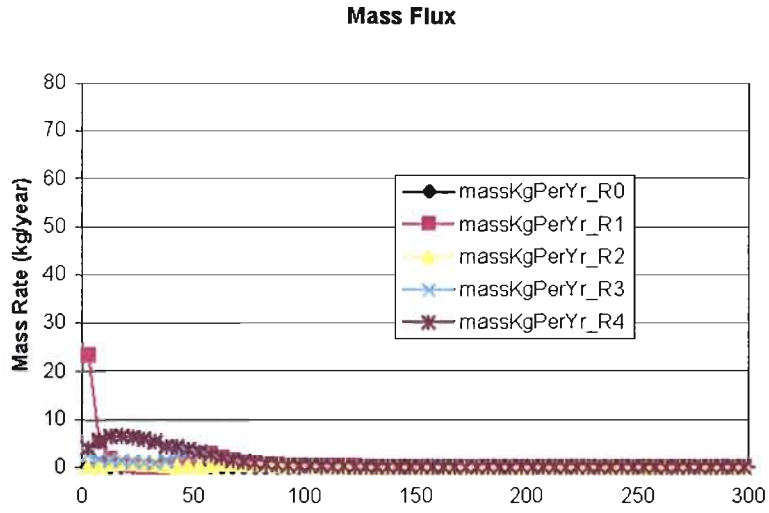
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	1802.81	582.73	169.06	181.78	189.26	2925.63
50	3037.09	950.03	261.82	270.79	288.75	4808.48
100	6111.58	1870.13	494.46	492.22	537.85	9506.24
150	9201.04	2790.23	727.85	714.39	785.45	14218.97
200	12268.05	3702.86	957.51	935.06	1039.79	18903.27
250	15335.06	4622.96	1196.88	1159.48	1286.65	23601.04
300	18402.08	5543.06	1428.78	1376.42	1533.51	28283.84

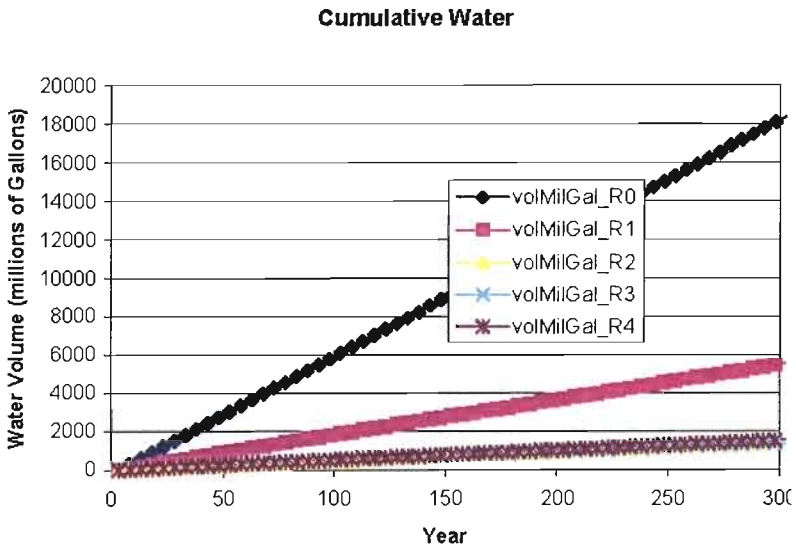
Cumulative Mass Across GHB Reaches (kg)

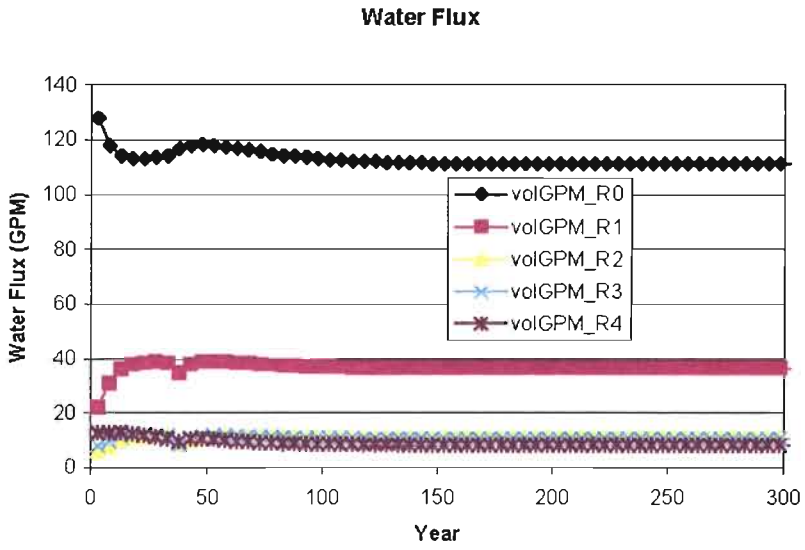
Model Year	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4	Total
30	3.03	41.06	19.45	37.94	182.36	283.85
50	4.08	69.66	23.45	87.22	261.65	446.05
100	4.50	126.01	44.74	137.05	311.49	623.79
150	4.50	133.66	47.01	141.30	317.15	643.61
200	4.50	134.51	47.57	142.15	317.15	645.88
250	4.50	134.51	47.57	142.43	317.15	646.16
300	4.50	134.51	47.86	142.43	317.15	646.45

MSPerched_20060419B_TRB









ATTACHMENT 2A
KEY SCREENING MODEL ALTERNATIVES RESULTS

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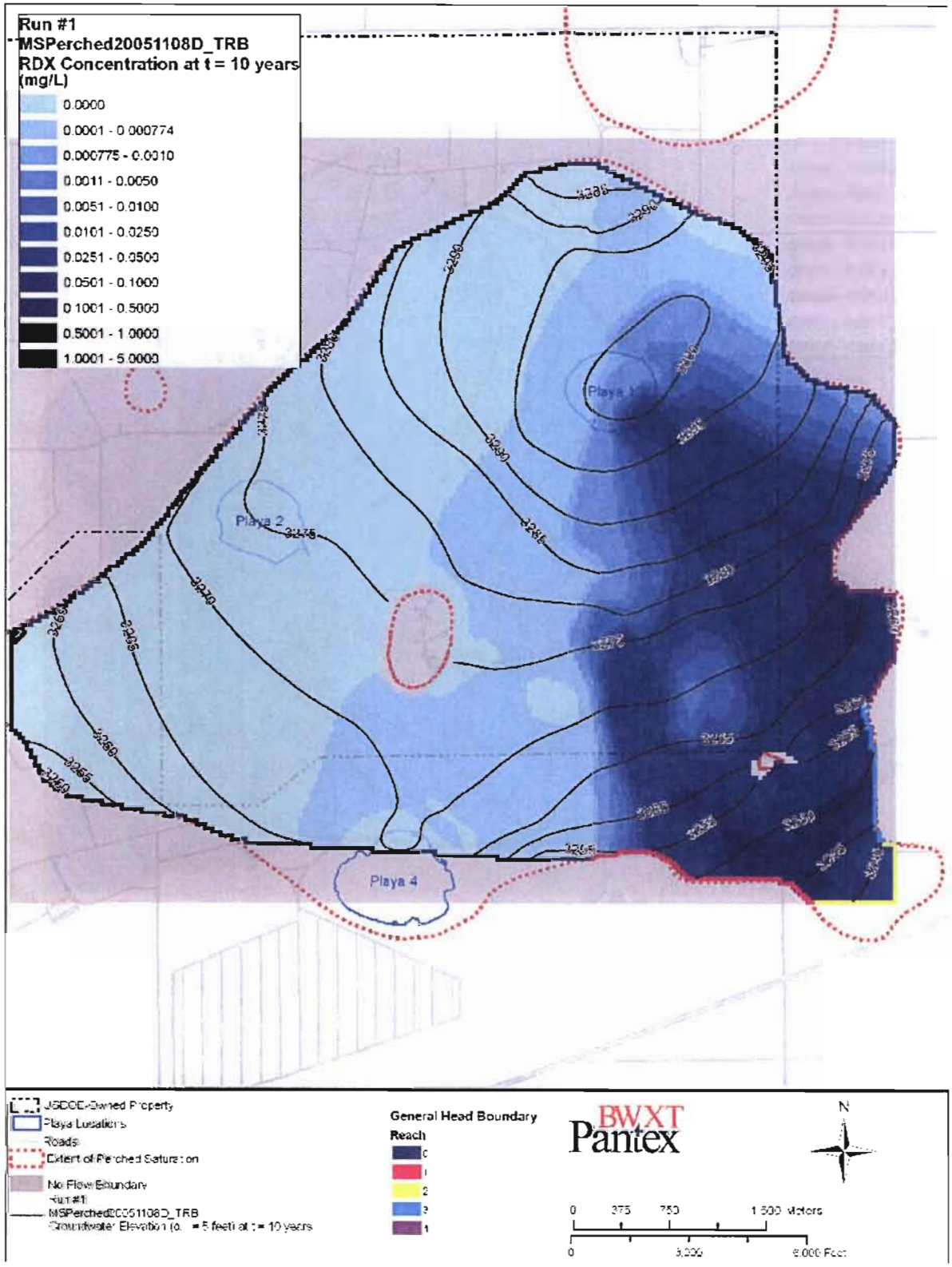


Figure 2A-1. Run 1 Simulated Water Levels and RDX Concentration at 10 Years

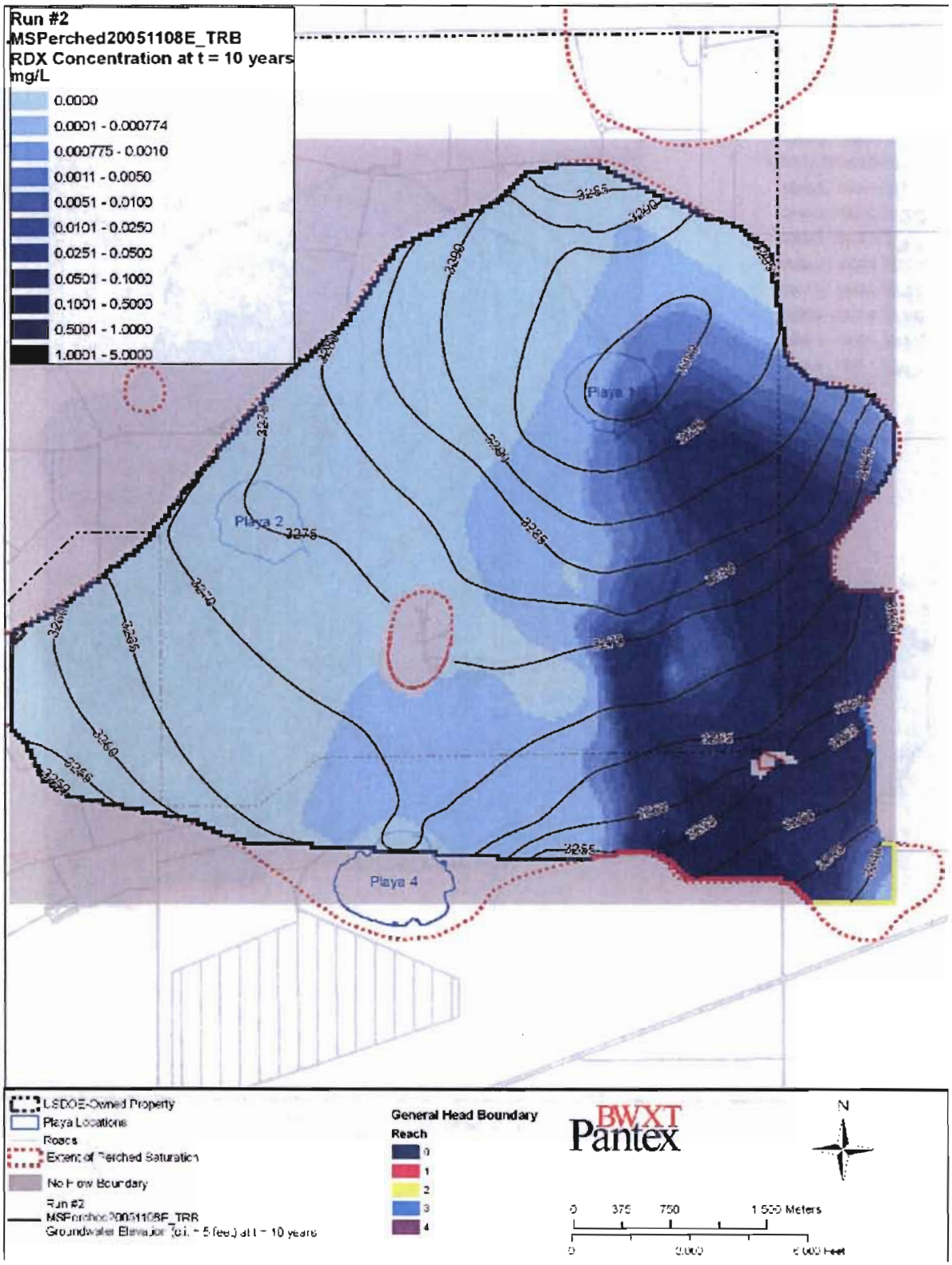
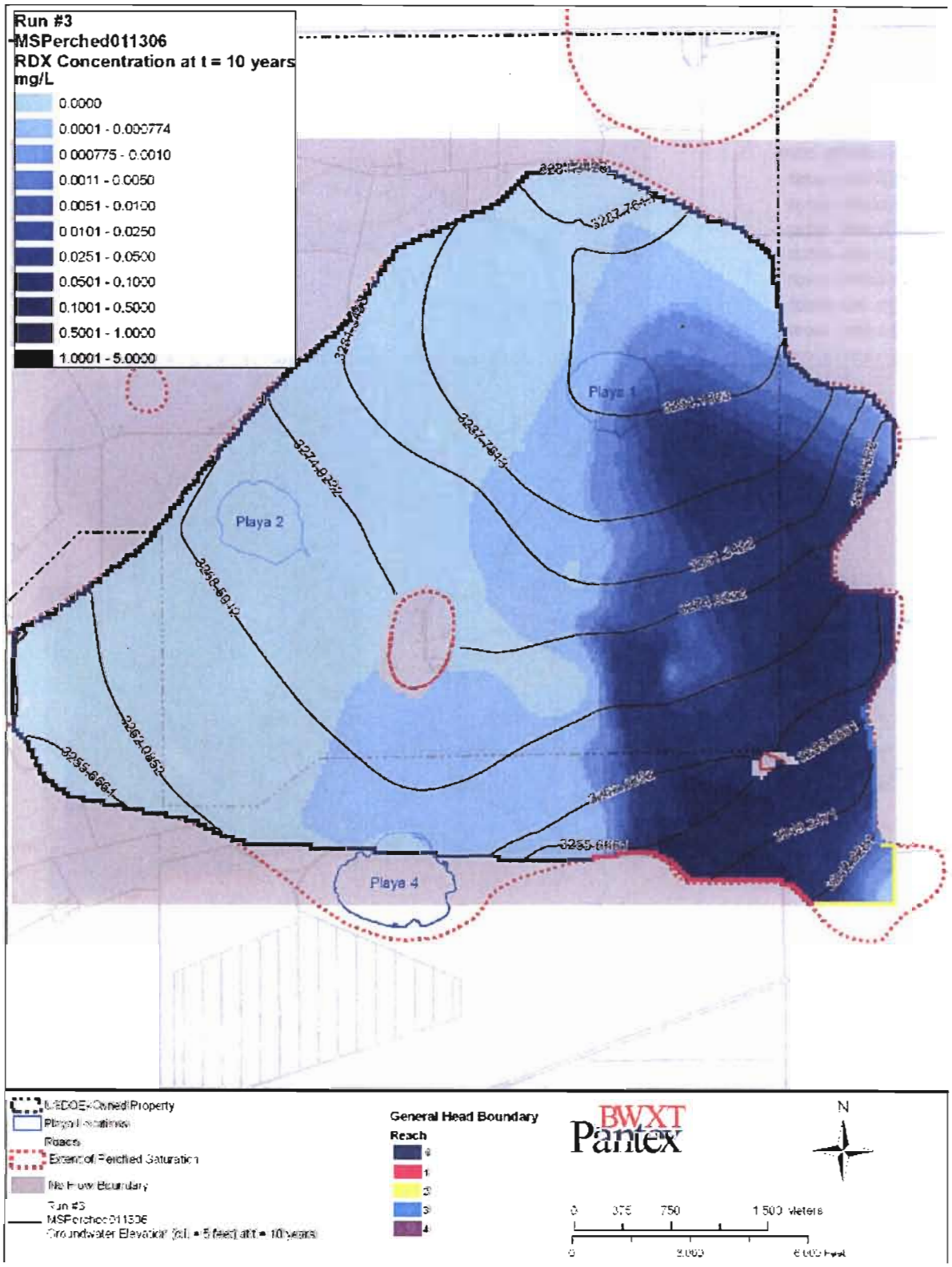


Figure 2A-2. Run 2 Simulated Water Levels and RDX Concentration at 10 Years



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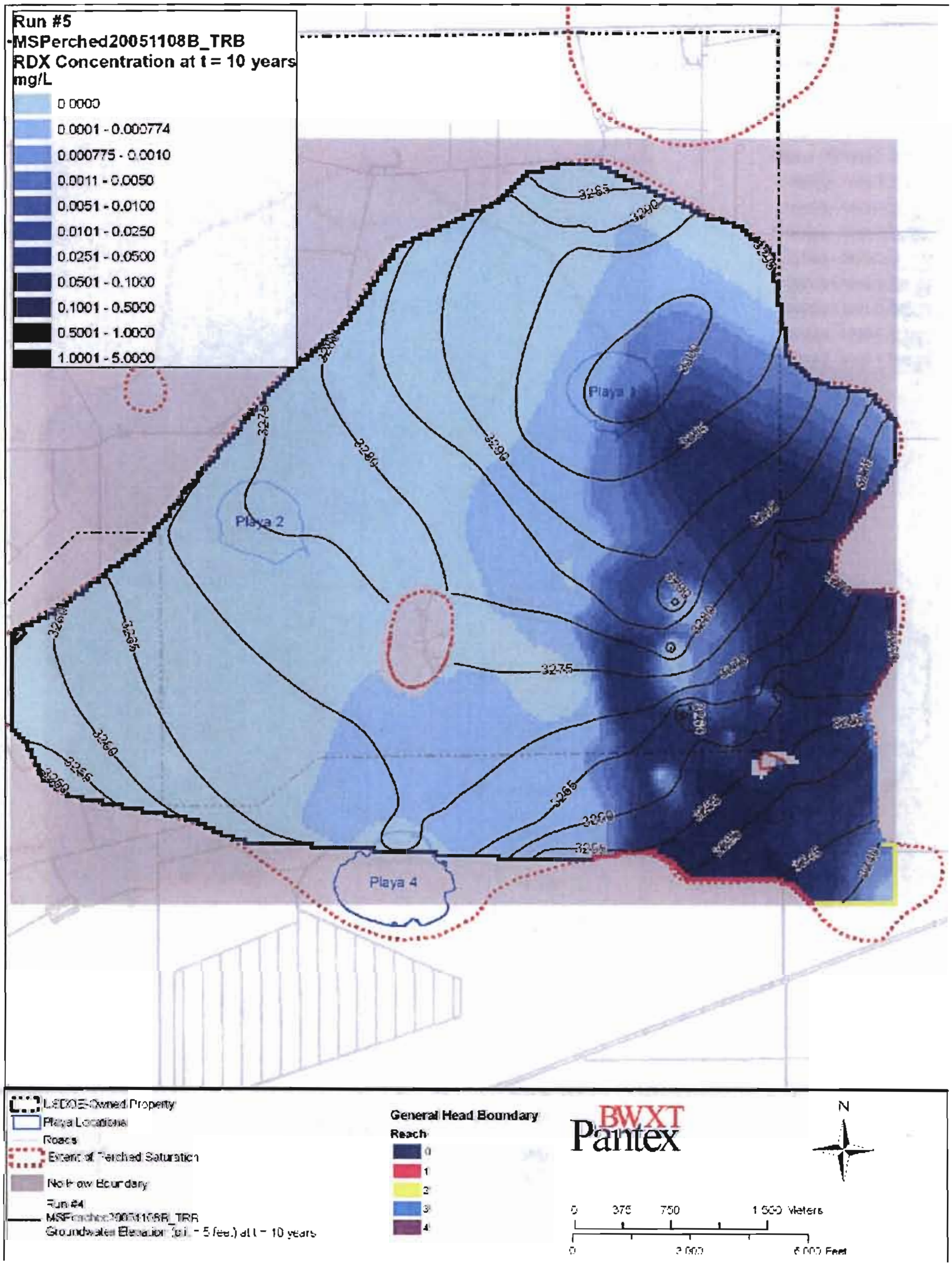

Figure 2A-4. Run 5 Simulated Water Levels and RDX Concentration at 10 Years

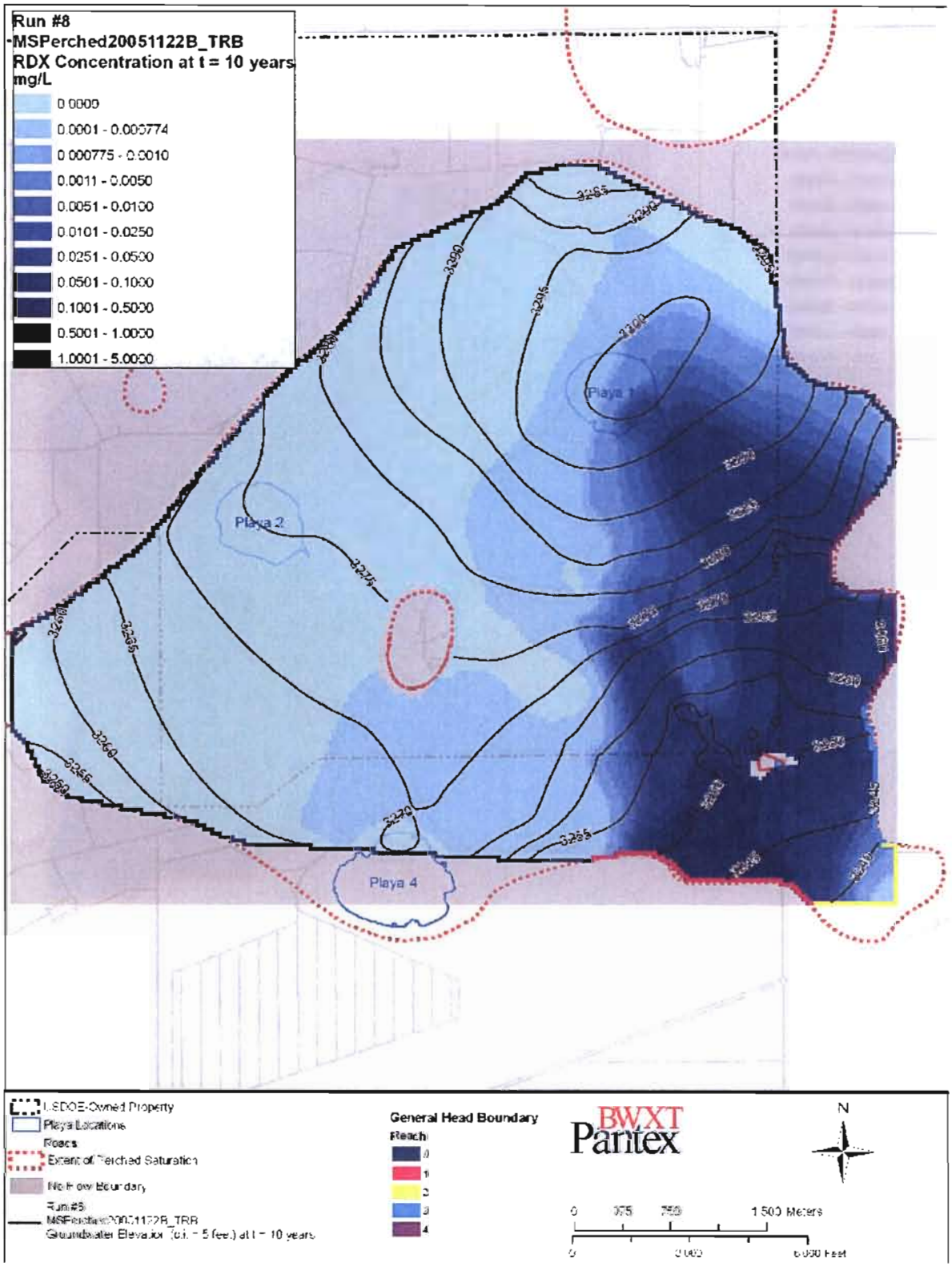

Figure 2A-5. Run 8 Simulated Water Levels and RDX Concentration at 10 Years

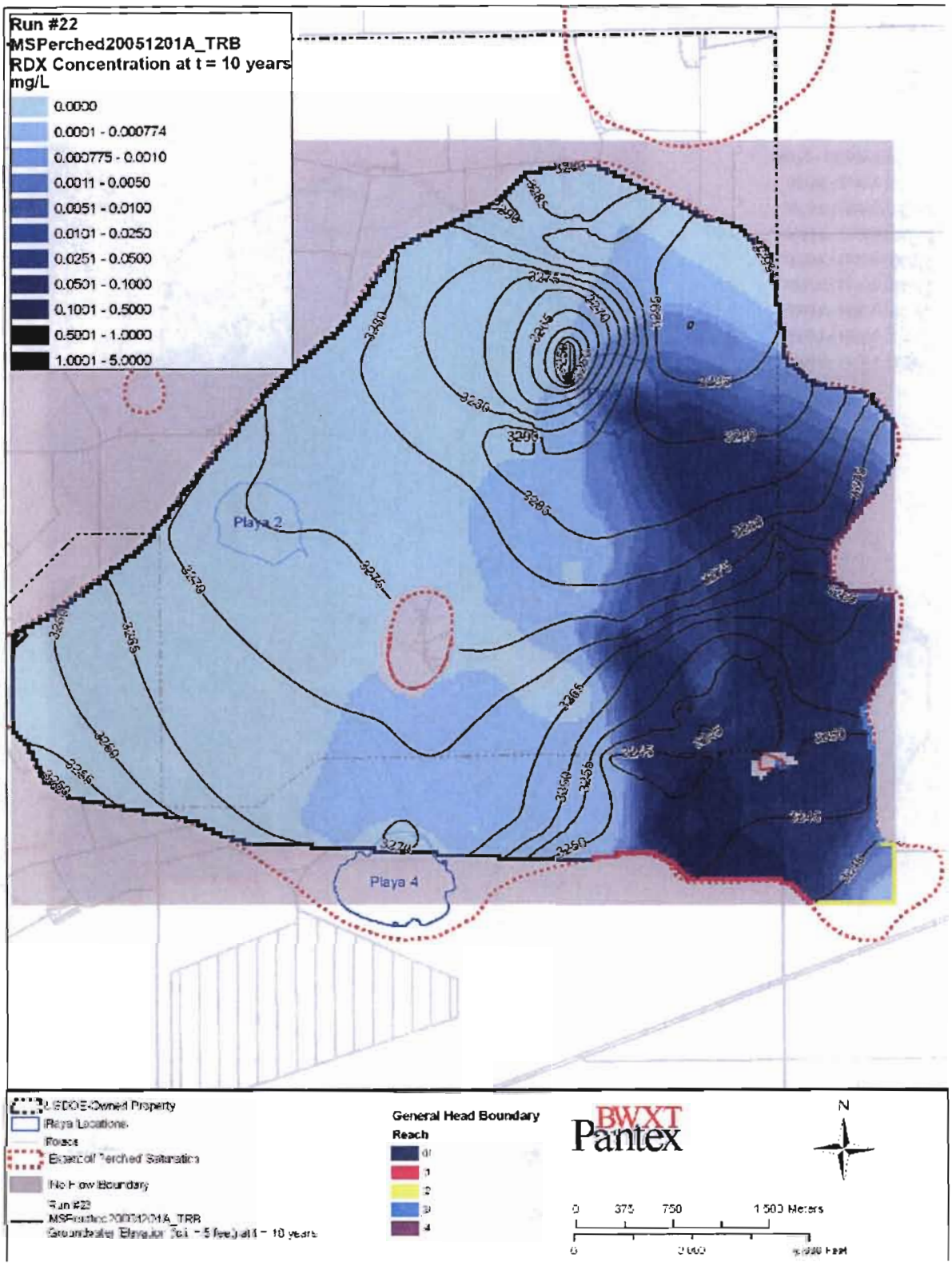

Figure 2A-6. Run 22 Simulated Water Levels and RDX Concentration at 10 Years

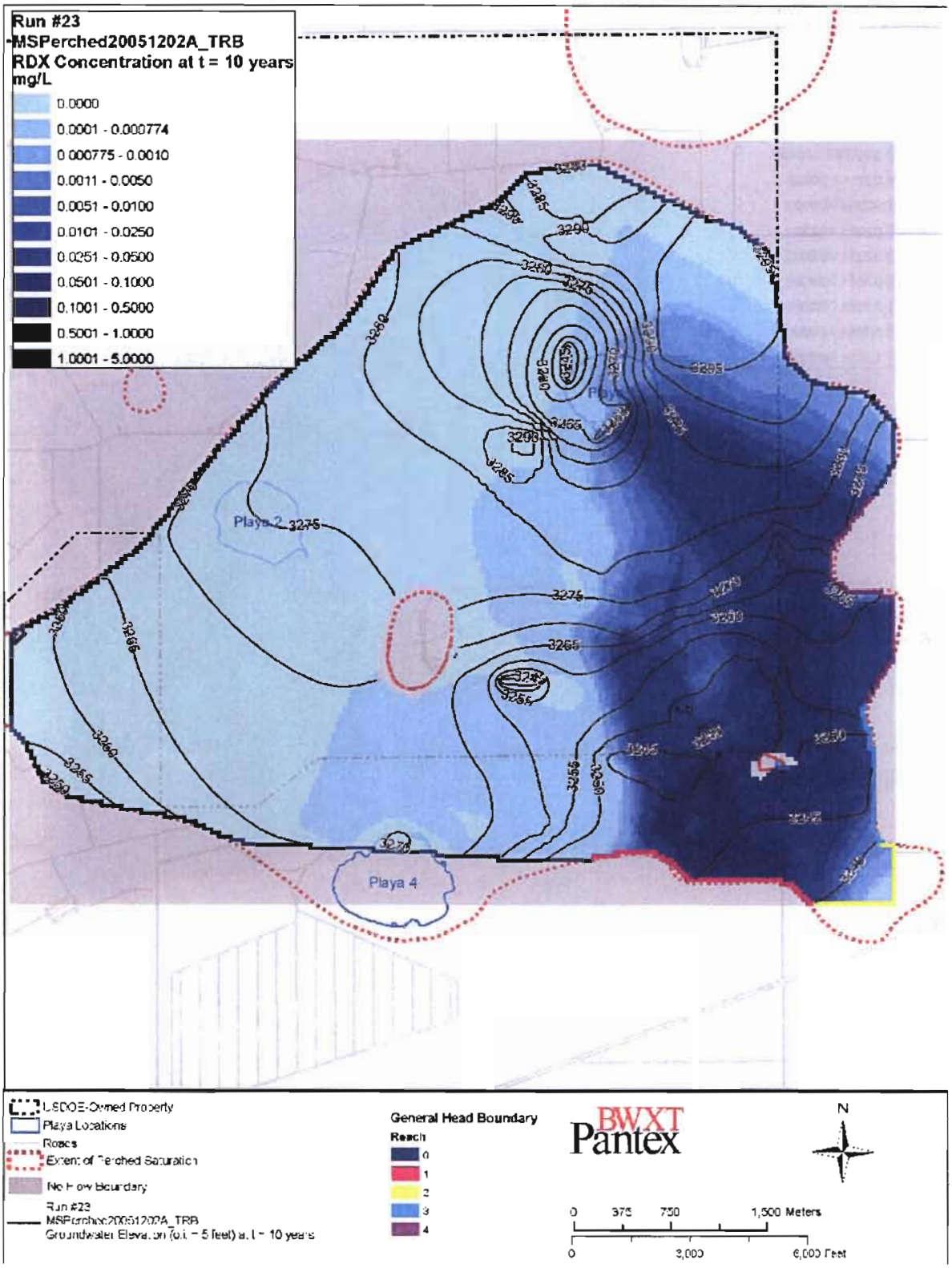

Figure 2A-7. Run 23 Simulated Water Levels and RDX Concentration at 10 Years

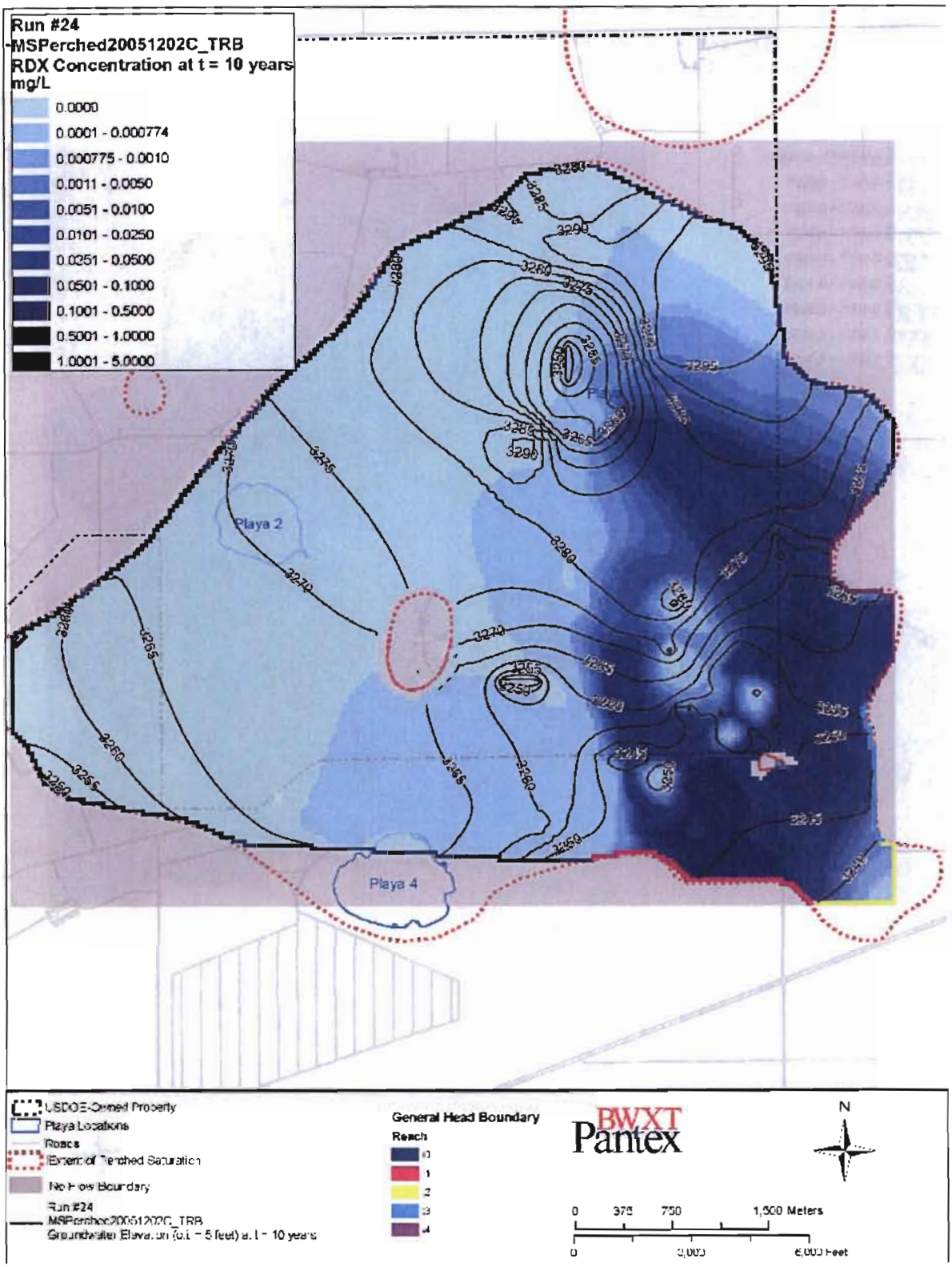

Figure 2A-8. Run 24 Simulated Water Levels and RDX Concentration at 10 Years

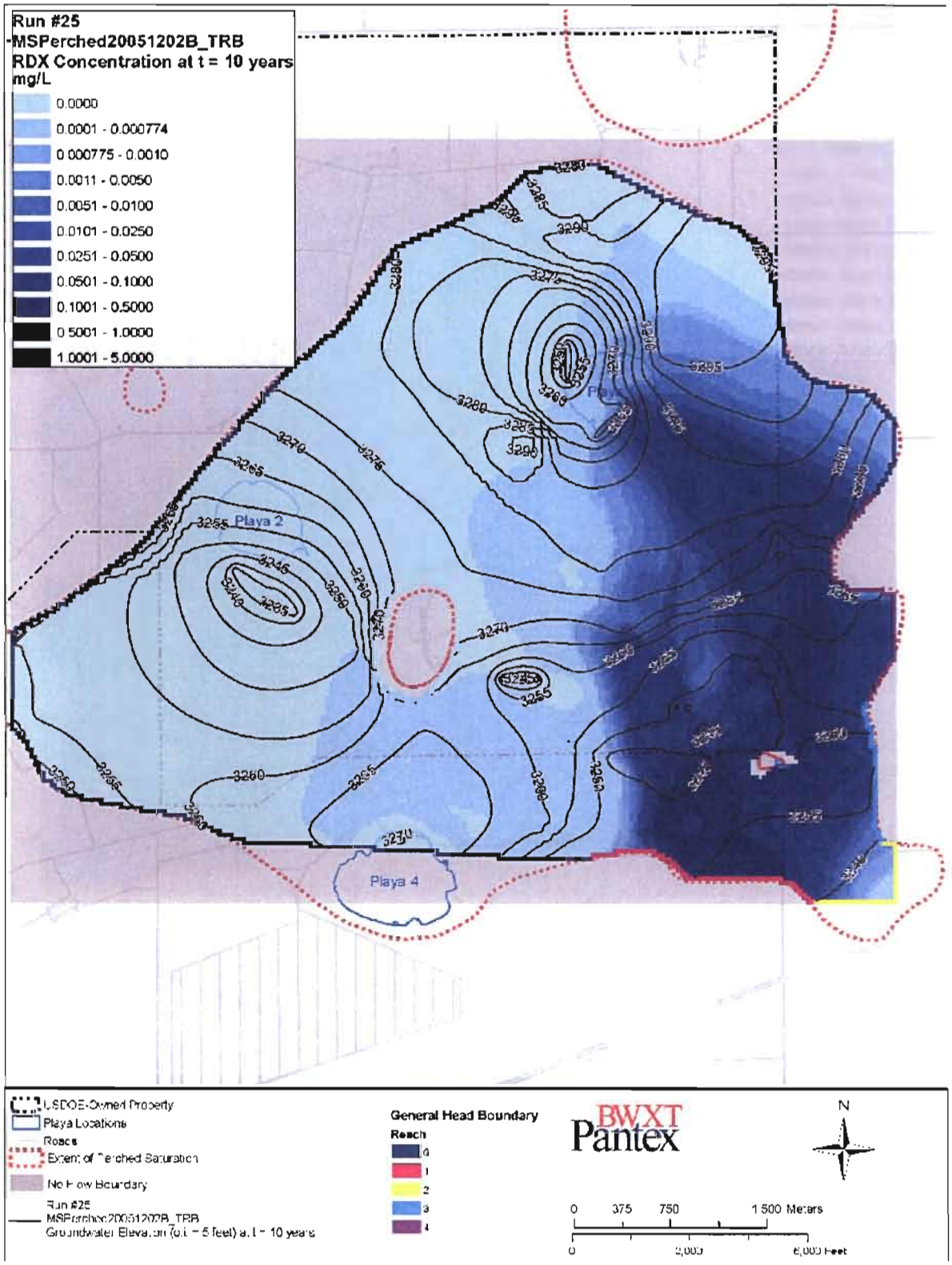

Figure 2A-9. Run 25 Simulated Water Levels and RDX Concentration at 10 Years

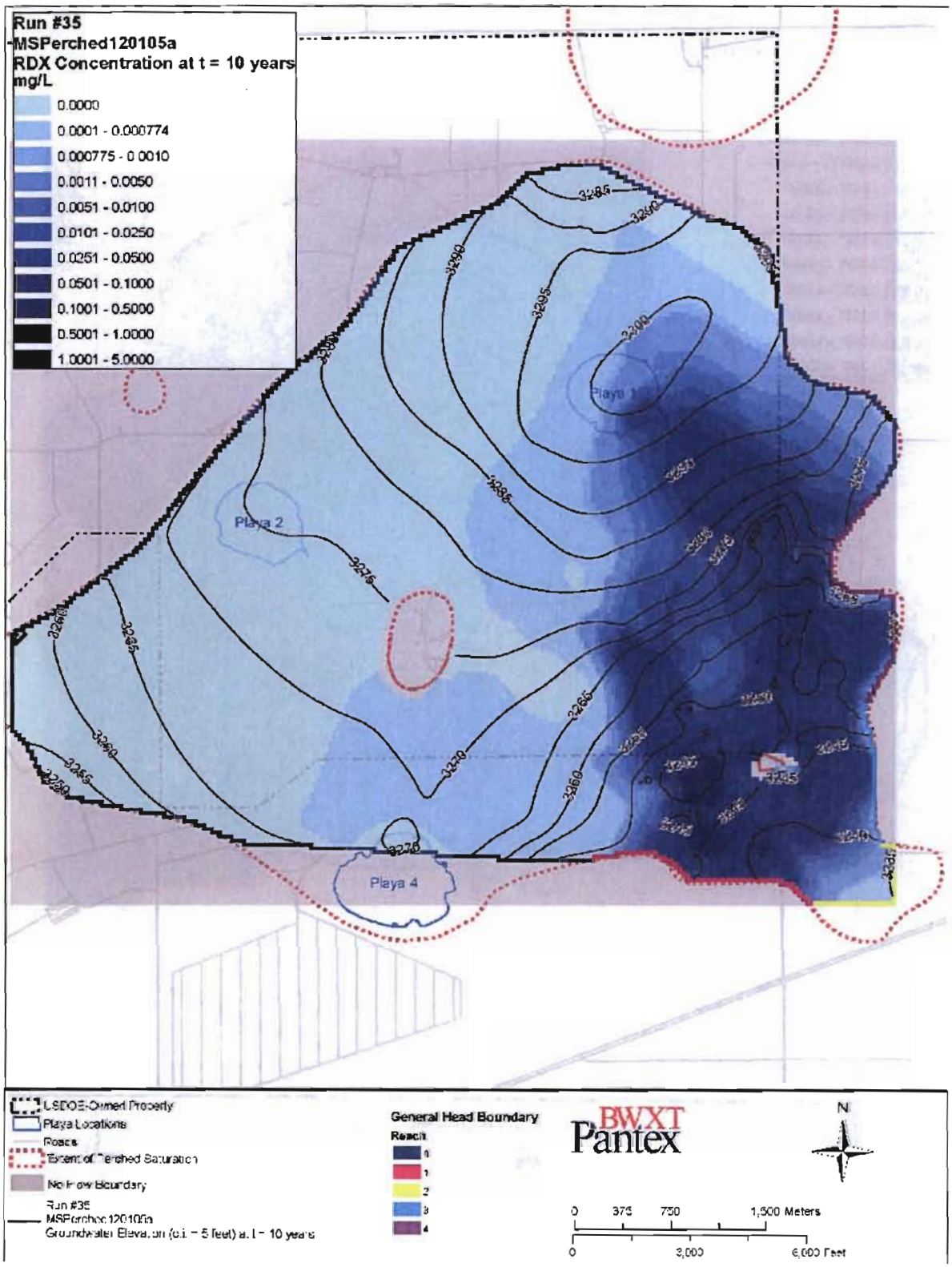

Figure 2A-10. Run 35 Simulated Water Levels and RDX Concentration at 10 Years

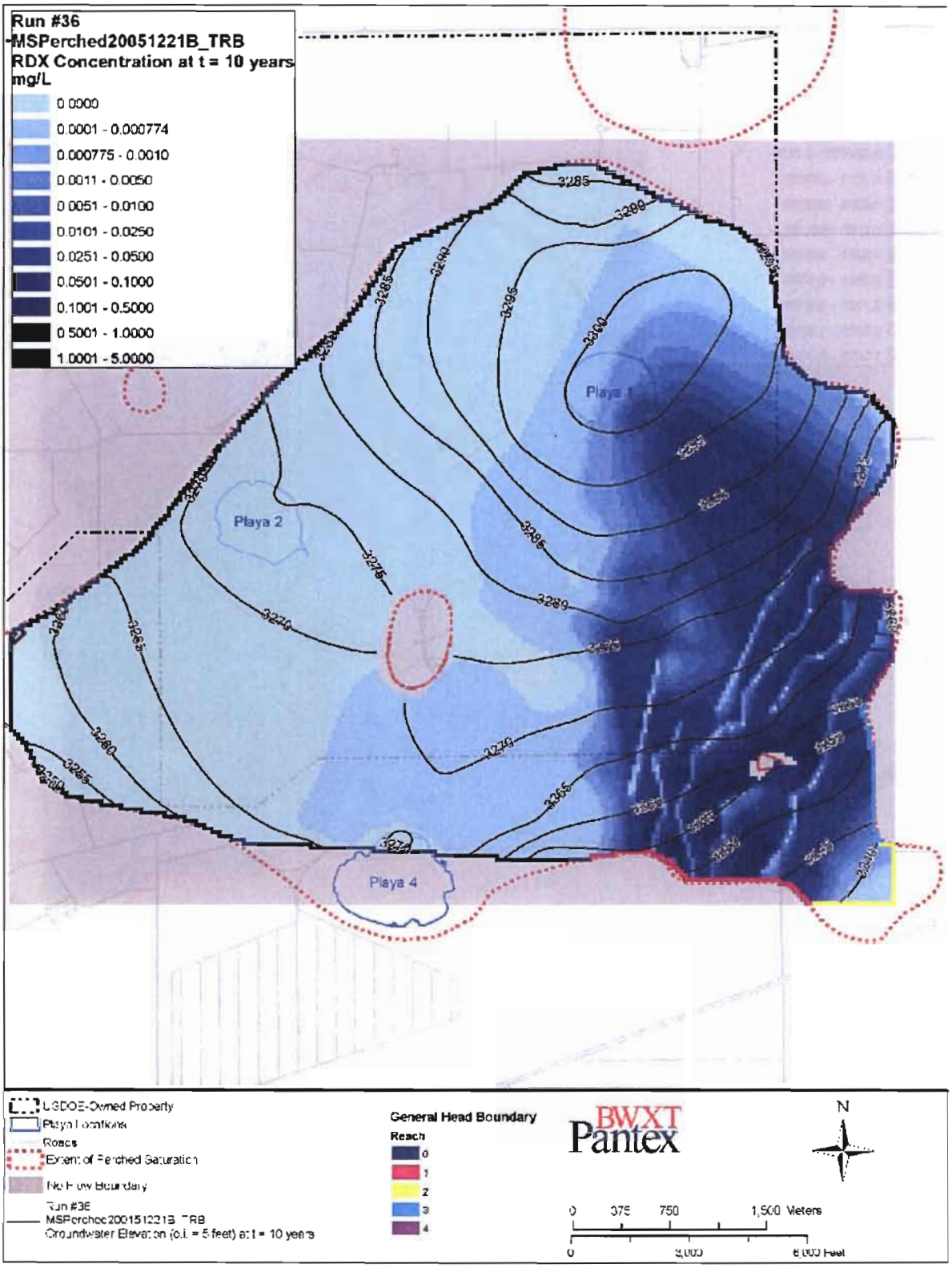

Figure 2A-11. Run 36 Simulated Water Levels and RDX Concentration at 10 Years

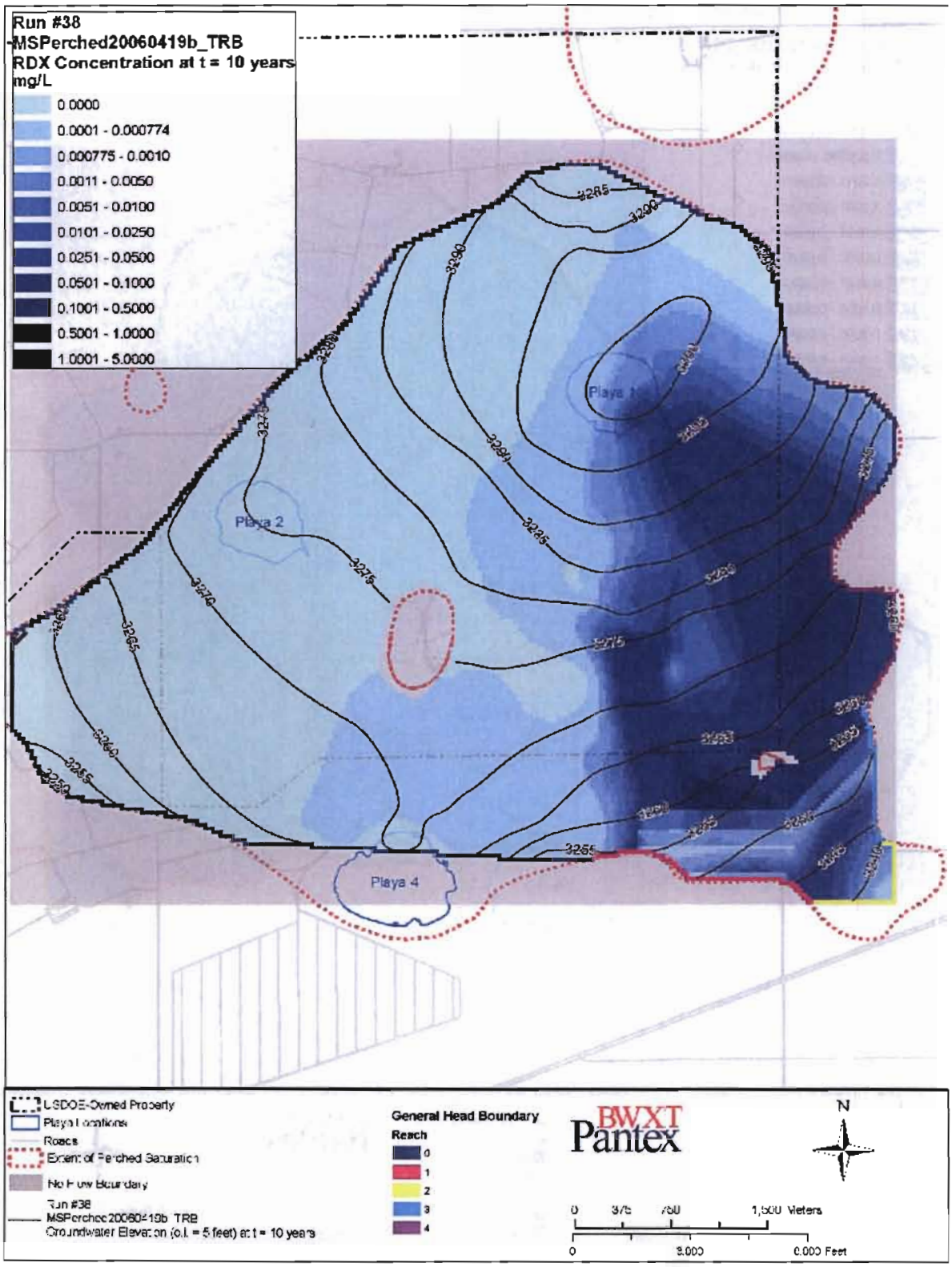

Figure 2A-12. Run 38 Simulated Water Levels and RDX Concentration at 10 Years

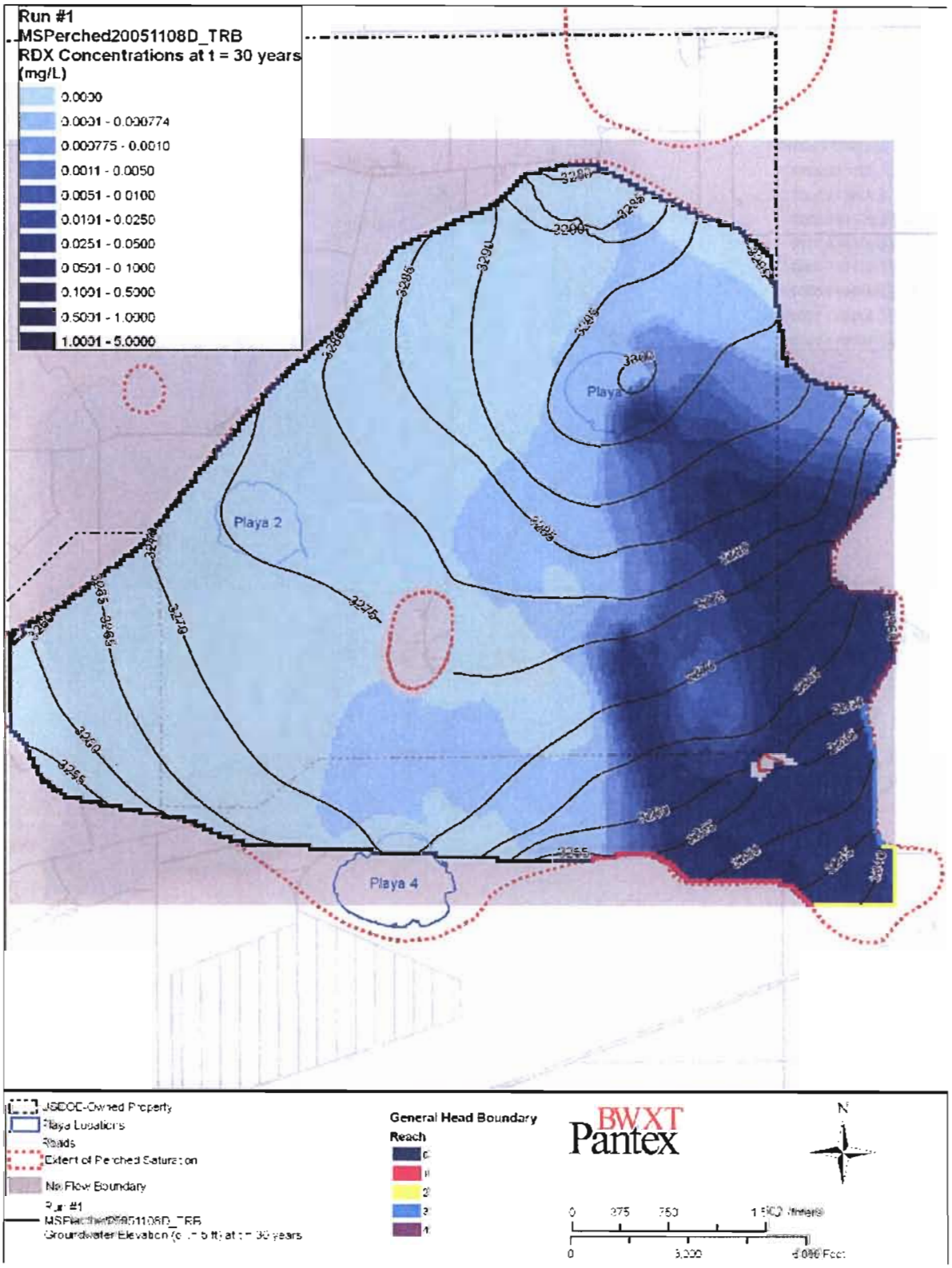

Figure 2A-13. Run 1 Simulated Water Levels and RDX Concentration at 30 Years

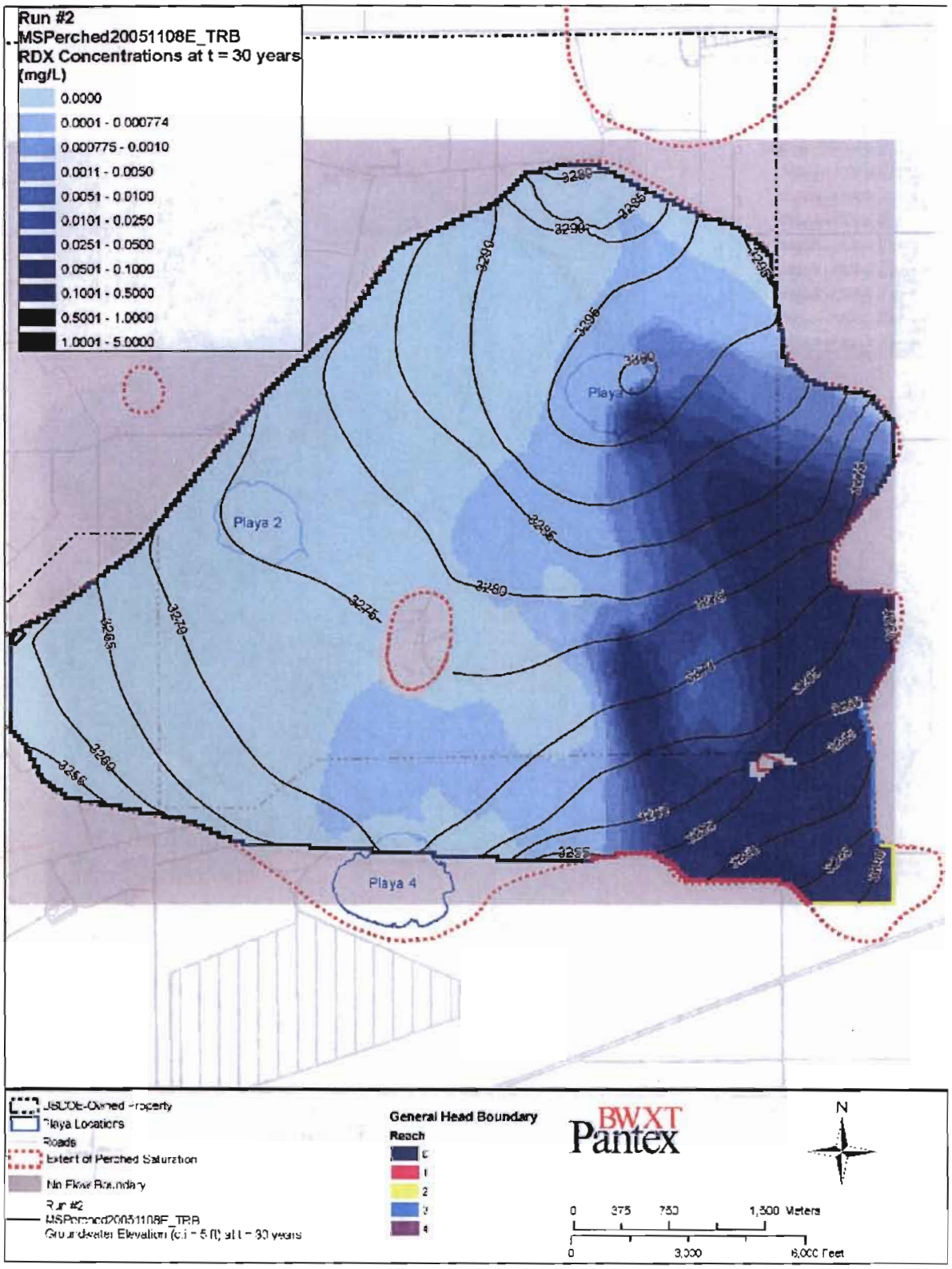

Figure 2A-14. Run 2 Simulated Water Levels and RDX Concentration at 30 Years

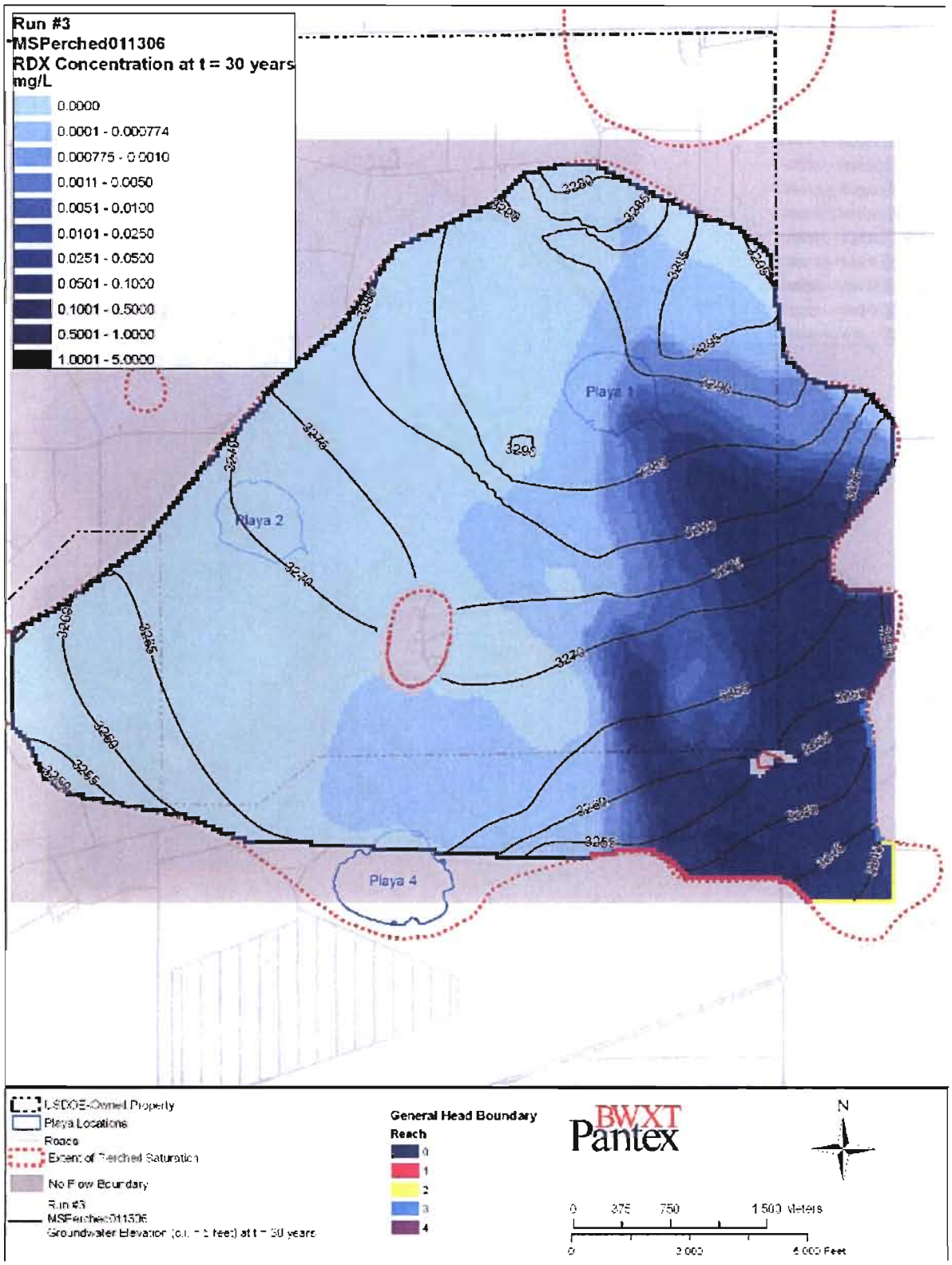

Figure 2A-15. Run 3 Simulated Water Levels and RDX Concentration at 30 Years

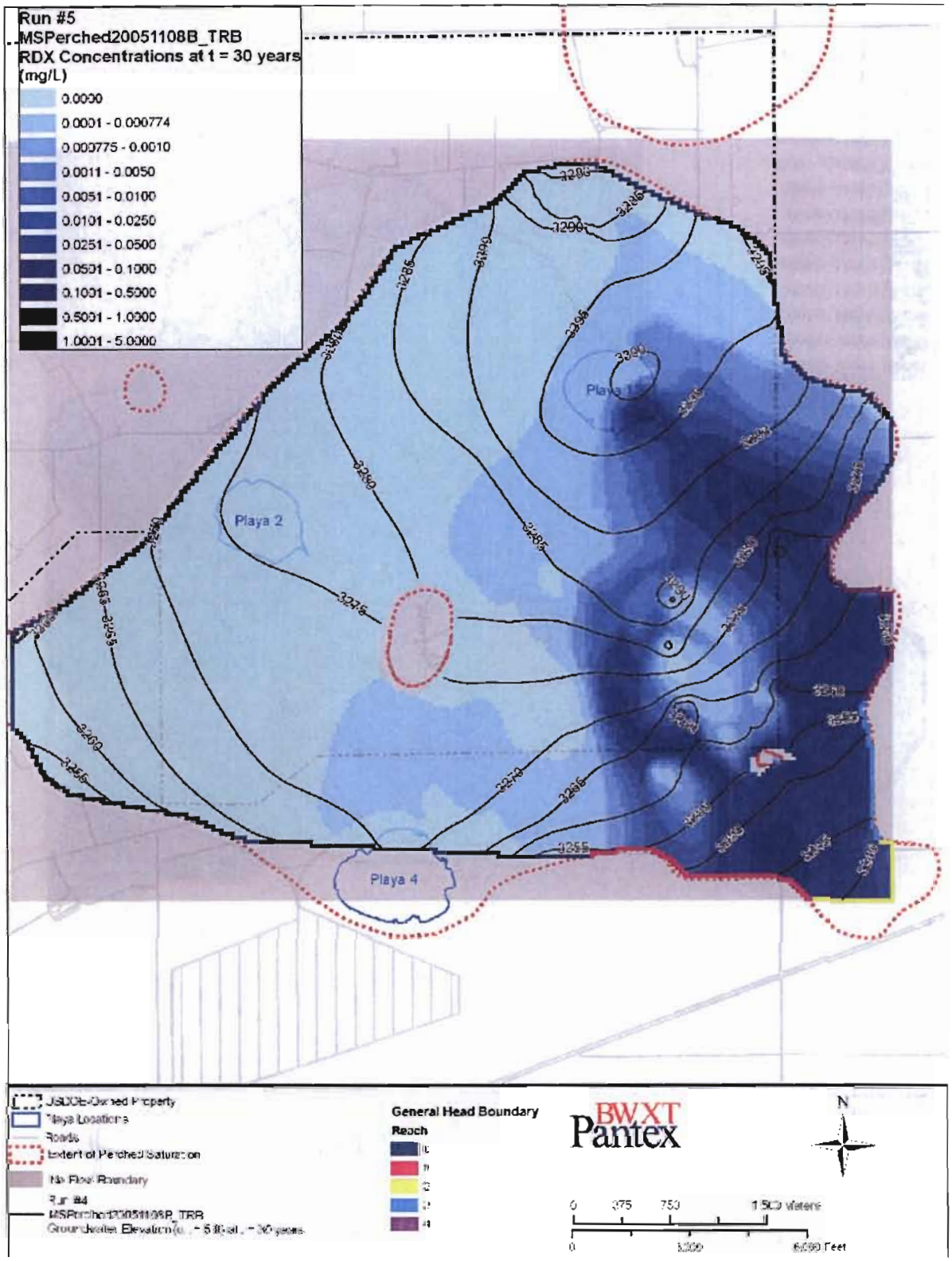

Figure 2A-16. Run 5 Simulated Water Levels and RDX Concentration at 30 Years

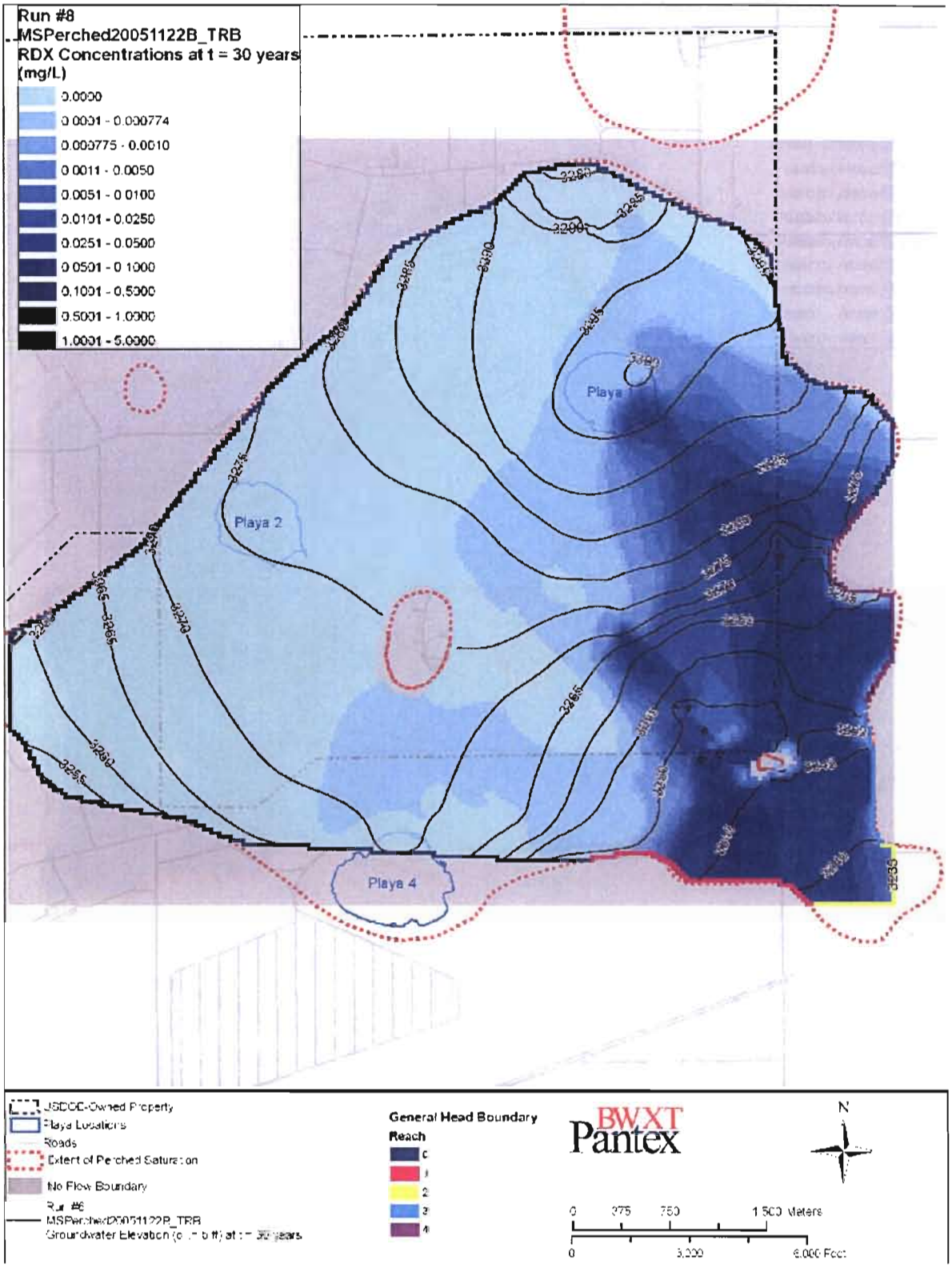

Figure 2A-17. Run 8 Simulated Water Levels and RDX Concentration at 30 Years

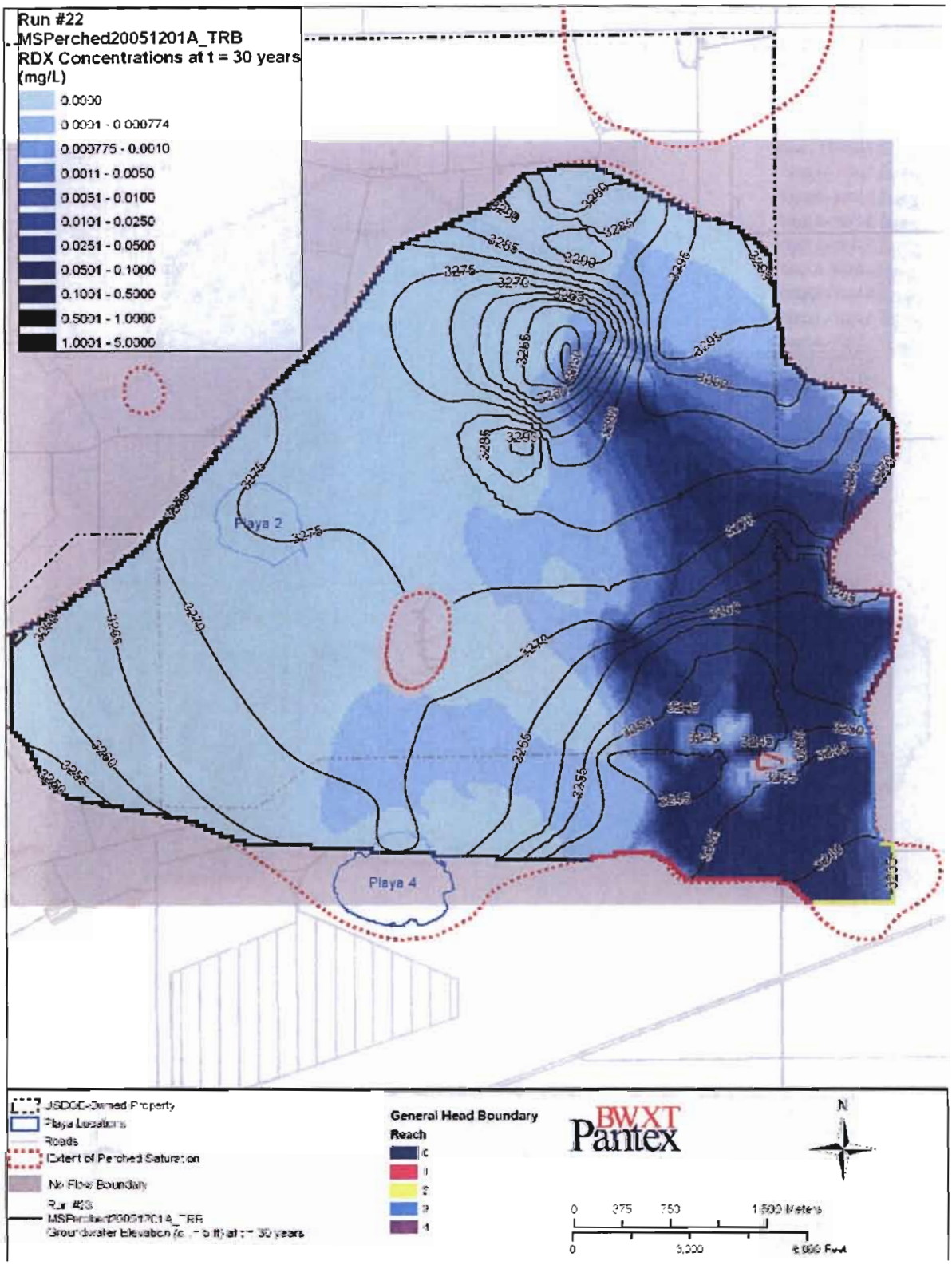

Figure 2A-18. Run 22 Simulated Water Levels and RDX Concentration at 30 Years

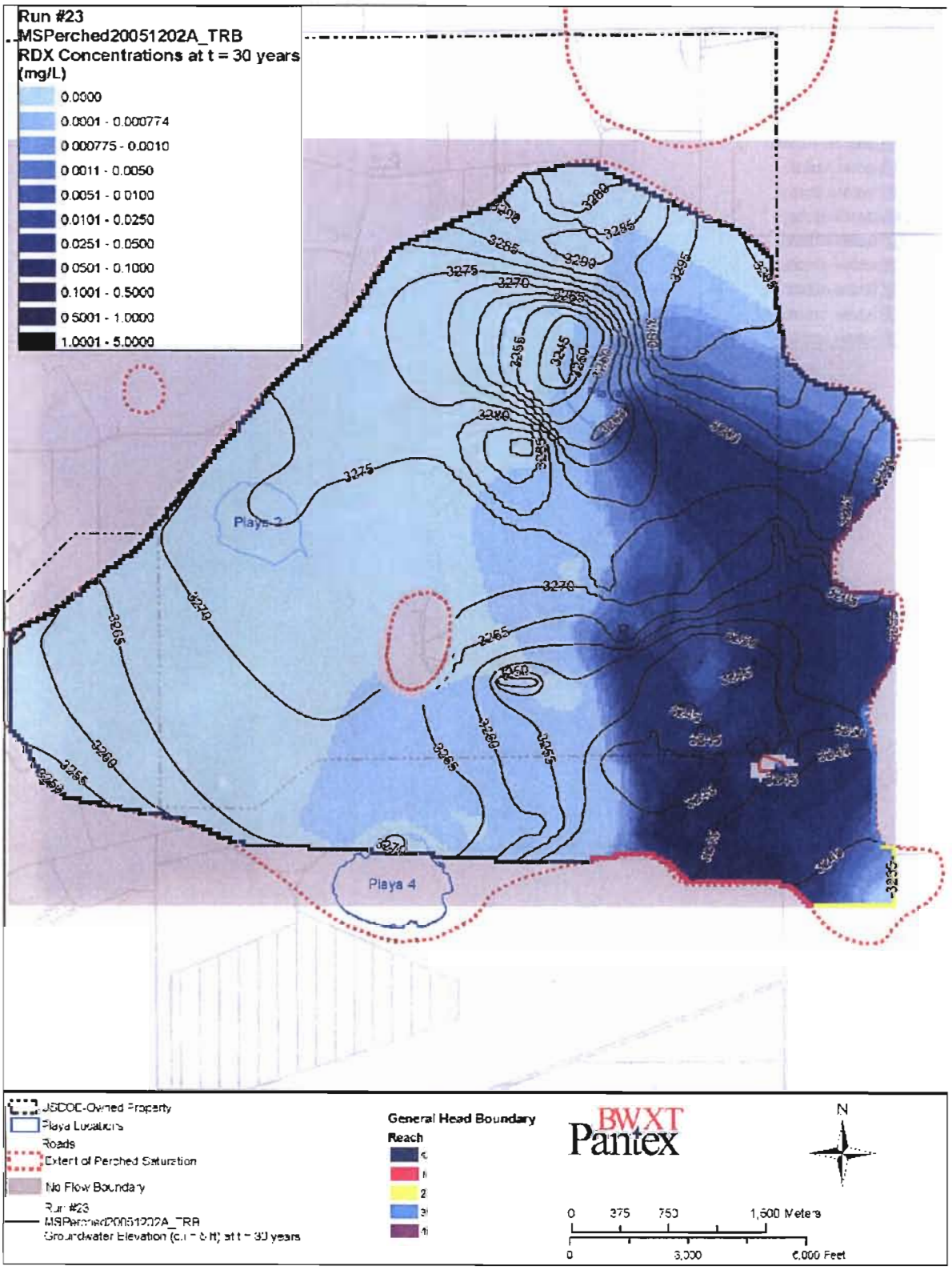

Figure 2A-19. Run 23 Simulated Water Levels and RDX Concentration at 30 Years

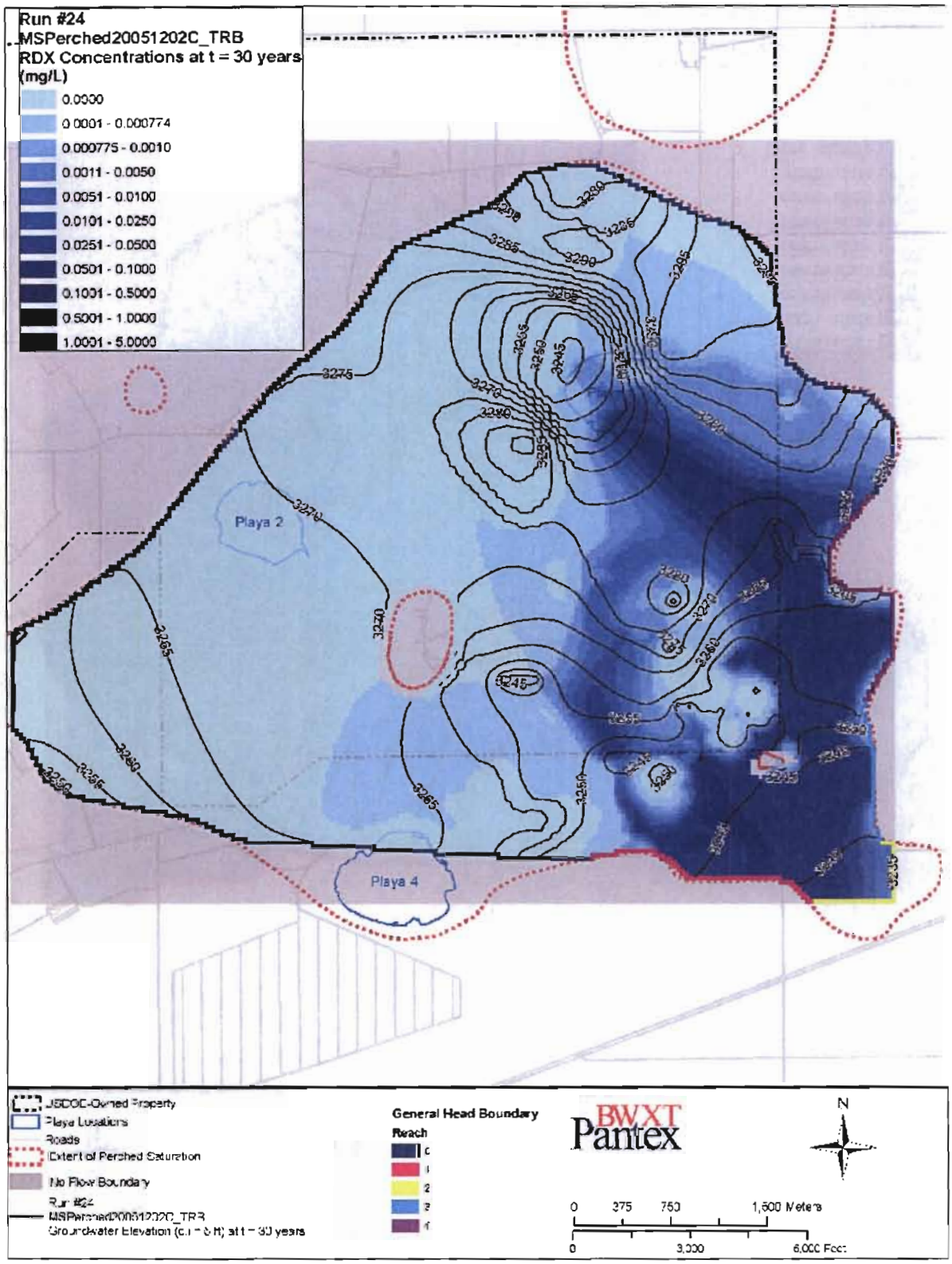

Figure 2A-20. Run 24 Simulated Water Levels and RDX Concentration at 30 Years

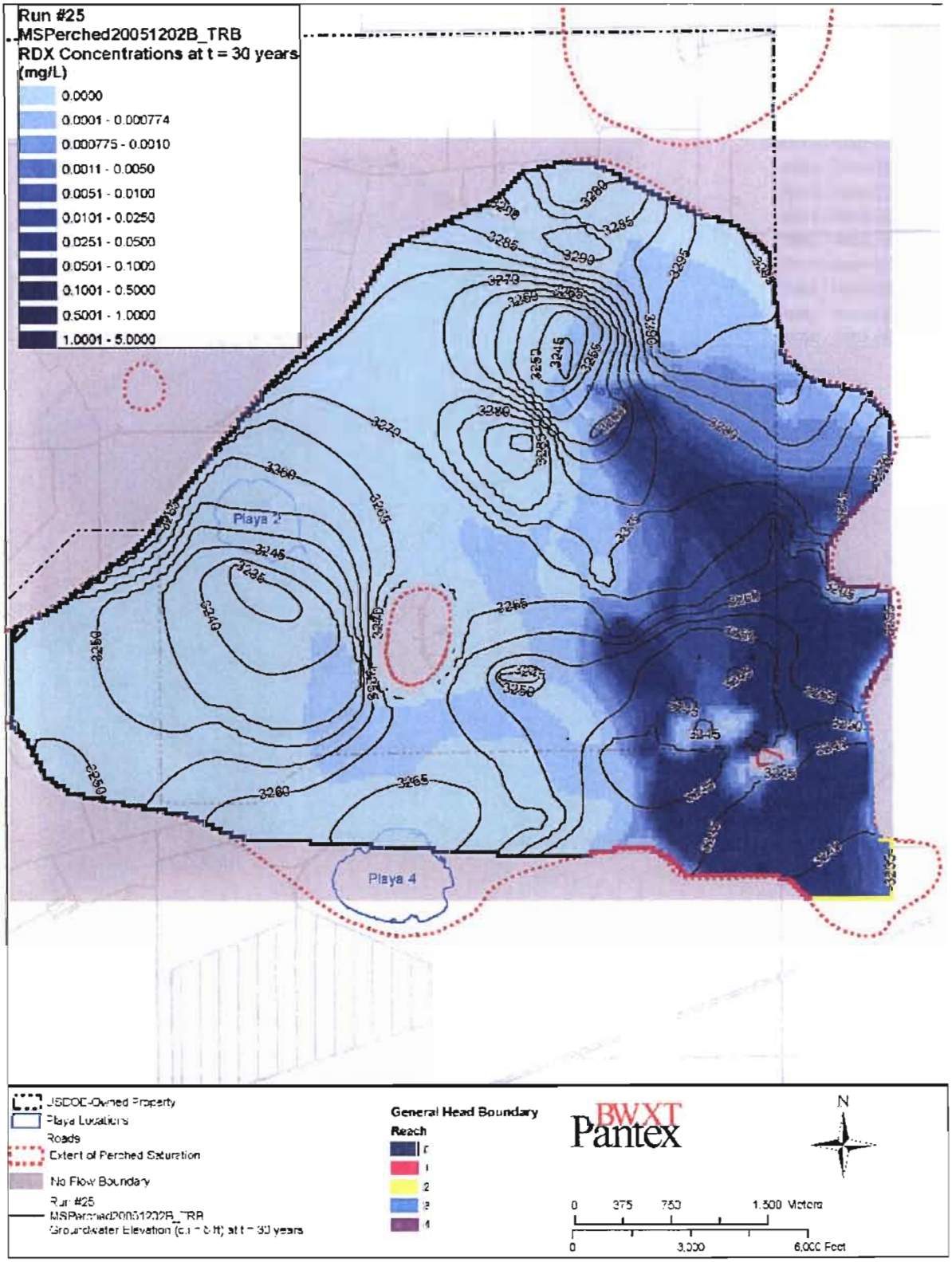

Figure 2A-21. Run 25 Simulated Water Levels and RDX Concentration at 30 Years

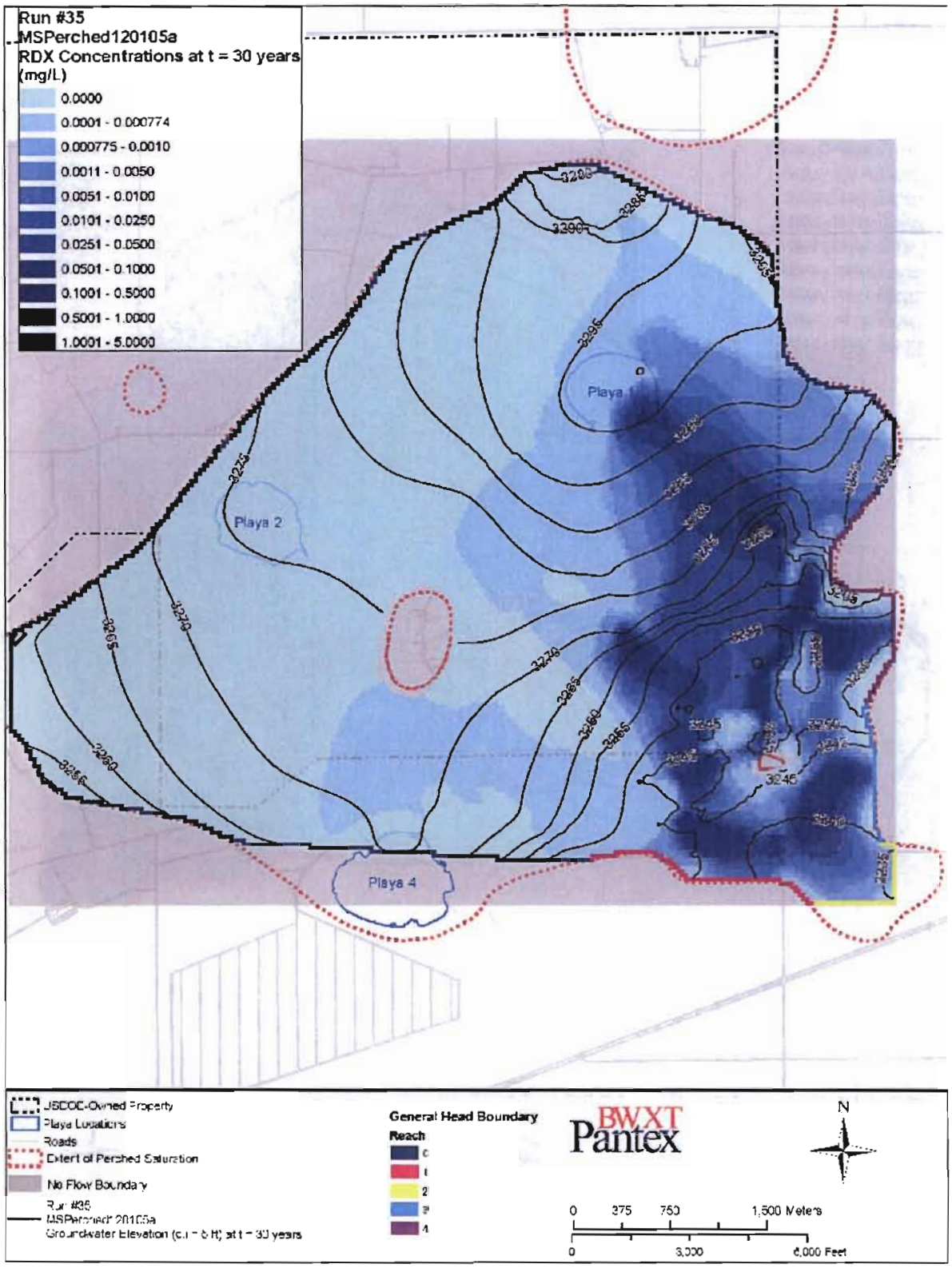

Figure 2A-22. Run 35 Simulated Water Levels and RDX Concentration at 30 Years

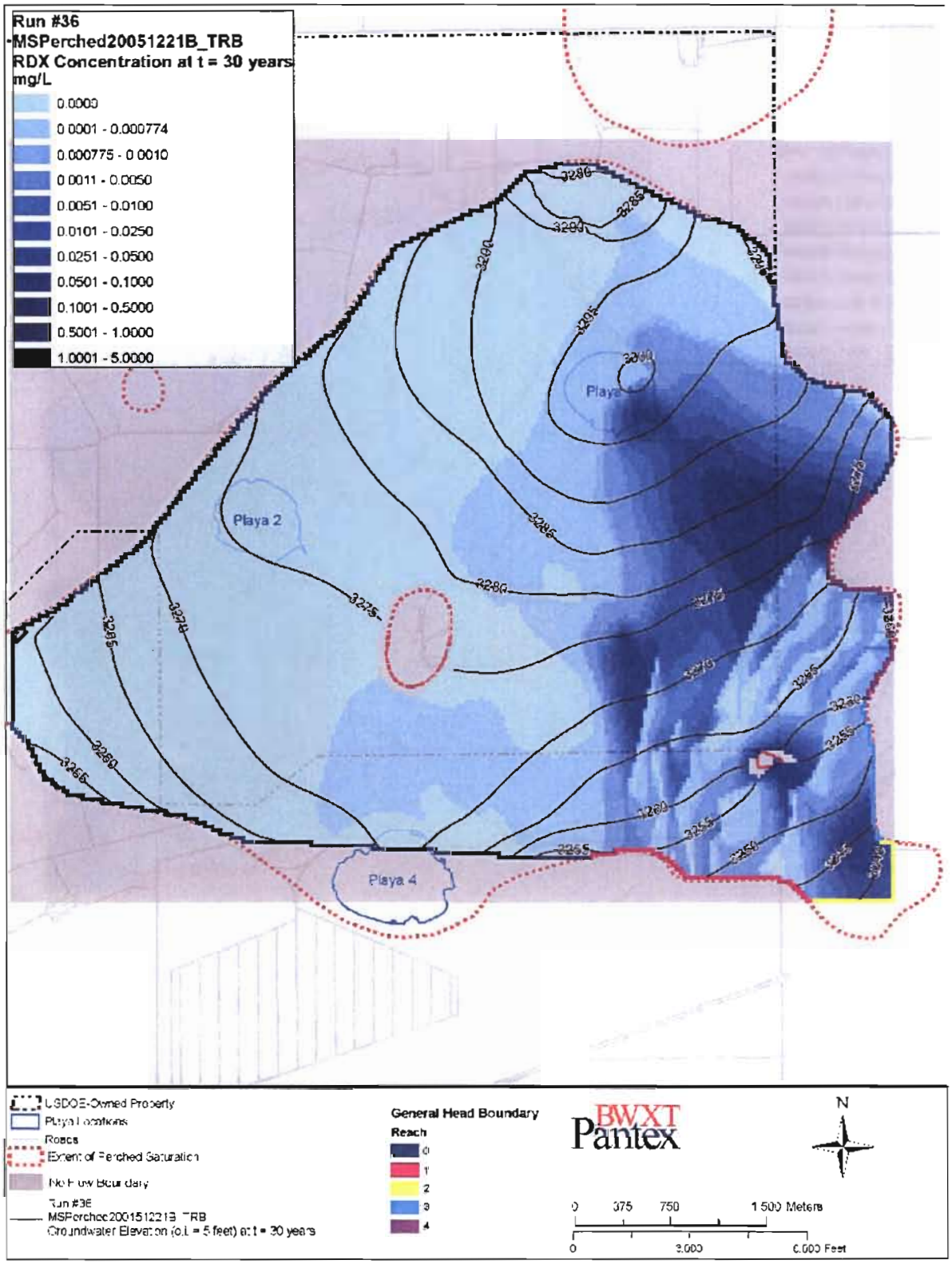

Figure 2A-23. Run 36 Simulated Water Levels and RDX Concentration at 30 Years

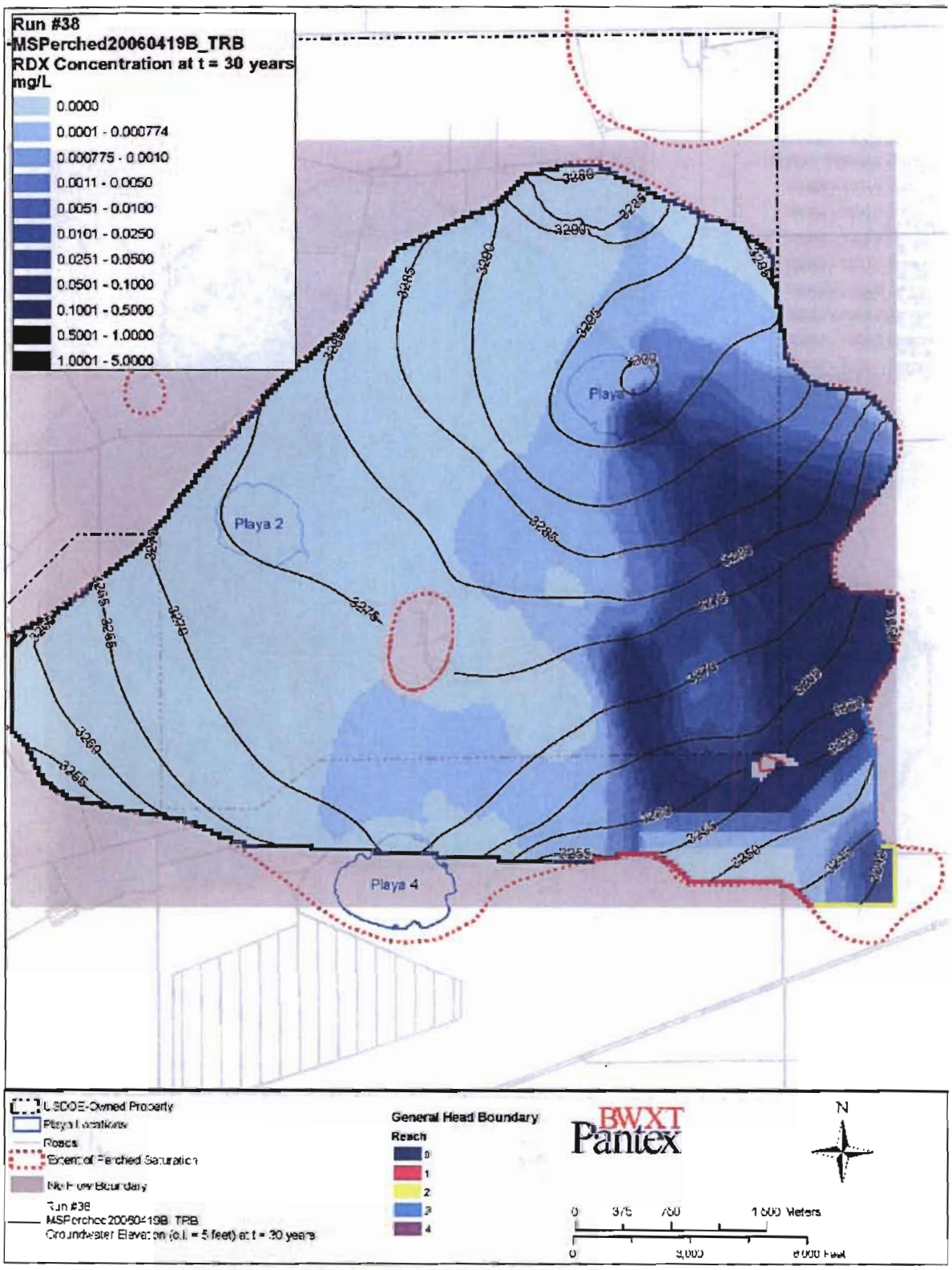

Figure 2A-24. Run 38 Simulated Water Levels and RDX Concentration at 30 Years

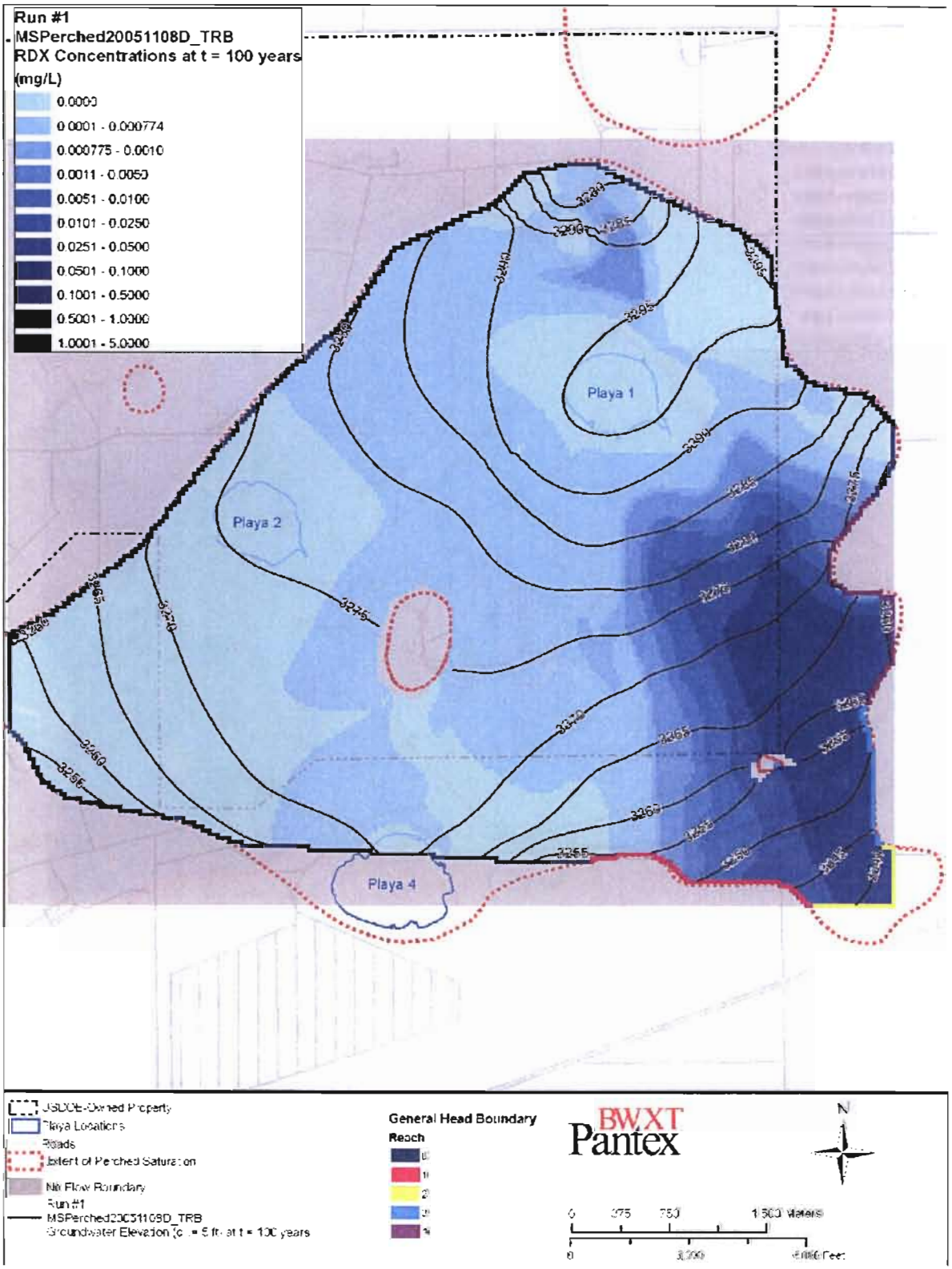

Figure 2A-25. Run 1 Simulated Water Levels and RDX Concentration at 100 Years

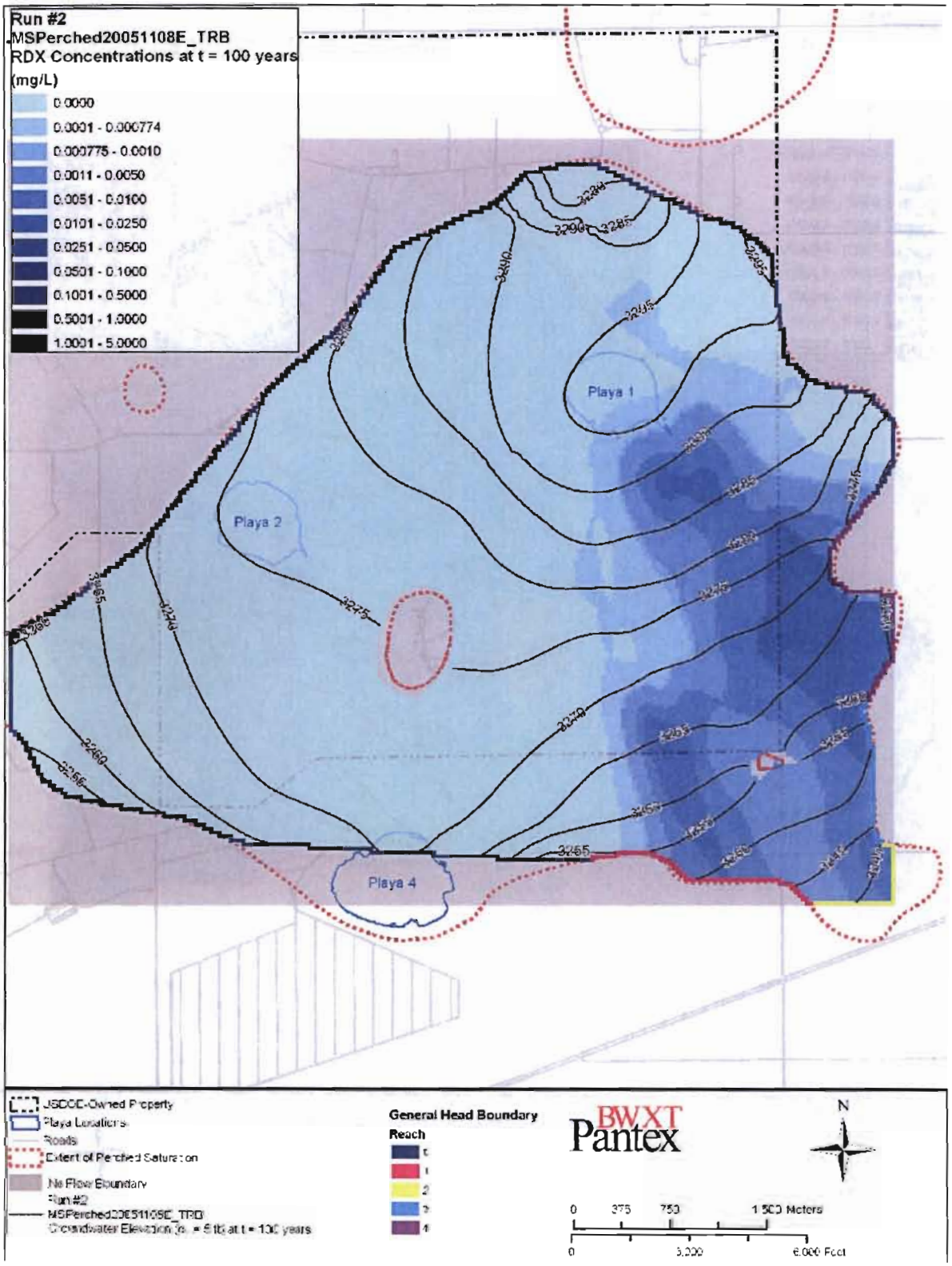

Figure 2A-26. Run 2 Simulated Water Levels and RDX Concentration at 100 Years

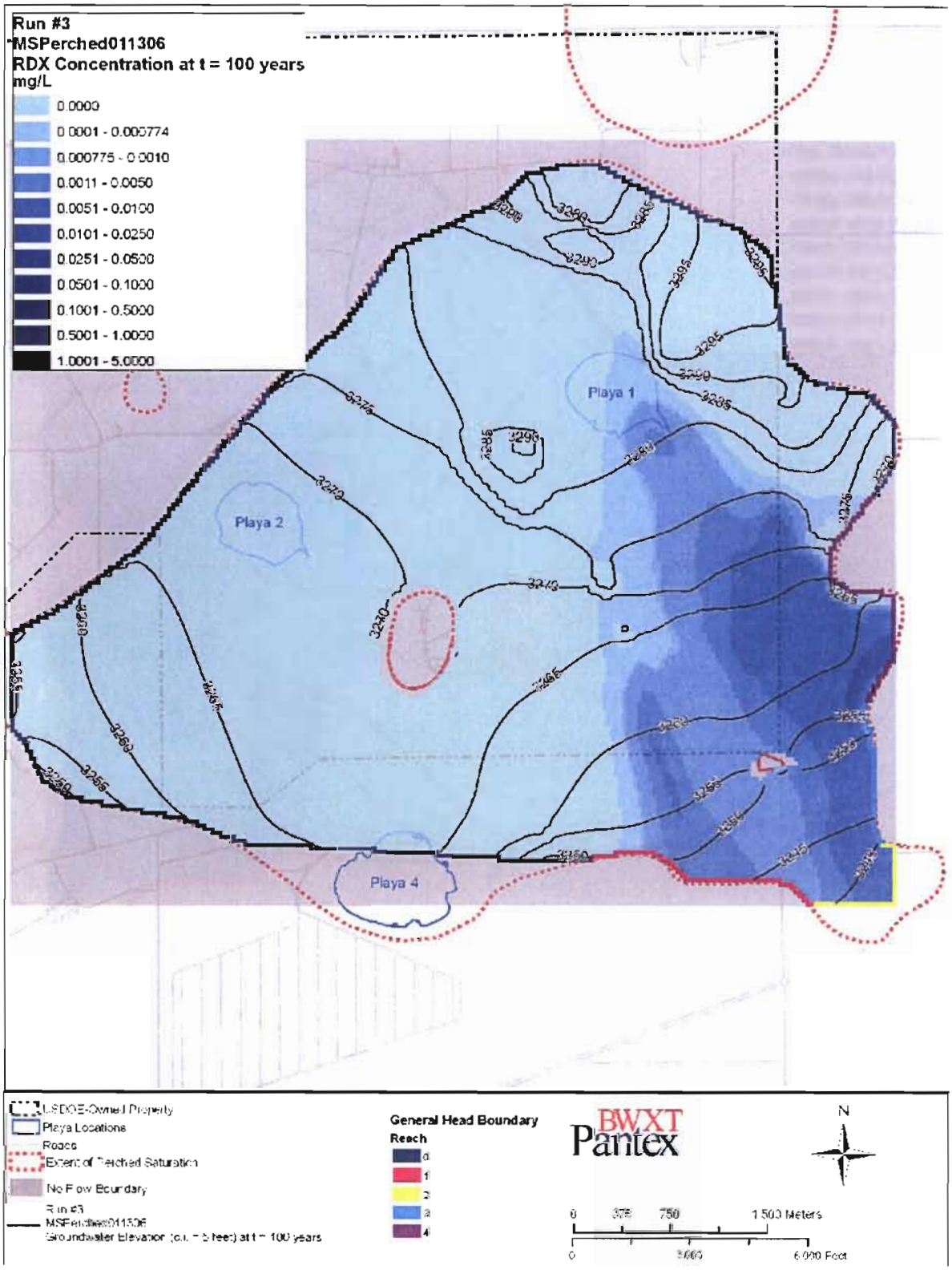

Figure 2A-27. Run 3 Simulated Water Levels and RDX Concentration at 100 Years

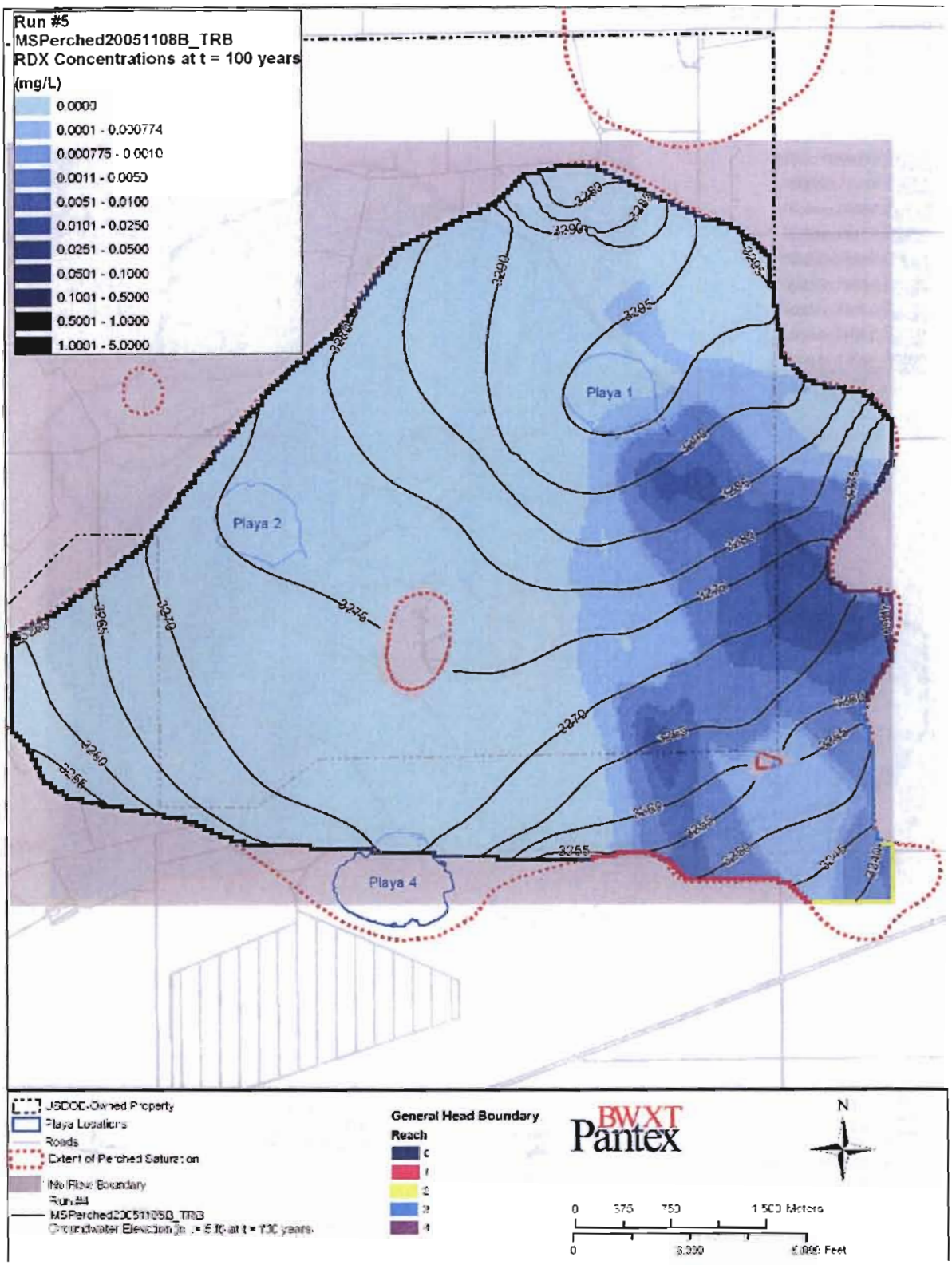

Figure 2A-28. Run 5 Simulated Water Levels and RDX Concentration at 100 Years

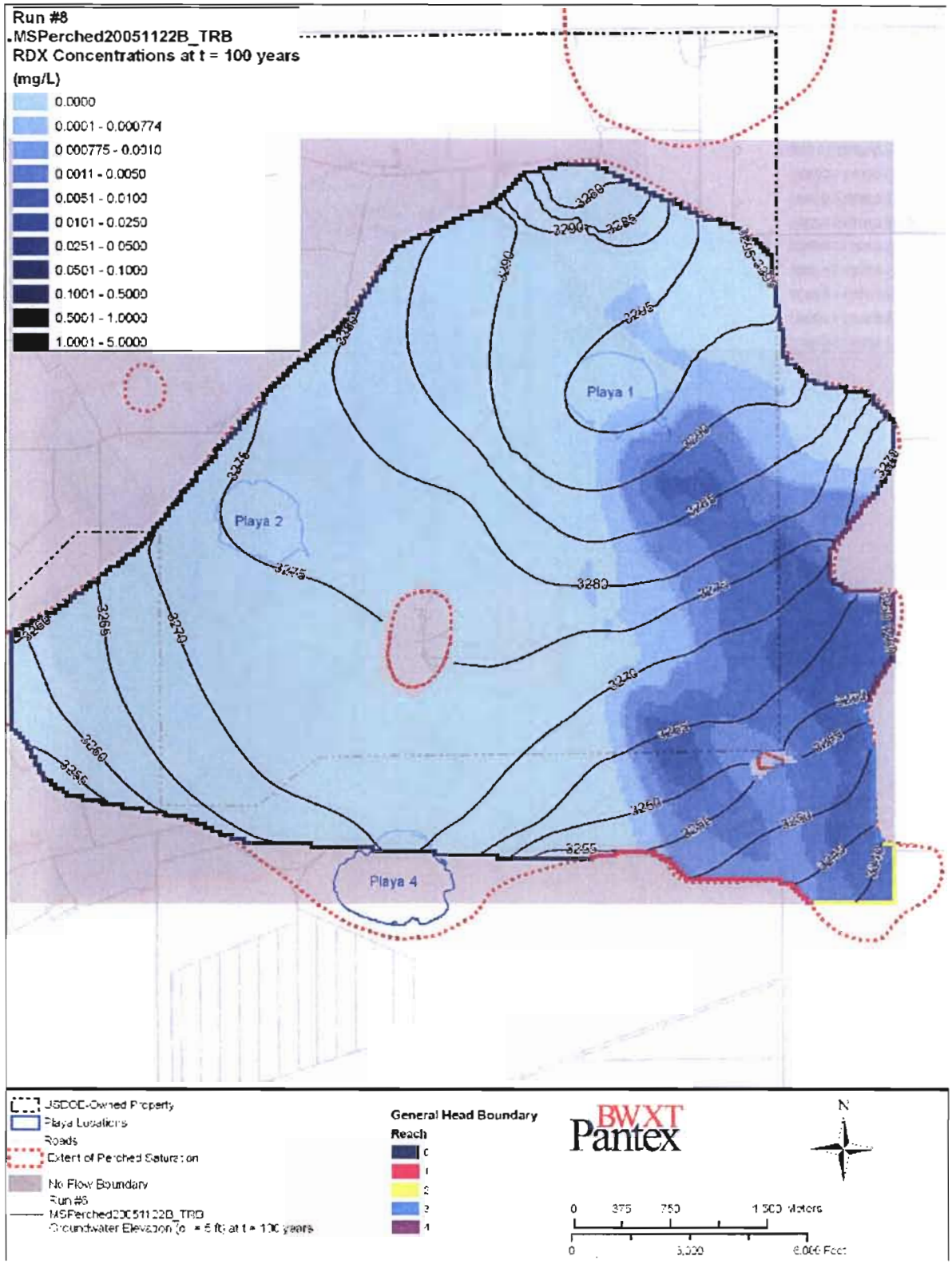

Figure 2A-29. Run 8 Simulated Water Levels and RDX Concentration at 100 Years

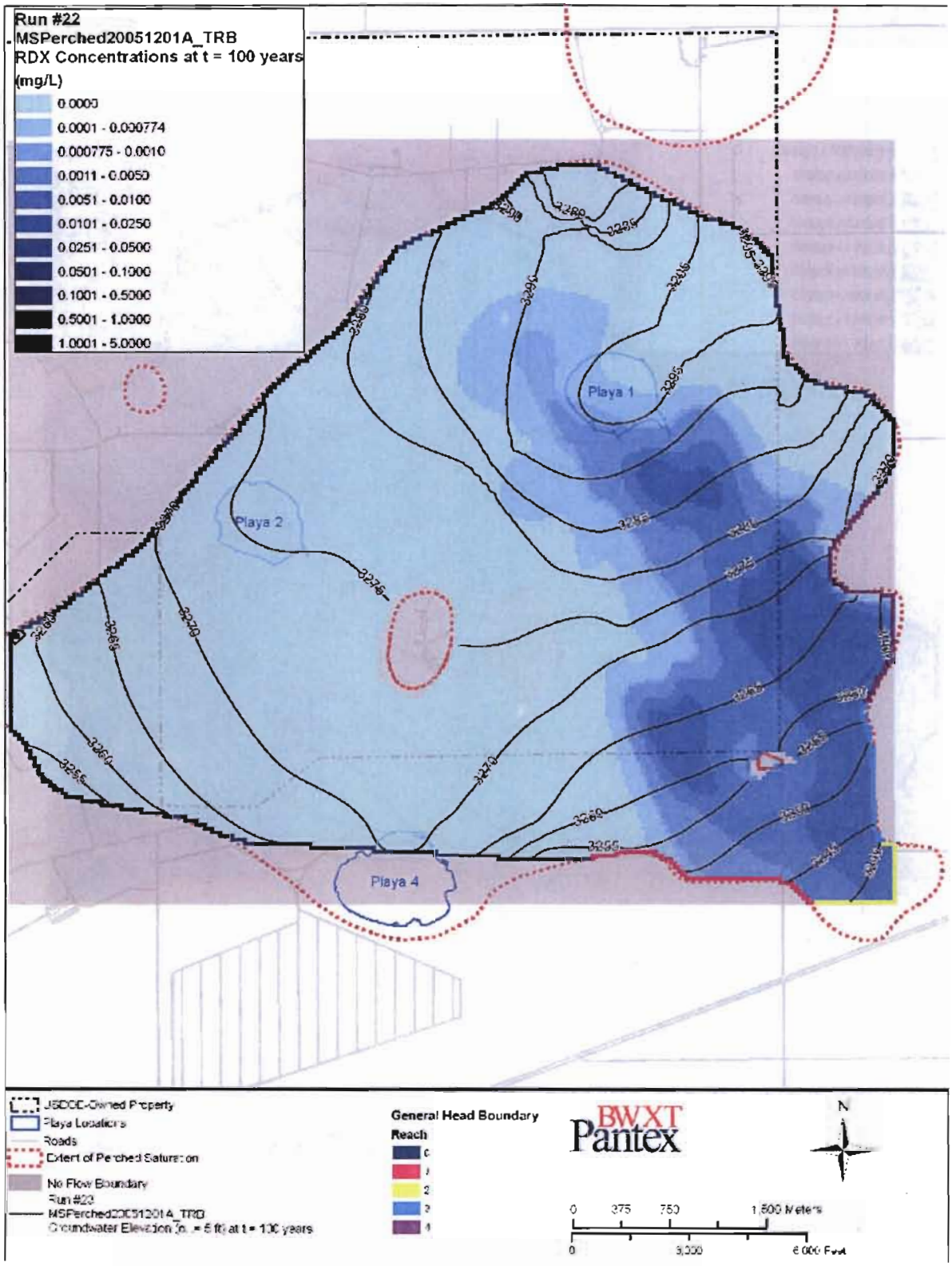

Figure 2A-30. Run 22 Simulated Water Levels and RDX Concentration at 100 Years

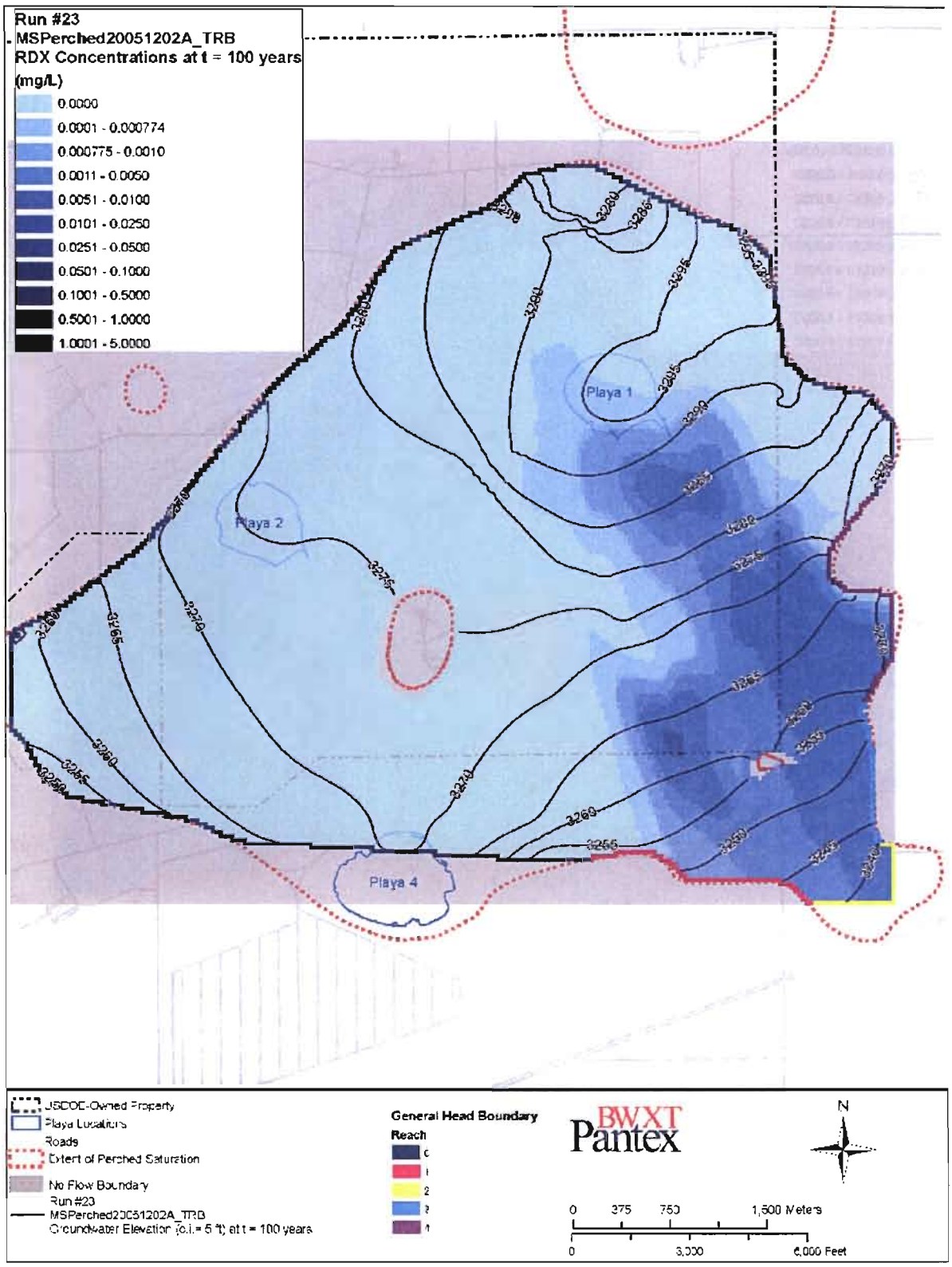

Figure 2A-31. Run 23 Simulated Water Levels and RDX Concentration at 100 Years

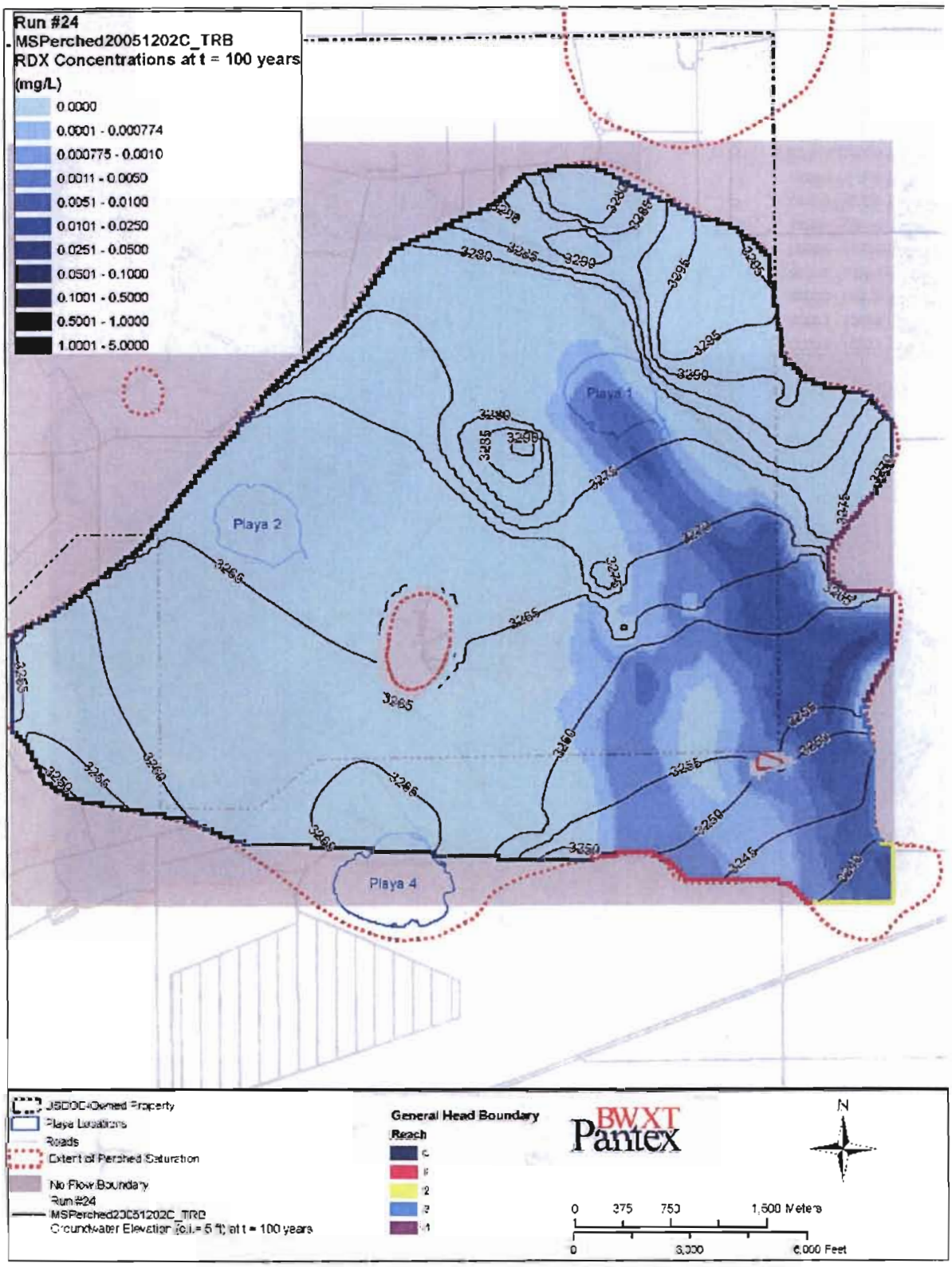

Figure 2A-32. Run 24 Simulated Water Levels and RDX Concentration at 100 Years

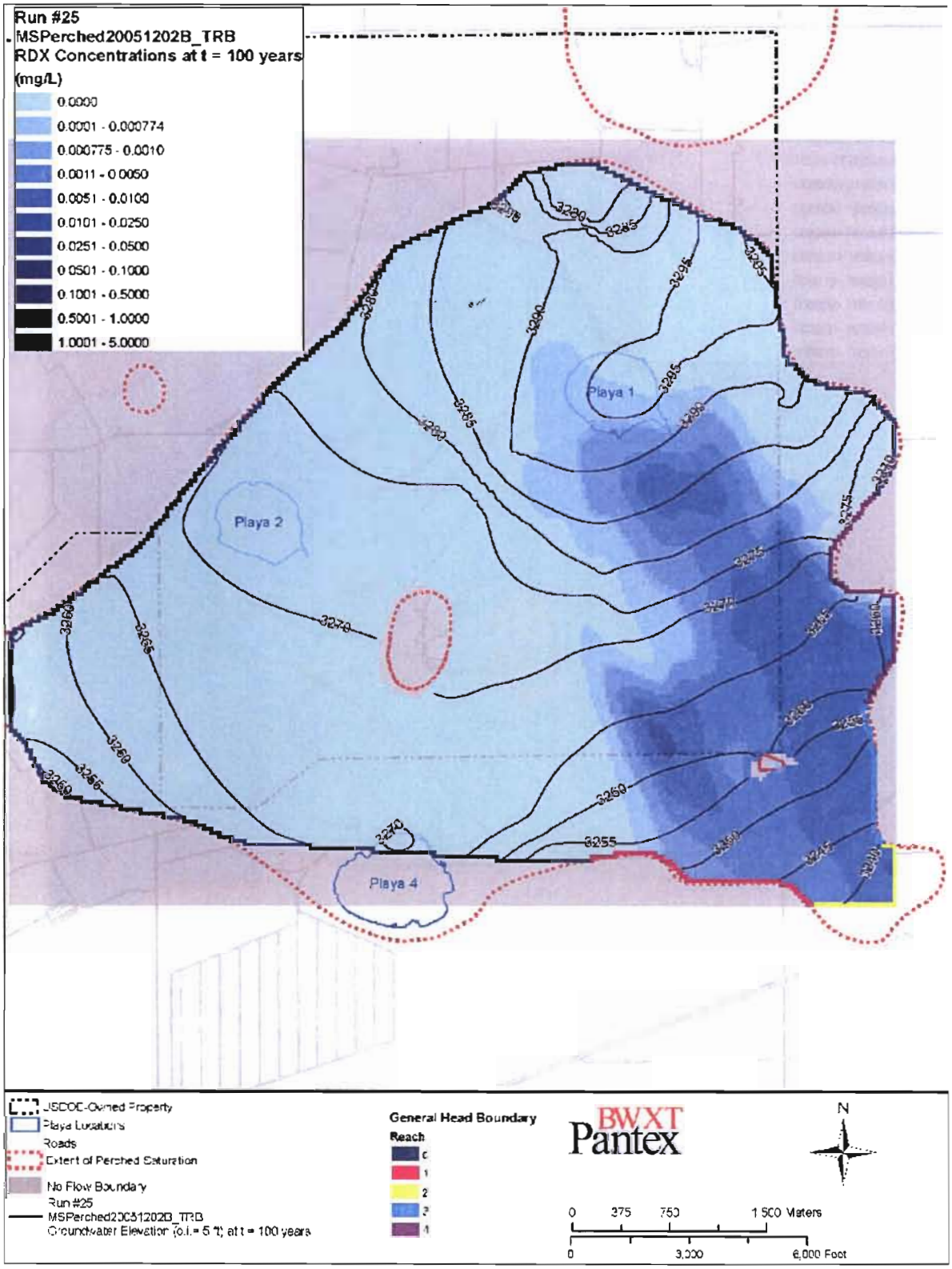

Figure 2A-33. Run 25 Simulated Water Levels and RDX Concentration at 100 Years

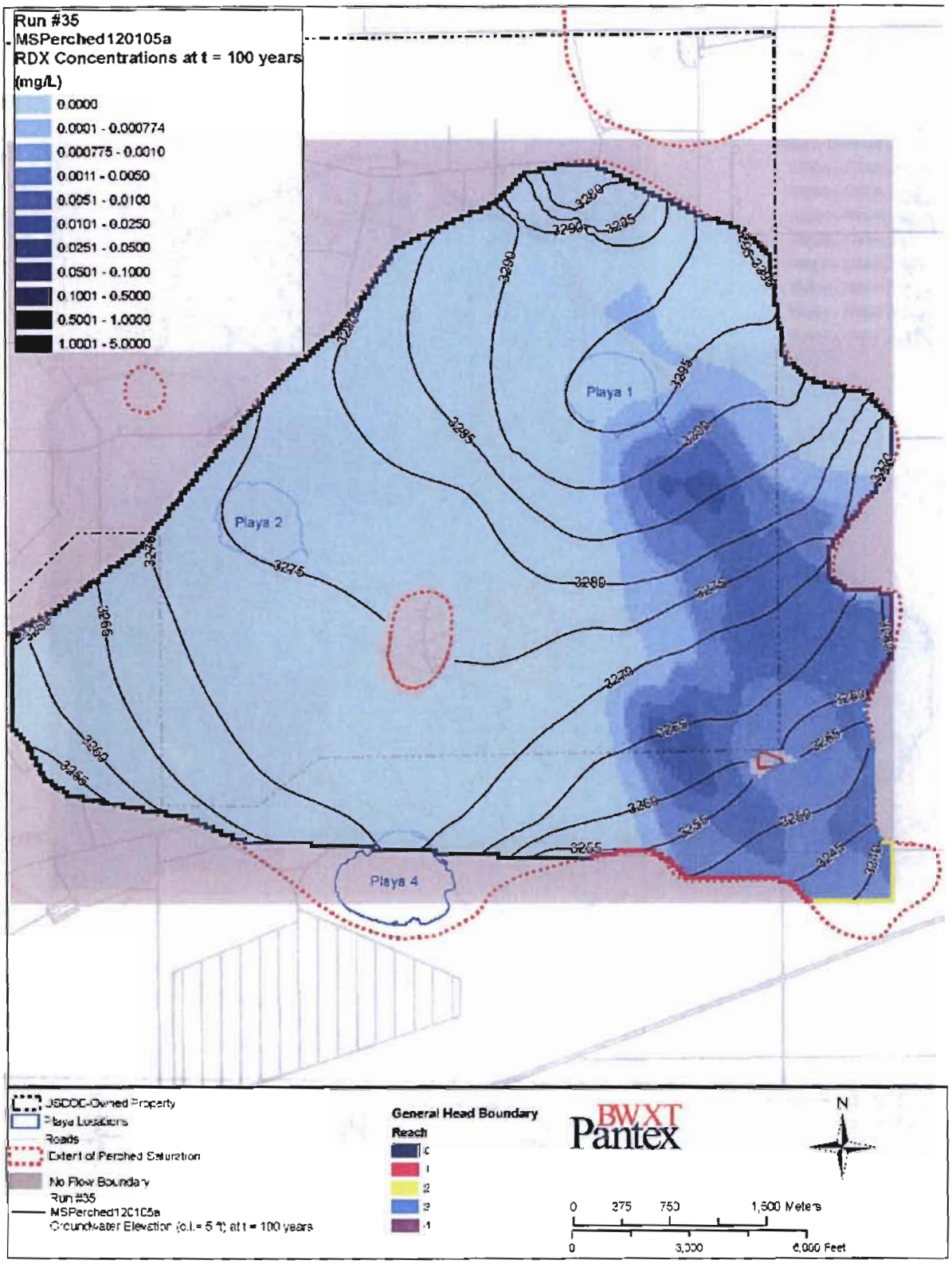

Figure 2A-34. Run 35 Simulated Water Levels and RDX Concentration at 100 Years

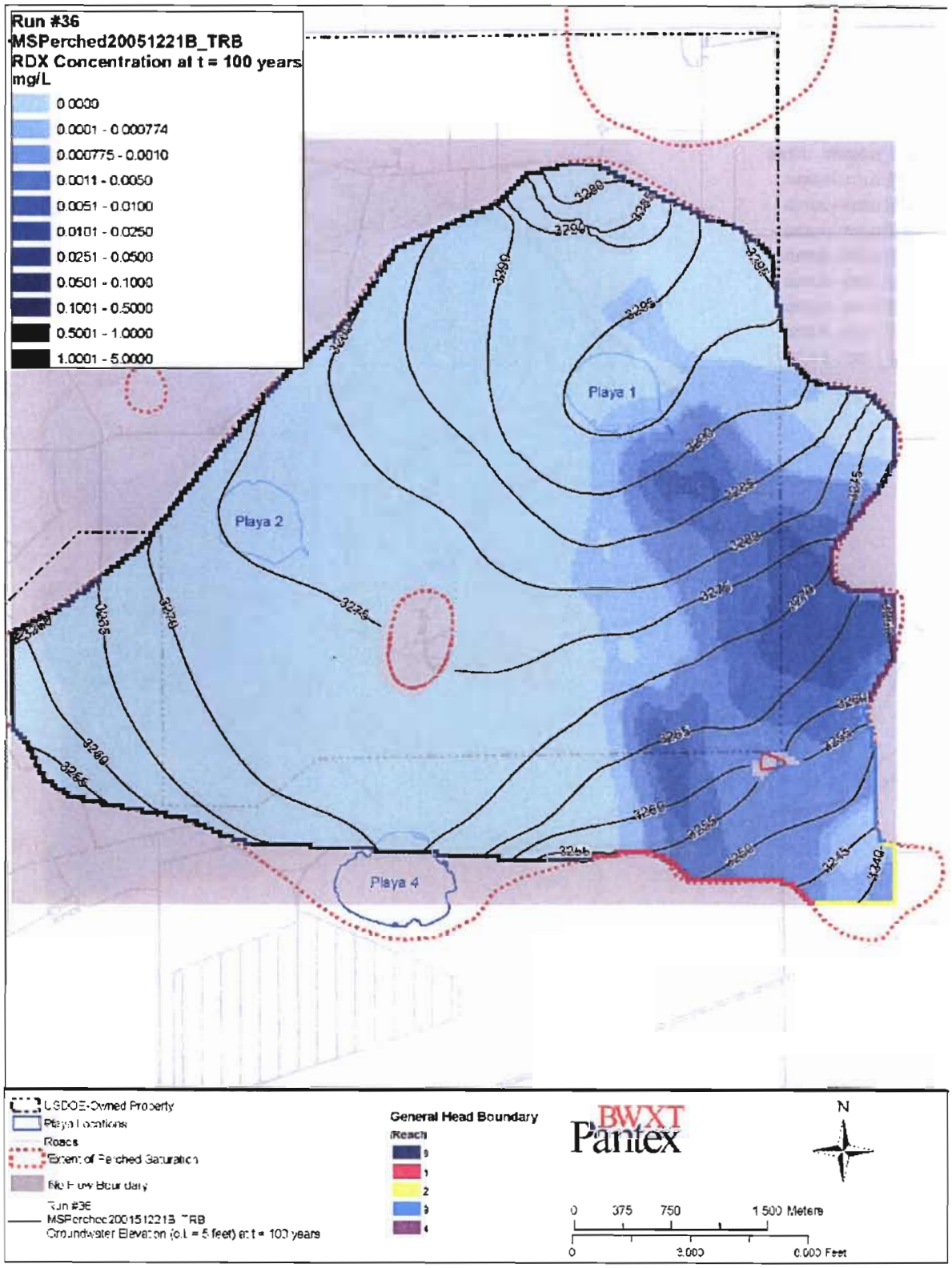

Figure 2A-35. Run 36 Simulated Water Levels and RDX Concentration at 100 Years

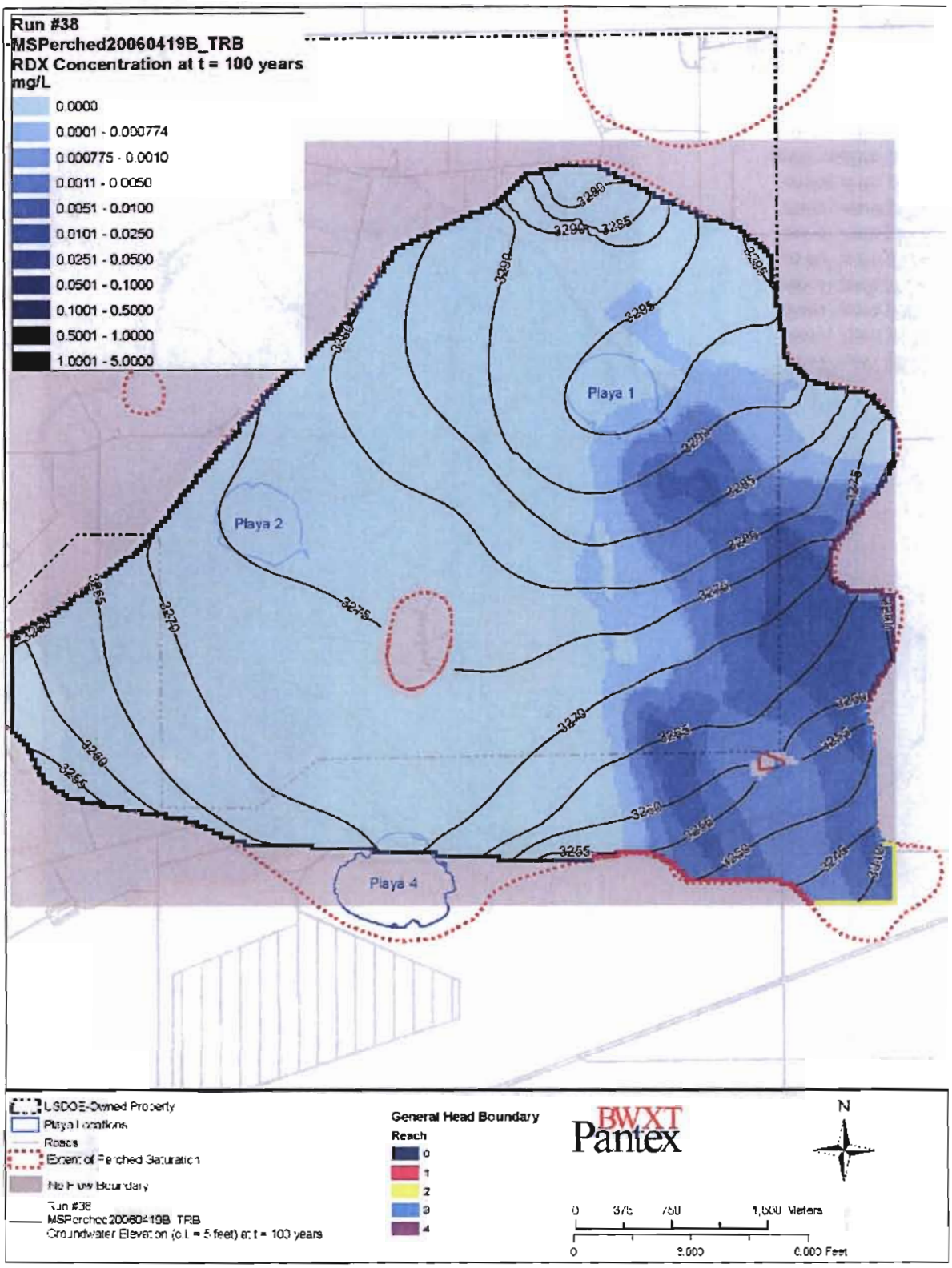

Figure 2A-36. Run 38 Simulated Water Levels and RDX Concentration at 100 Years

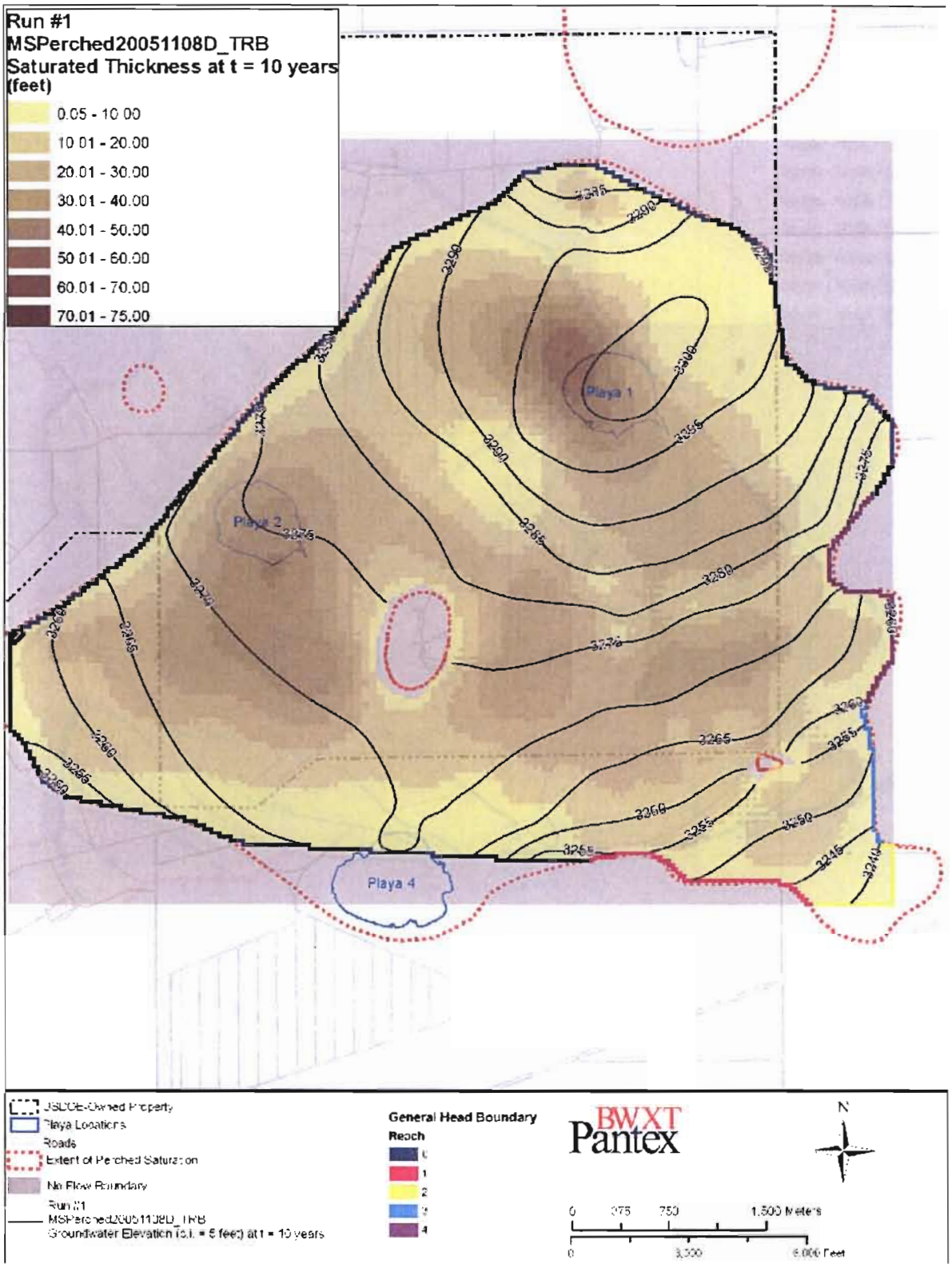

Figure 2A-37. Run 1 Simulated Water Levels and Saturated Thickness at 10 Years

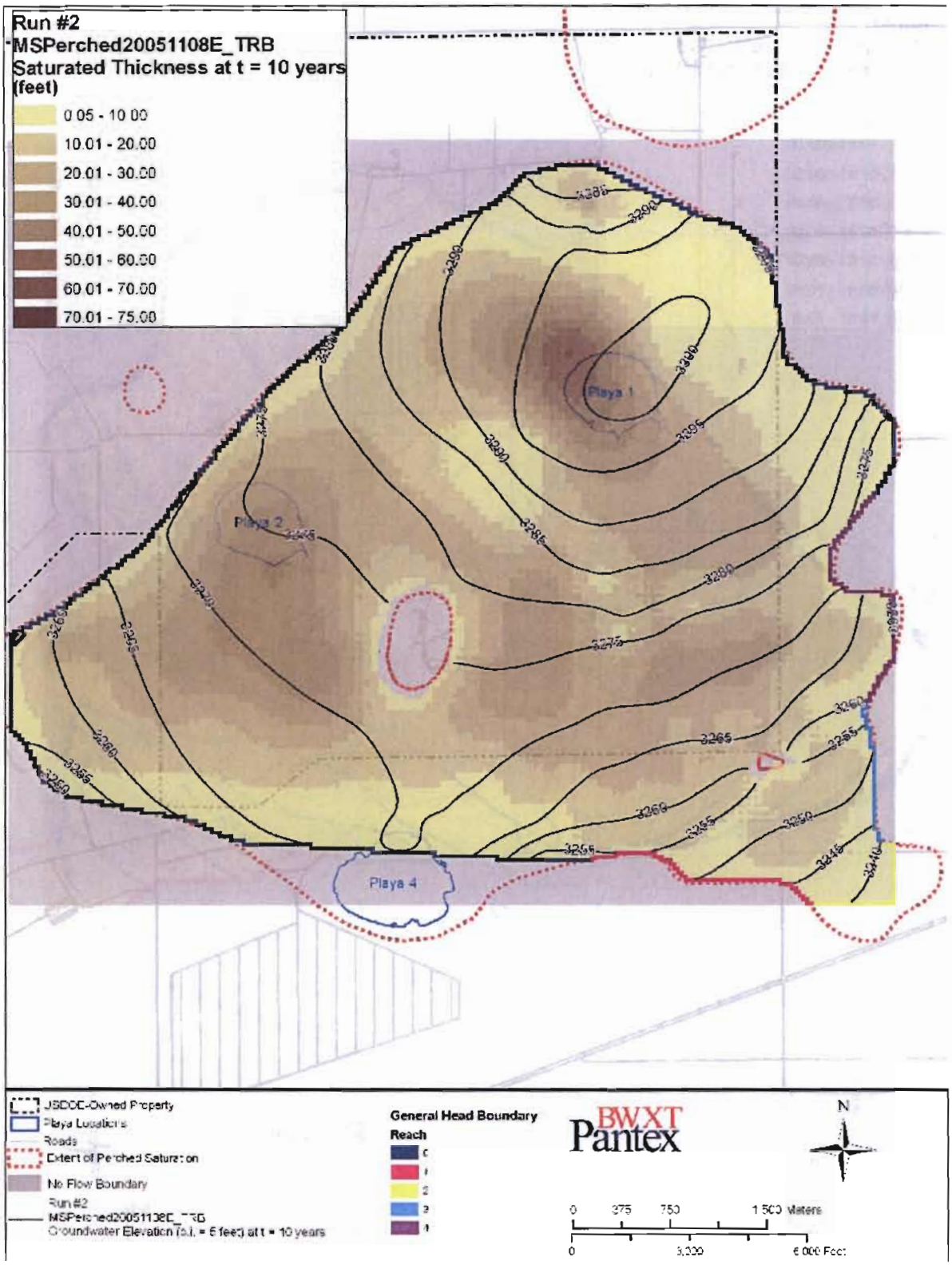

Figure 2A-38. Run 2 Simulated Water Levels and Saturated Thickness at 10 Years

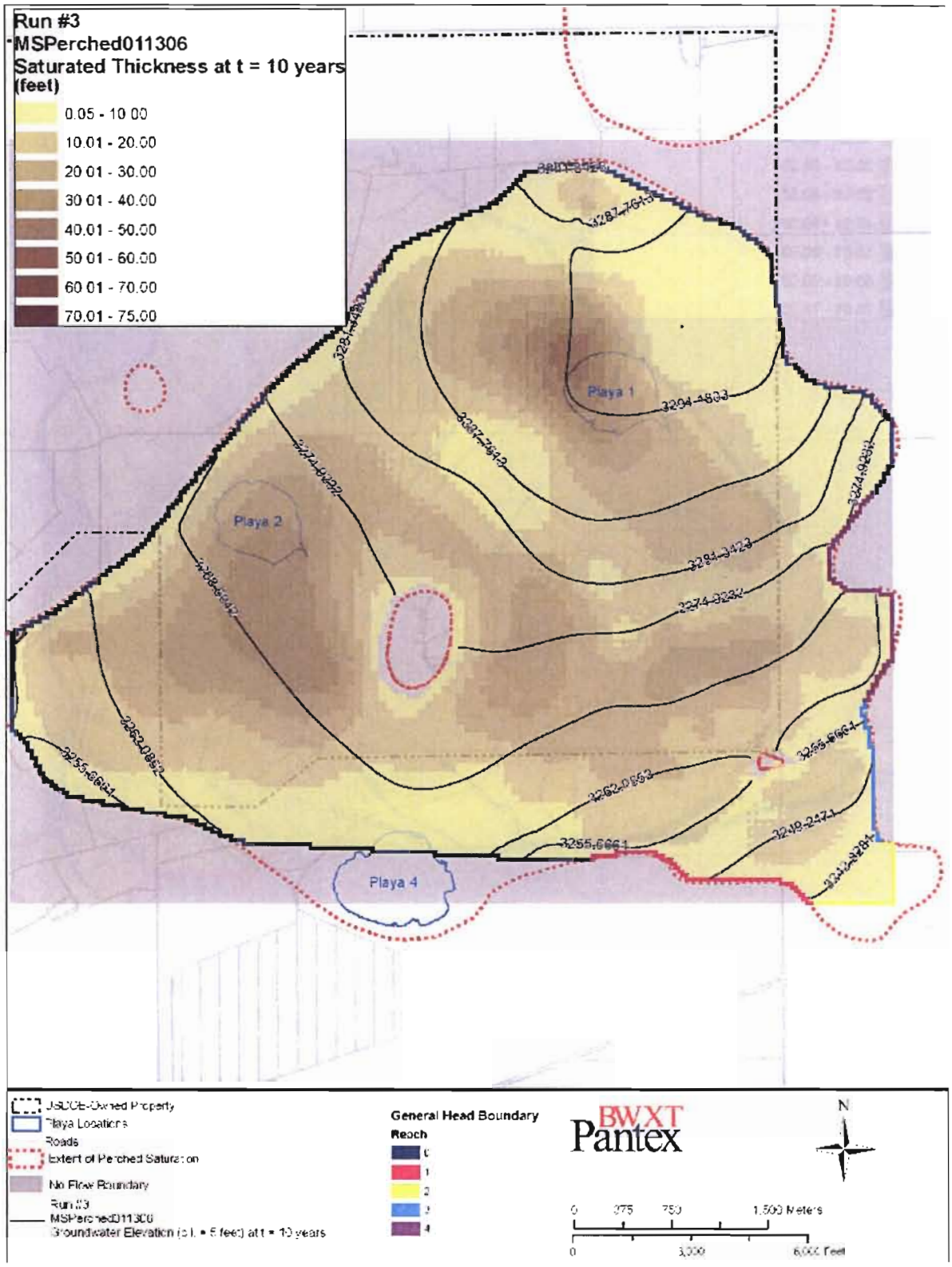

Figure 2A-39. Run 3 Simulated Water Levels and Saturated Thickness at 10 Years

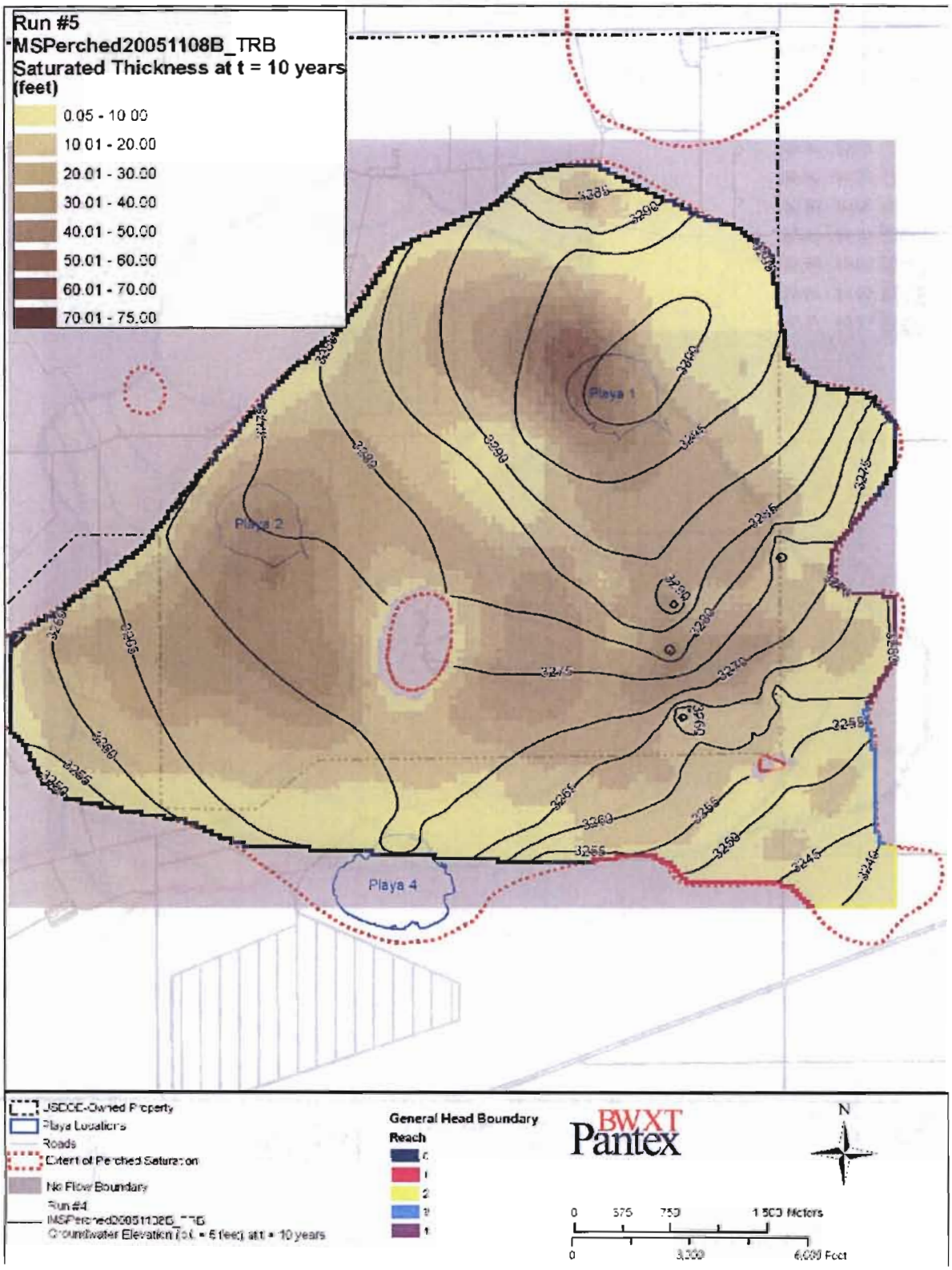

Figure 2A-40. Run 5 Simulated Water Levels and Saturated Thickness at 10 Years

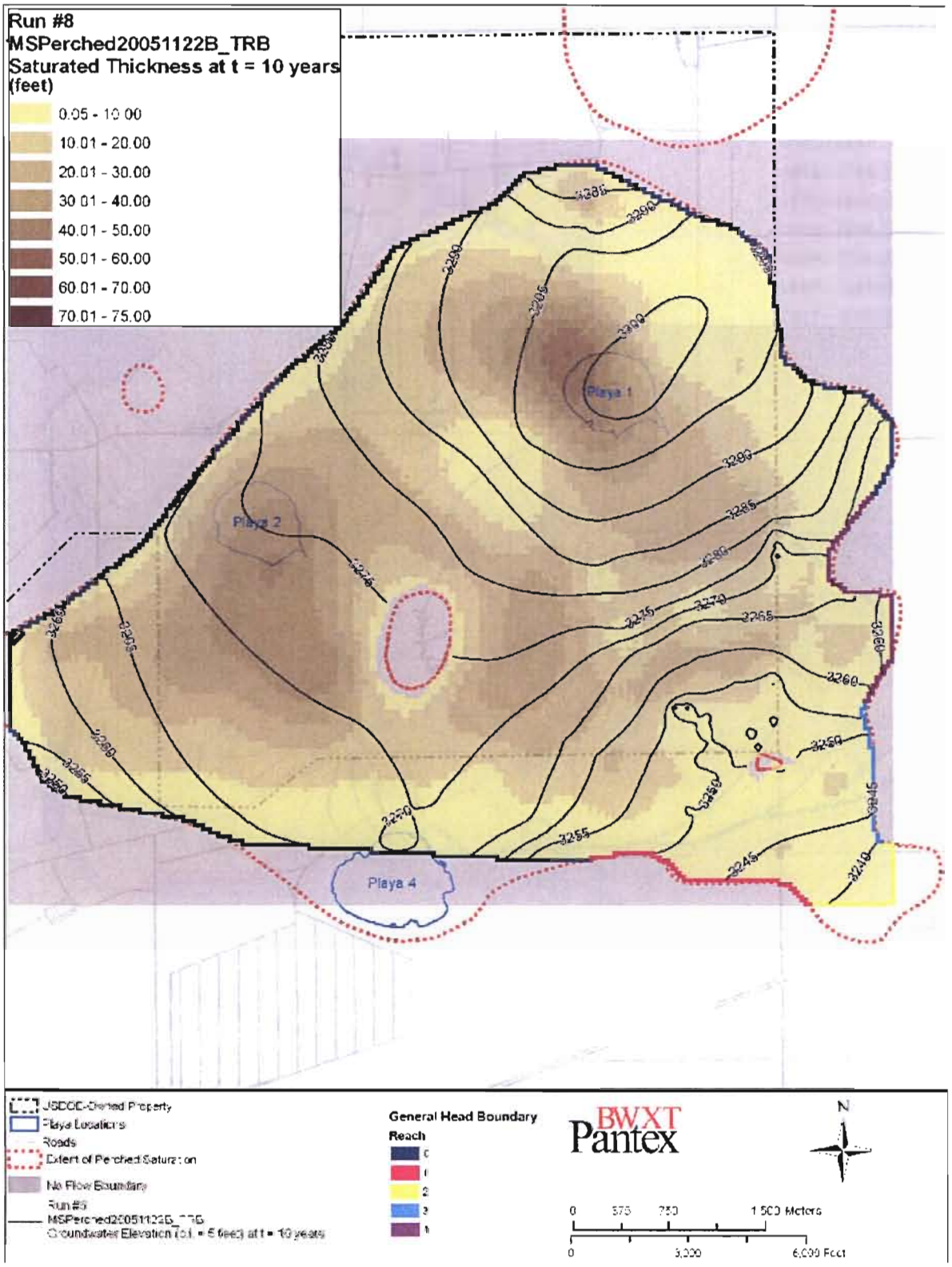

Figure 2A-41. Run 8 Simulated Water Levels and Saturated Thickness at 10 Years

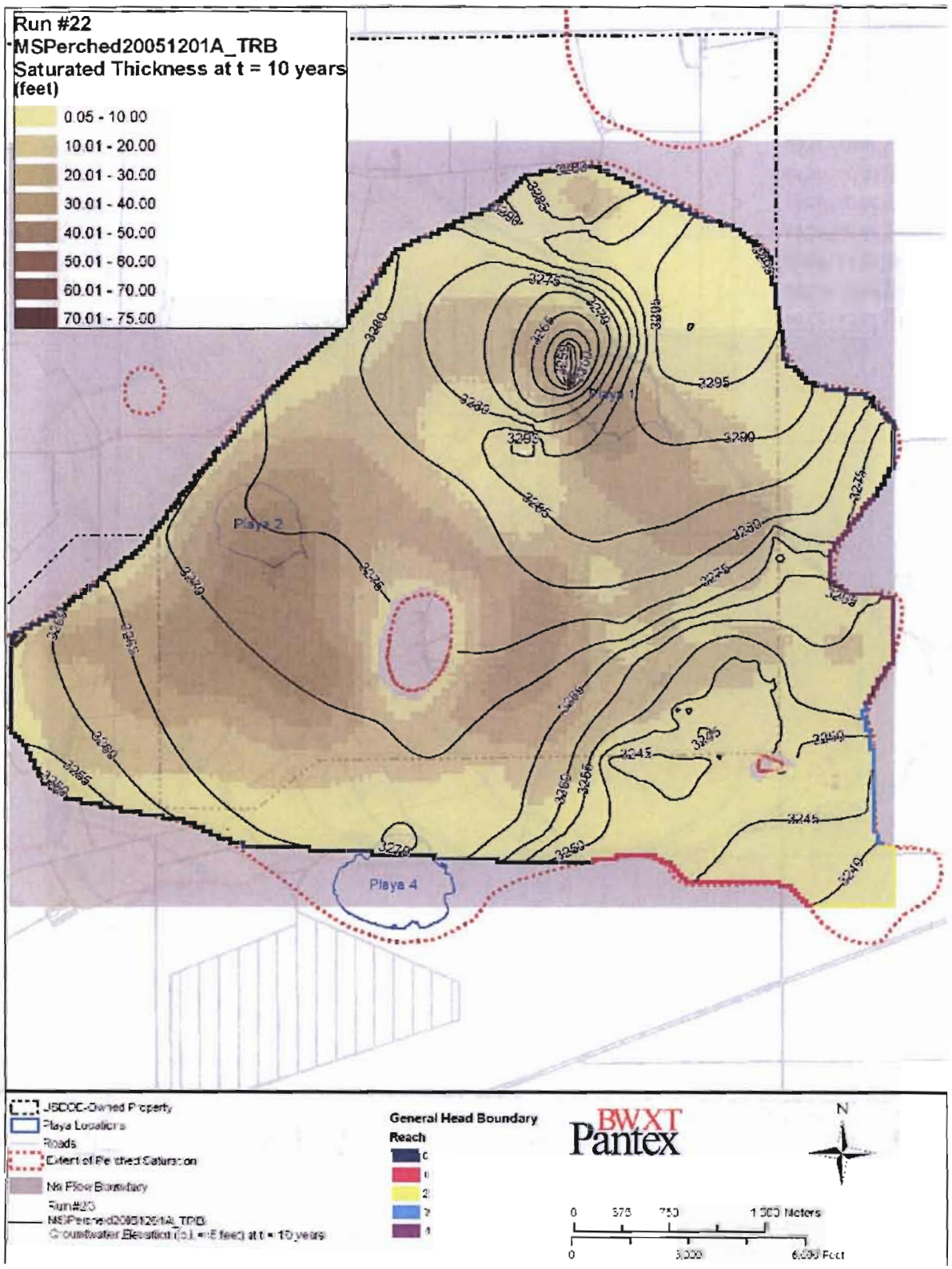

Figure 2A-42. Run 22 Simulated Water Levels and Saturated Thickness at 10 Years

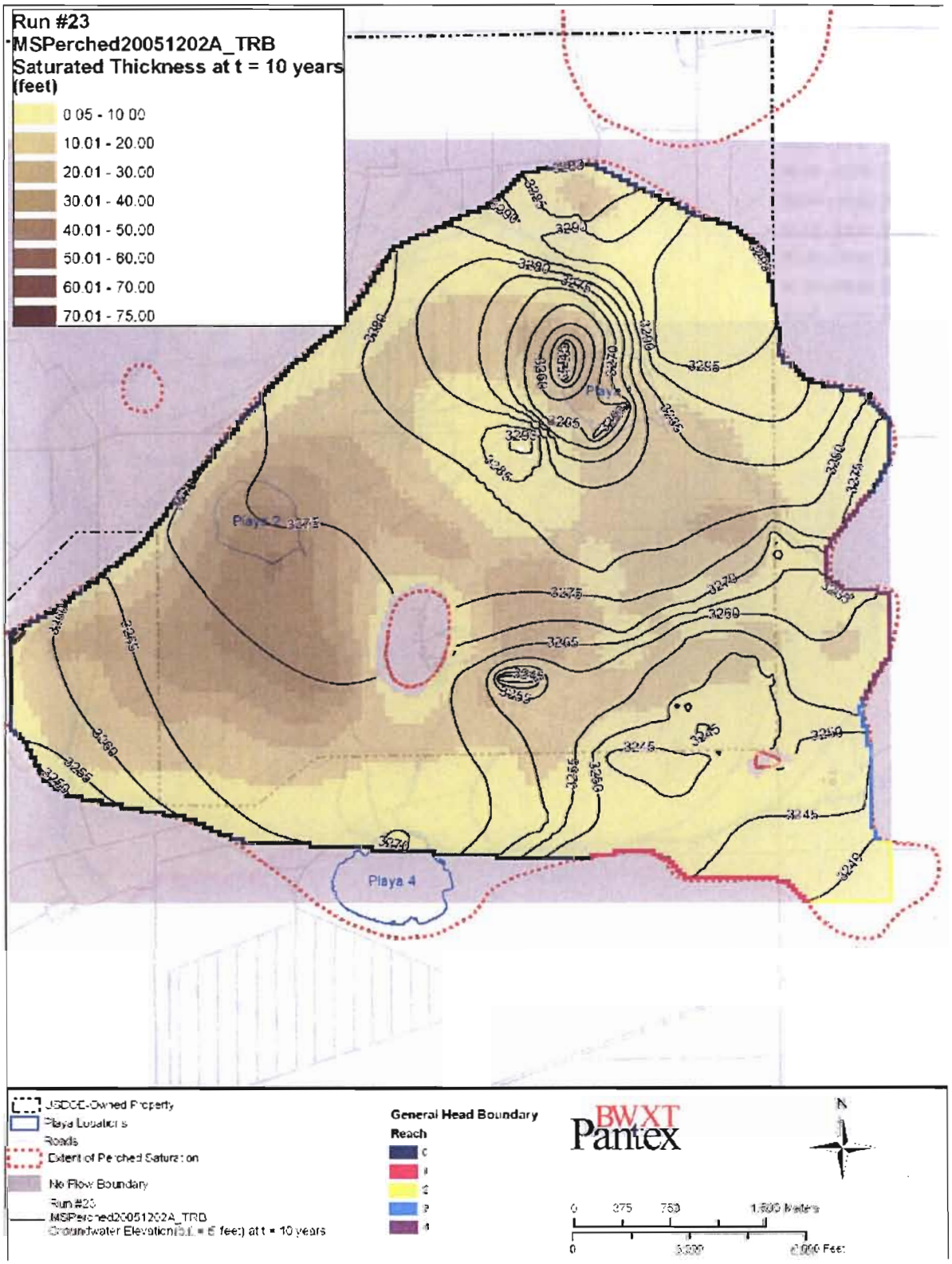

Figure 2A-43. Run 23 Simulated Water Levels and Saturated Thickness at 10 Years

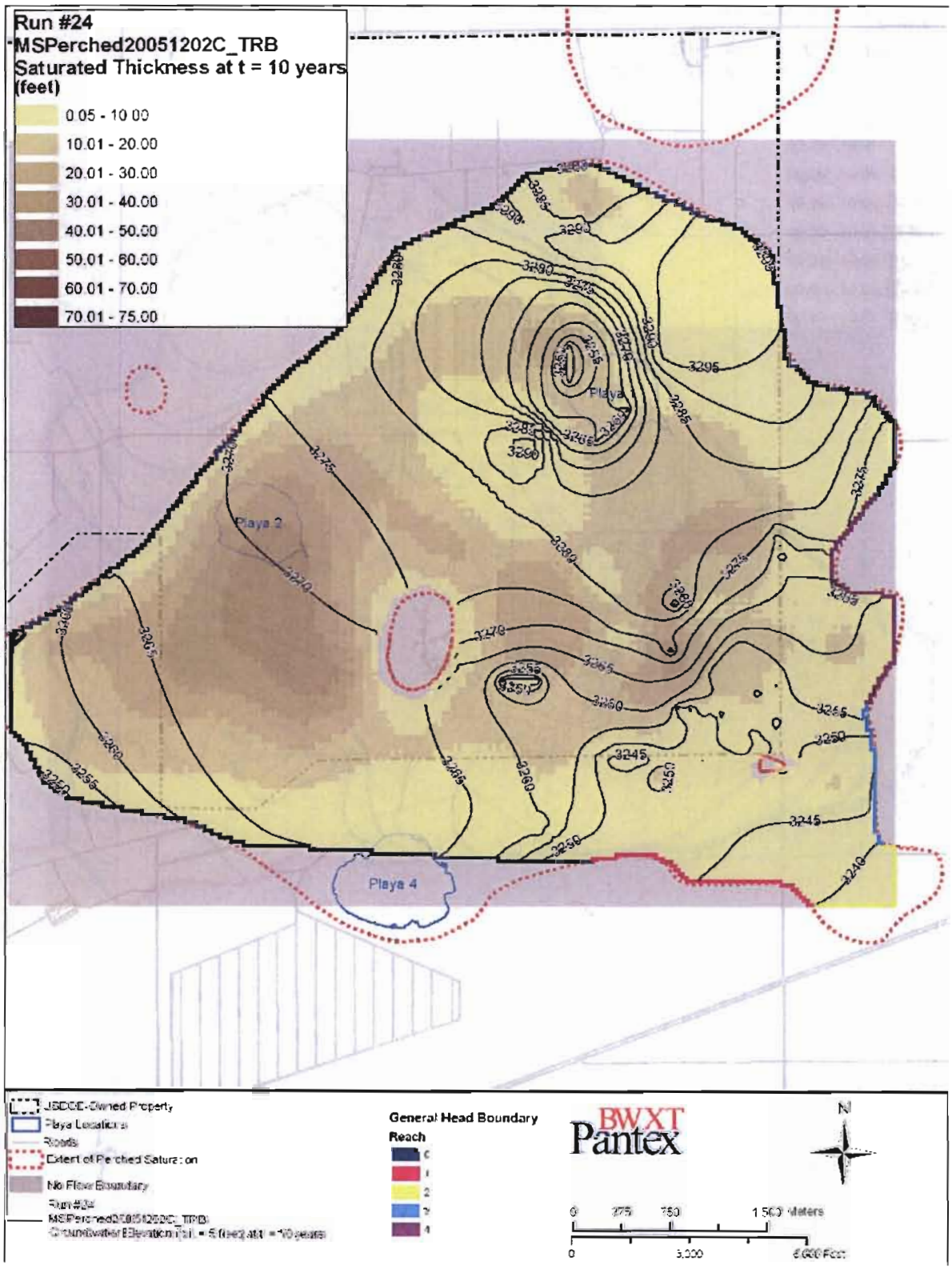

Figure 2A-44. Run 24 Simulated Water Levels and Saturated Thickness at 10 Years

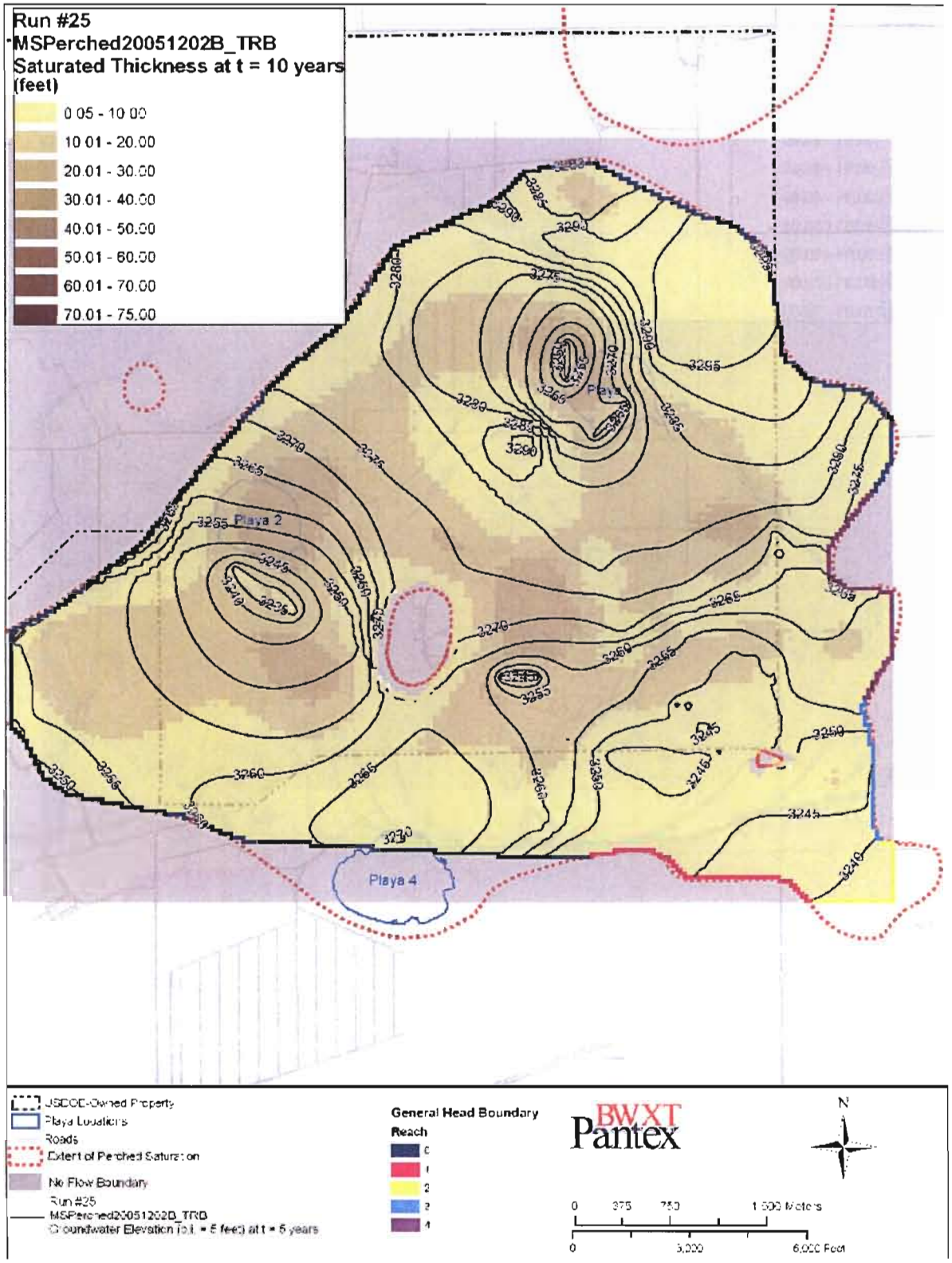

Figure 2A-45. Run 25 Simulated Water Levels and Saturated Thickness at 10 Years

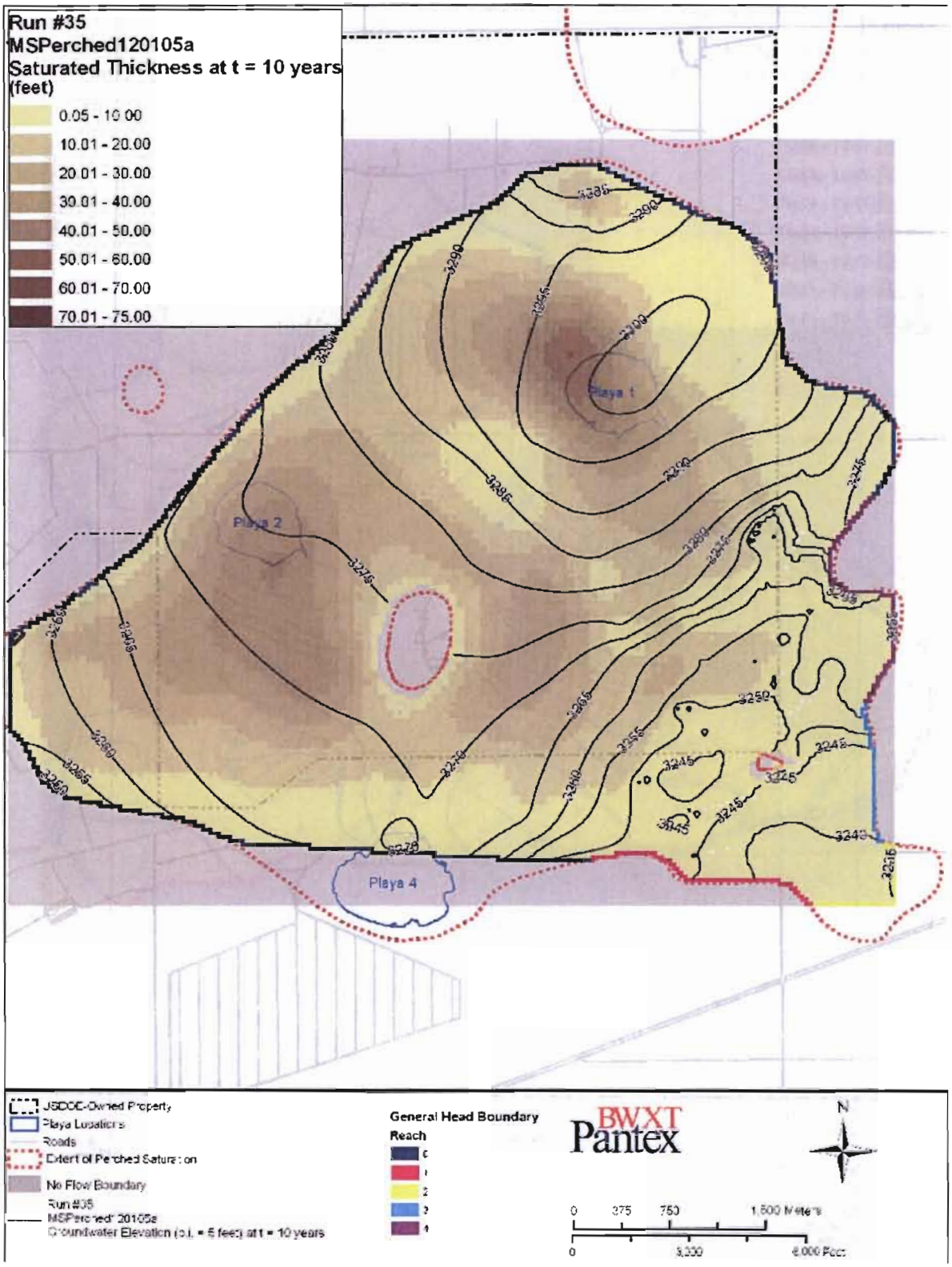

Figure 2A-46. Run 35 Simulated Water Levels and Saturated Thickness at 10 Years

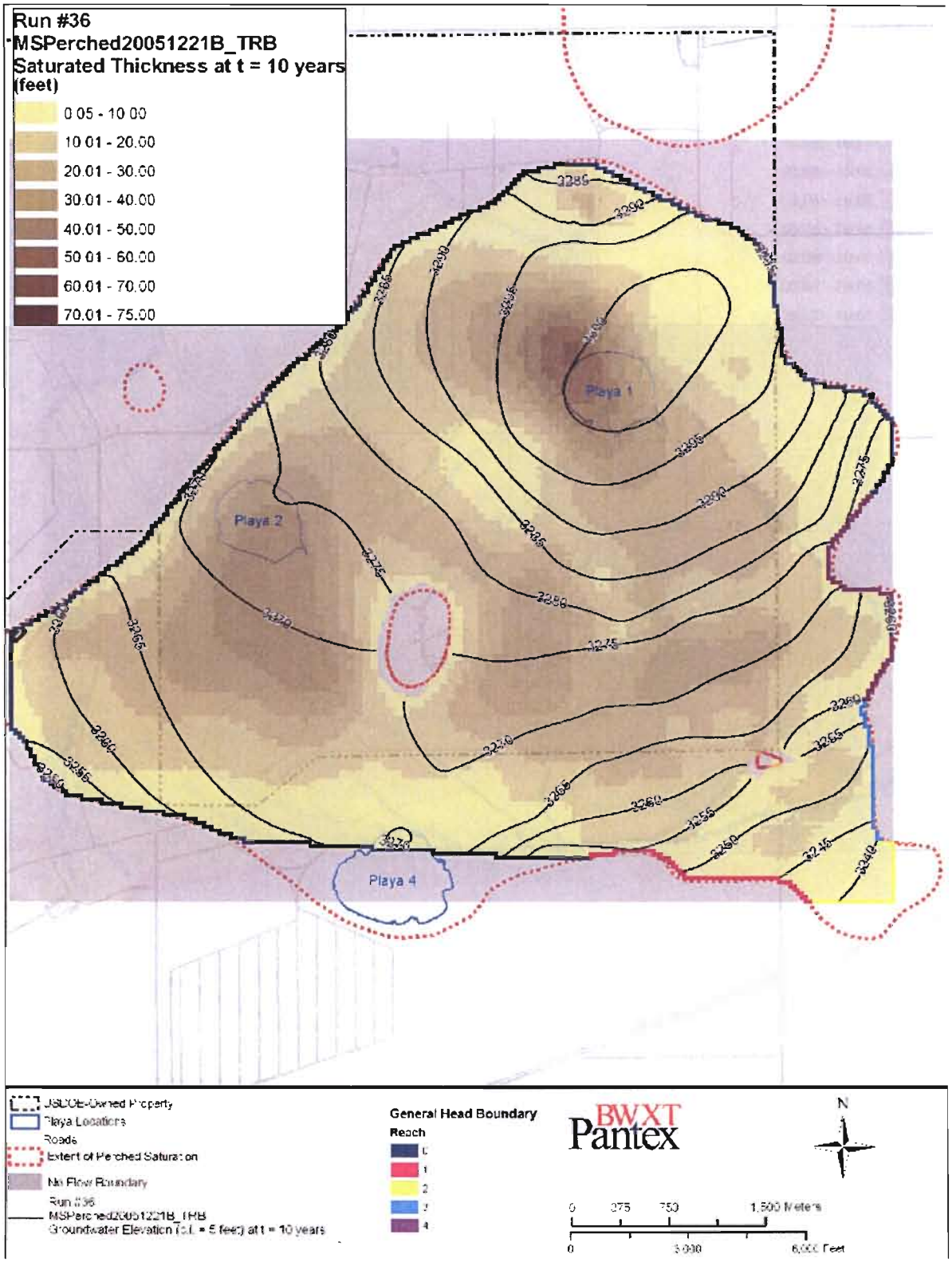

Figure 2A-47. Run 36 Simulated Water Levels and Saturated Thickness at 10 Years

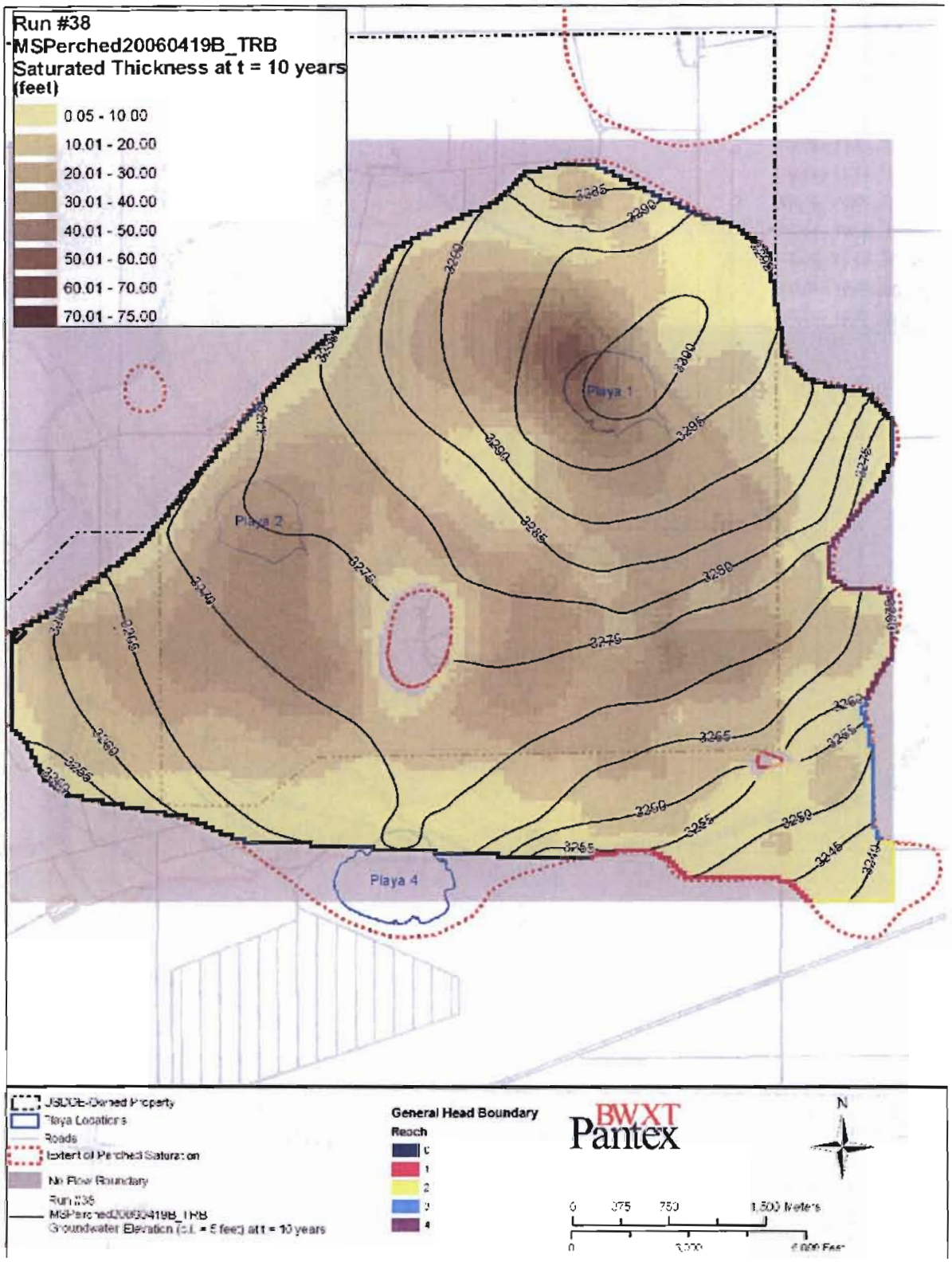

Figure 2A-48. Run 38 Simulated Water Levels and Saturated Thickness at 10 Years

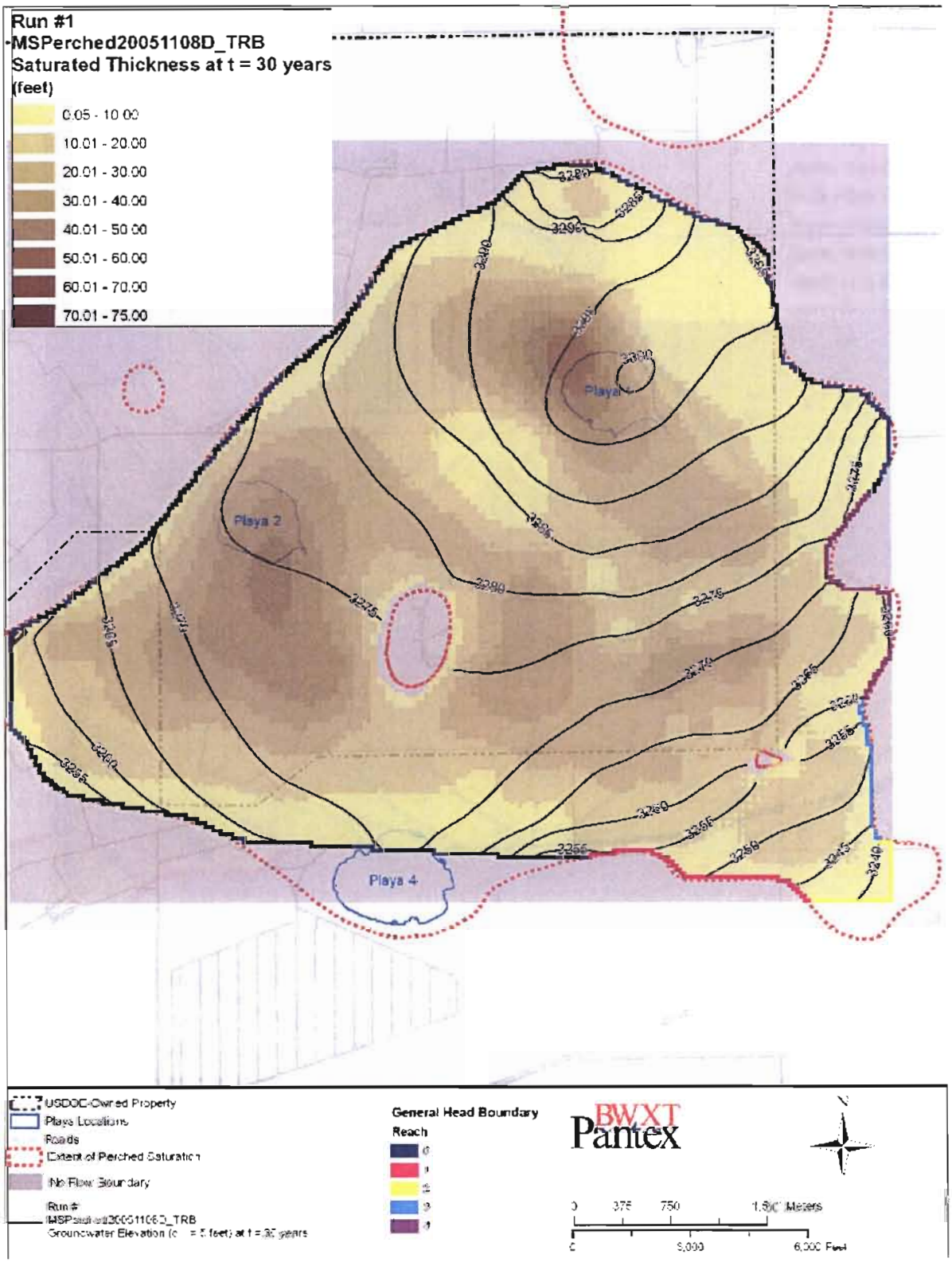

Figure 2A-49. Run 1 Simulated Water Levels and Saturated Thickness at 30 Years

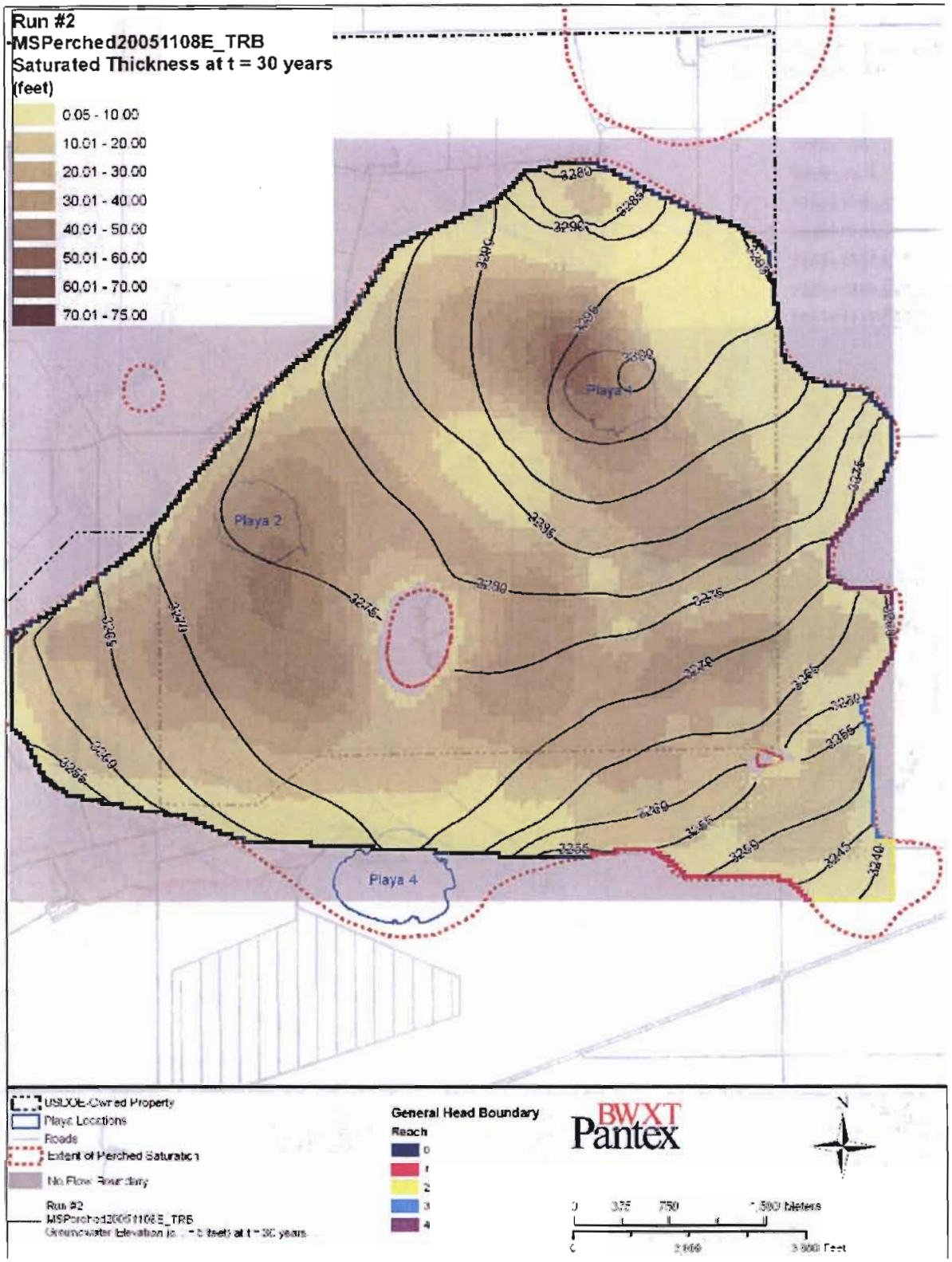

Figure 2A-50. Run 2 Simulated Water Levels and Saturated Thickness at 30 Years

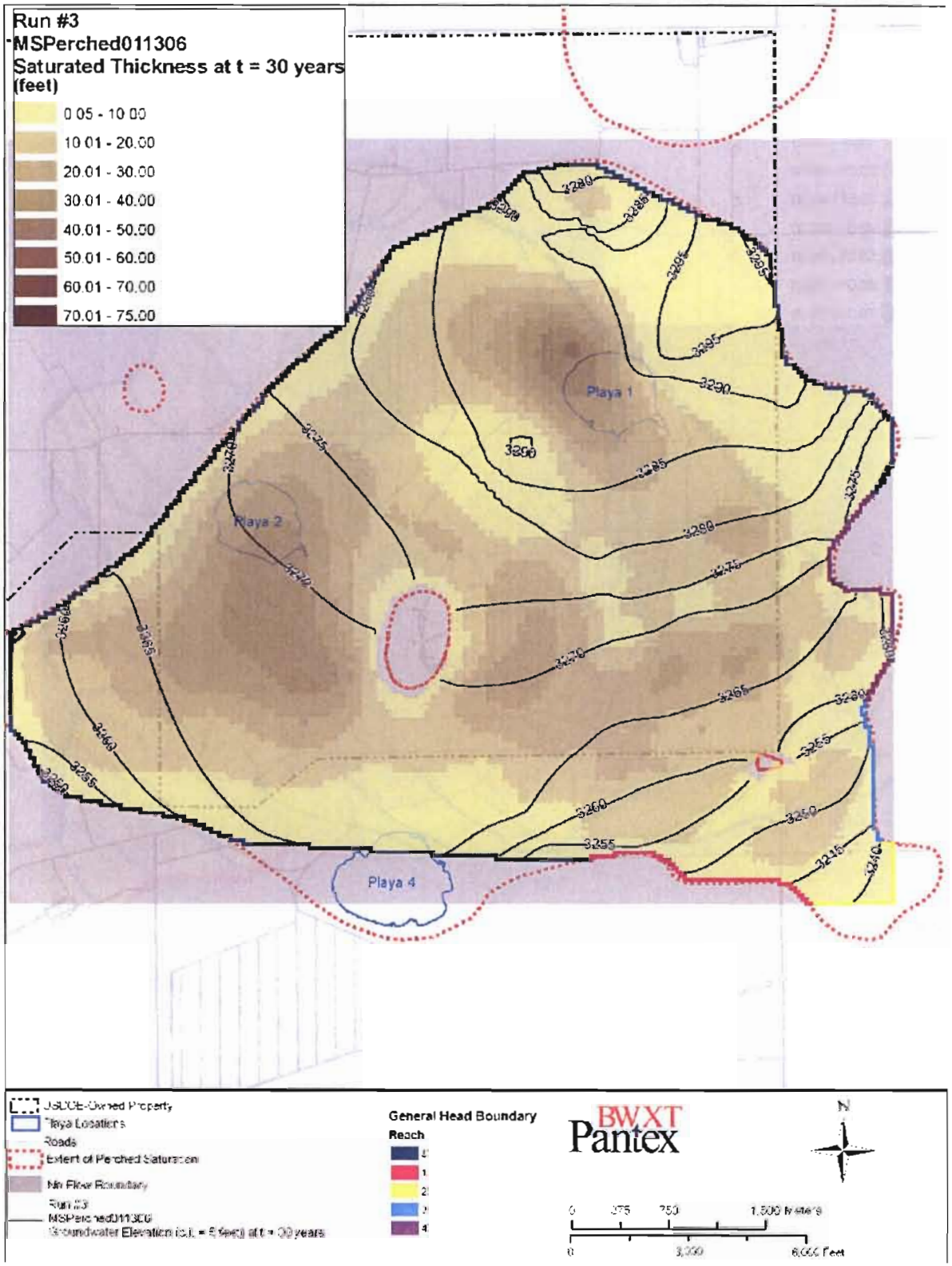

Figure 2A-51. Run 3 Simulated Water Levels and Saturated Thickness at 30 Years

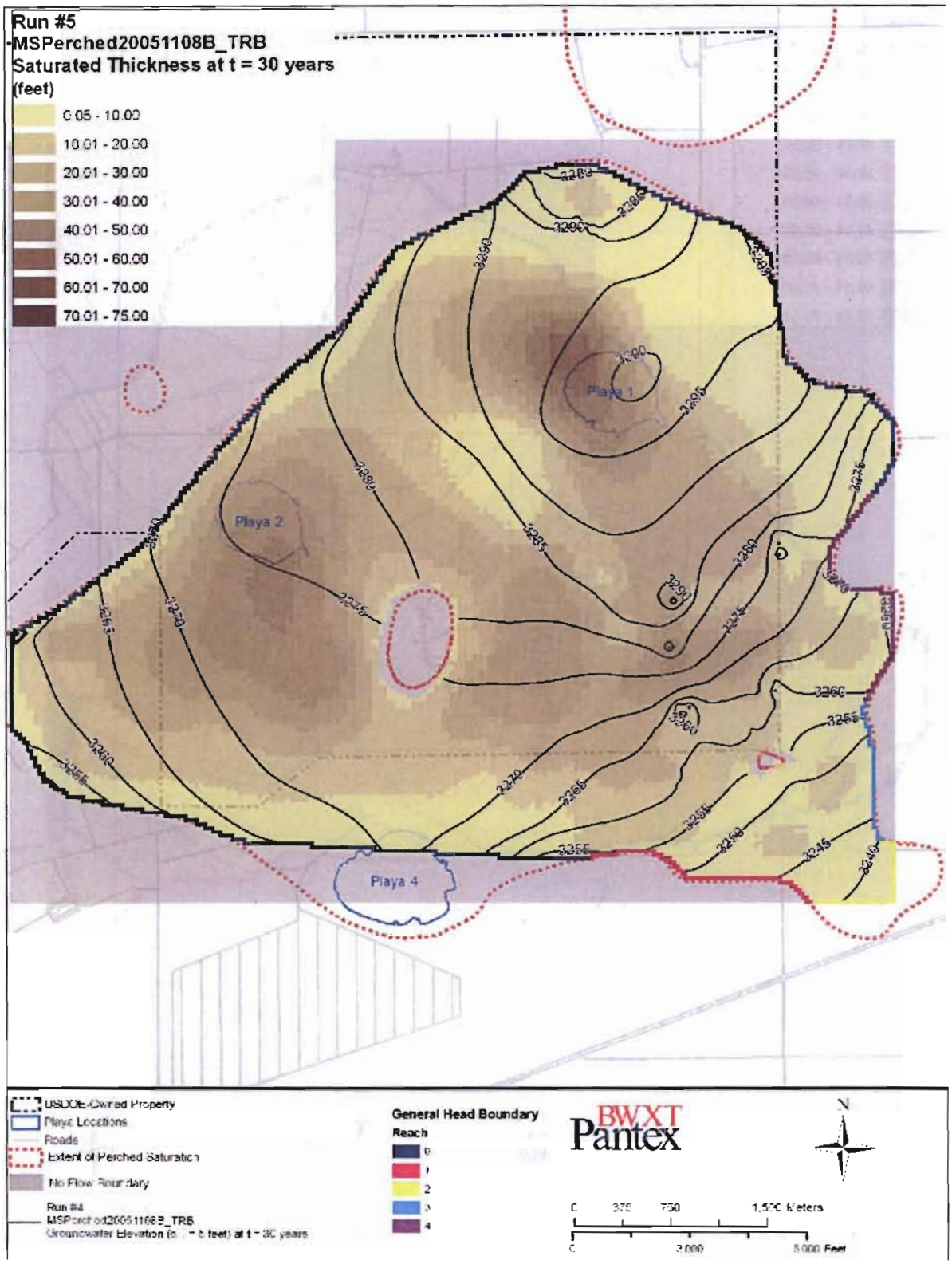

Figure 2A-52. Run 5 Simulated Water Levels and Saturated Thickness at 30 Years

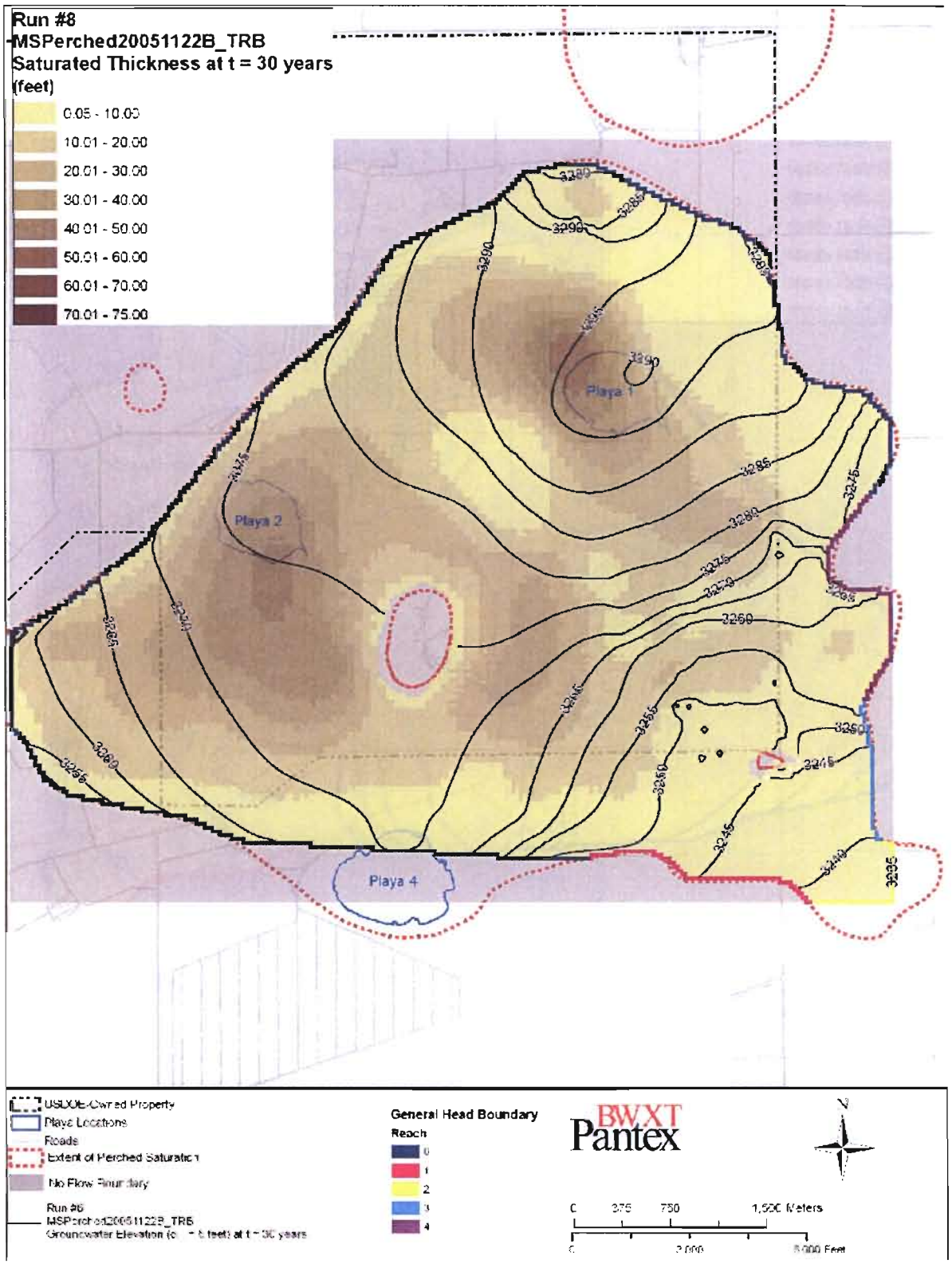

Figure 2A-53. Run 8 Simulated Water Levels and Saturated Thickness at 30 Years

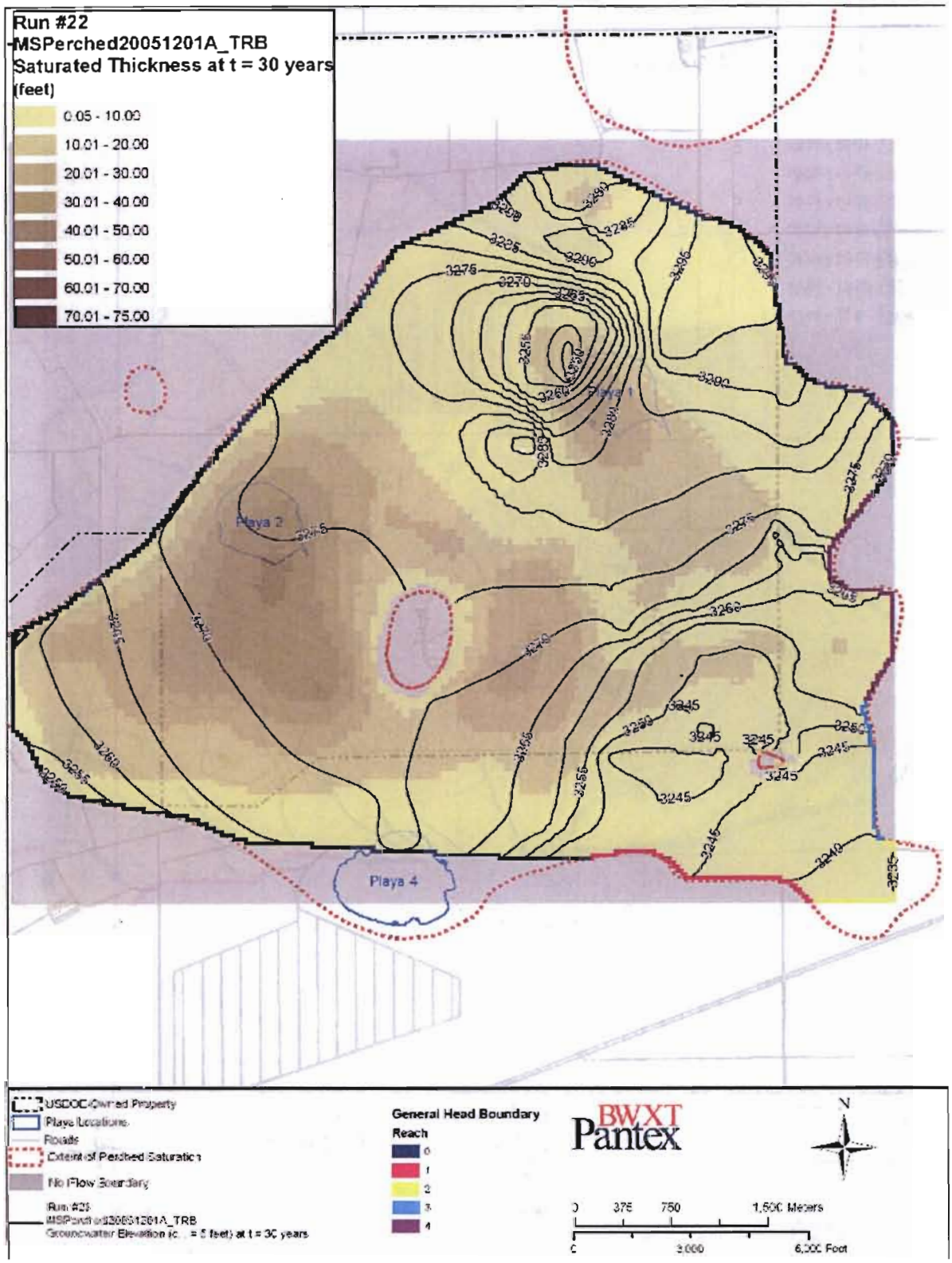

Figure 2A-54. Run 22 Simulated Water Levels and Saturated Thickness at 30 Years

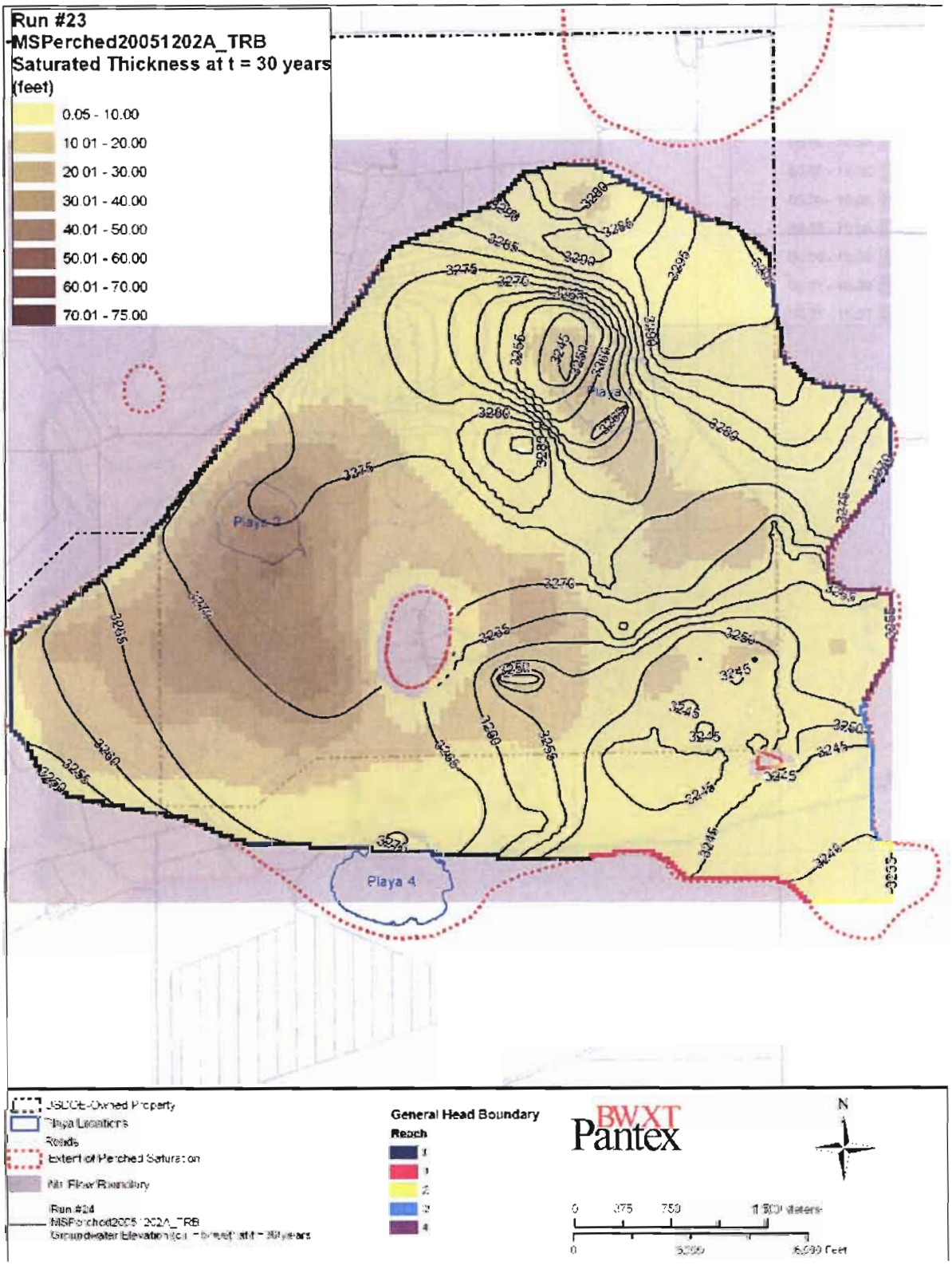

Figure 2A-55. Run 23 Simulated Water Levels and Saturated Thickness at 30 Years

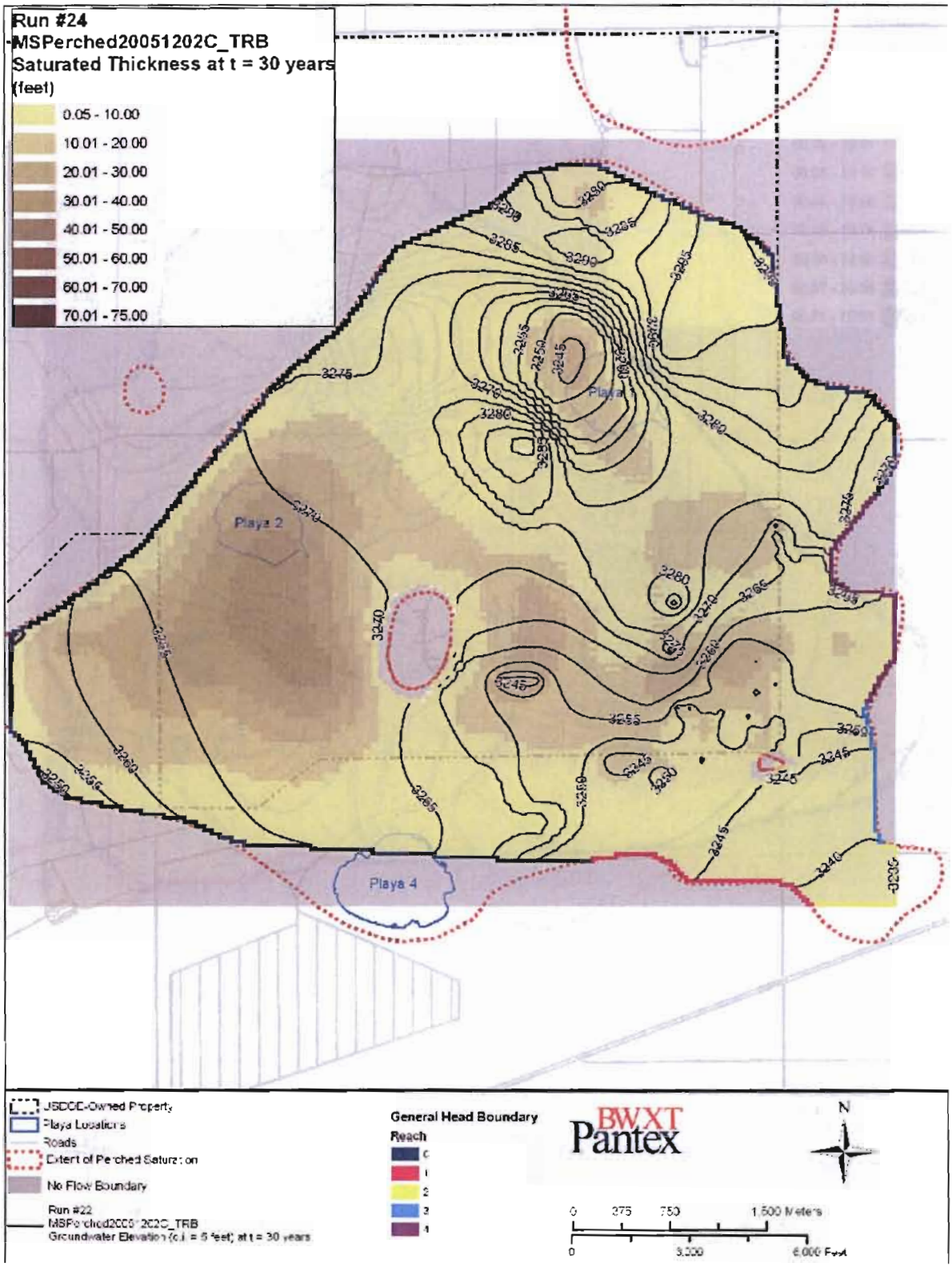

Figure 2A-56. Run 24 Simulated Water Levels and Saturated Thickness at 30 Years

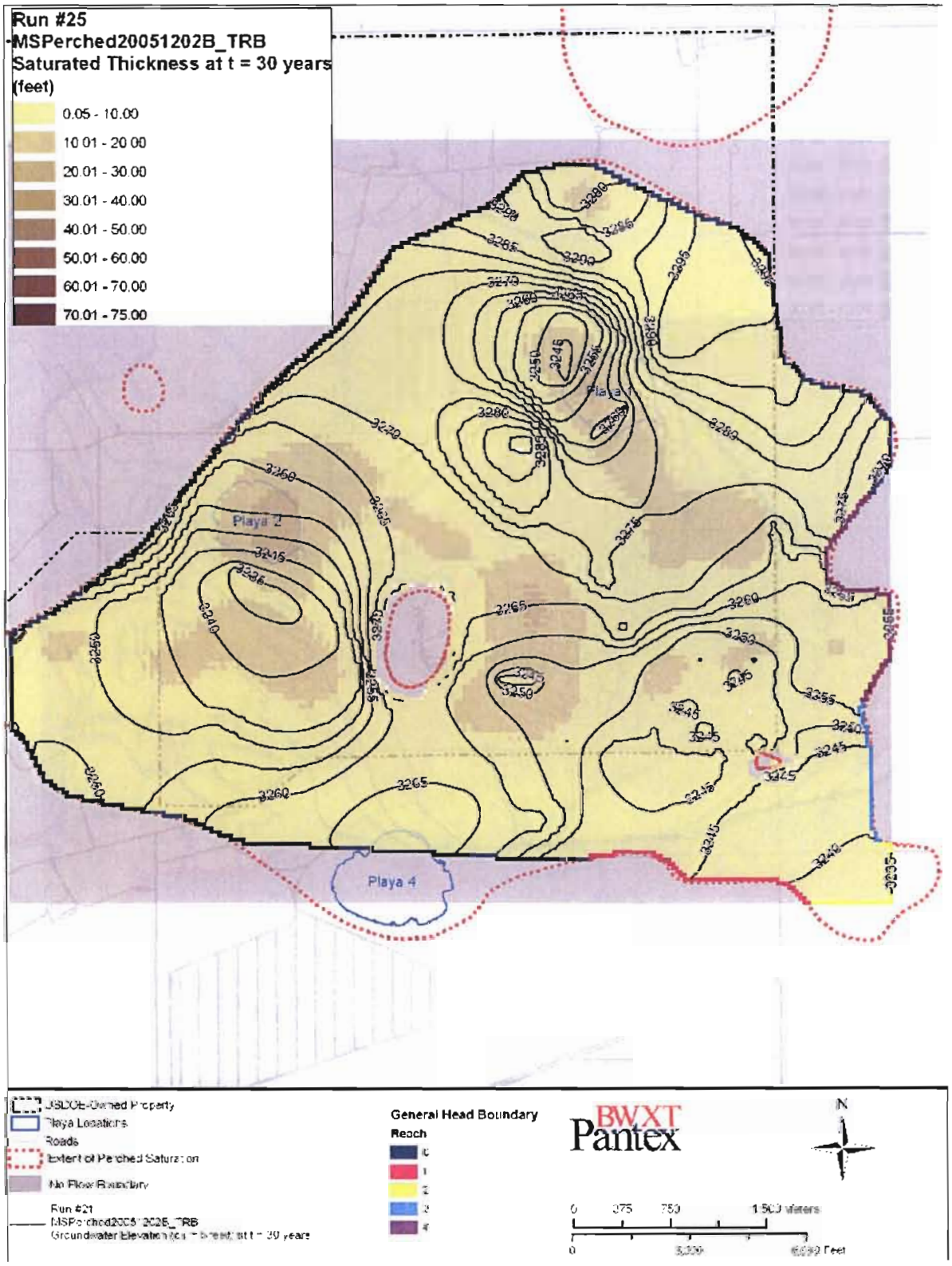

Figure 2A-57. Run 25 Simulated Water Levels and Saturated Thickness at 30 Years

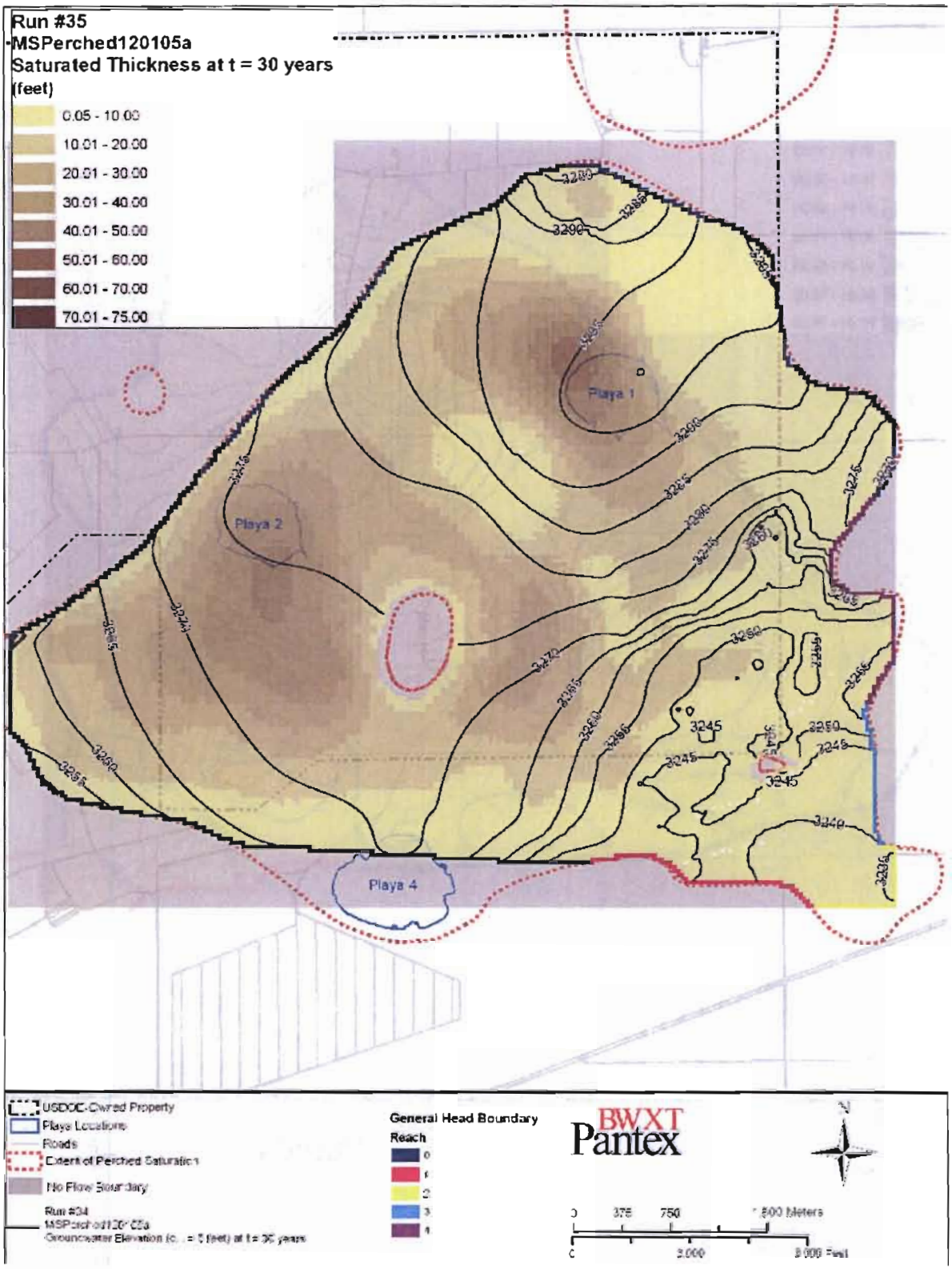

Figure 2A-58. Run 35 Simulated Water Levels and Saturated Thickness at 30 Years

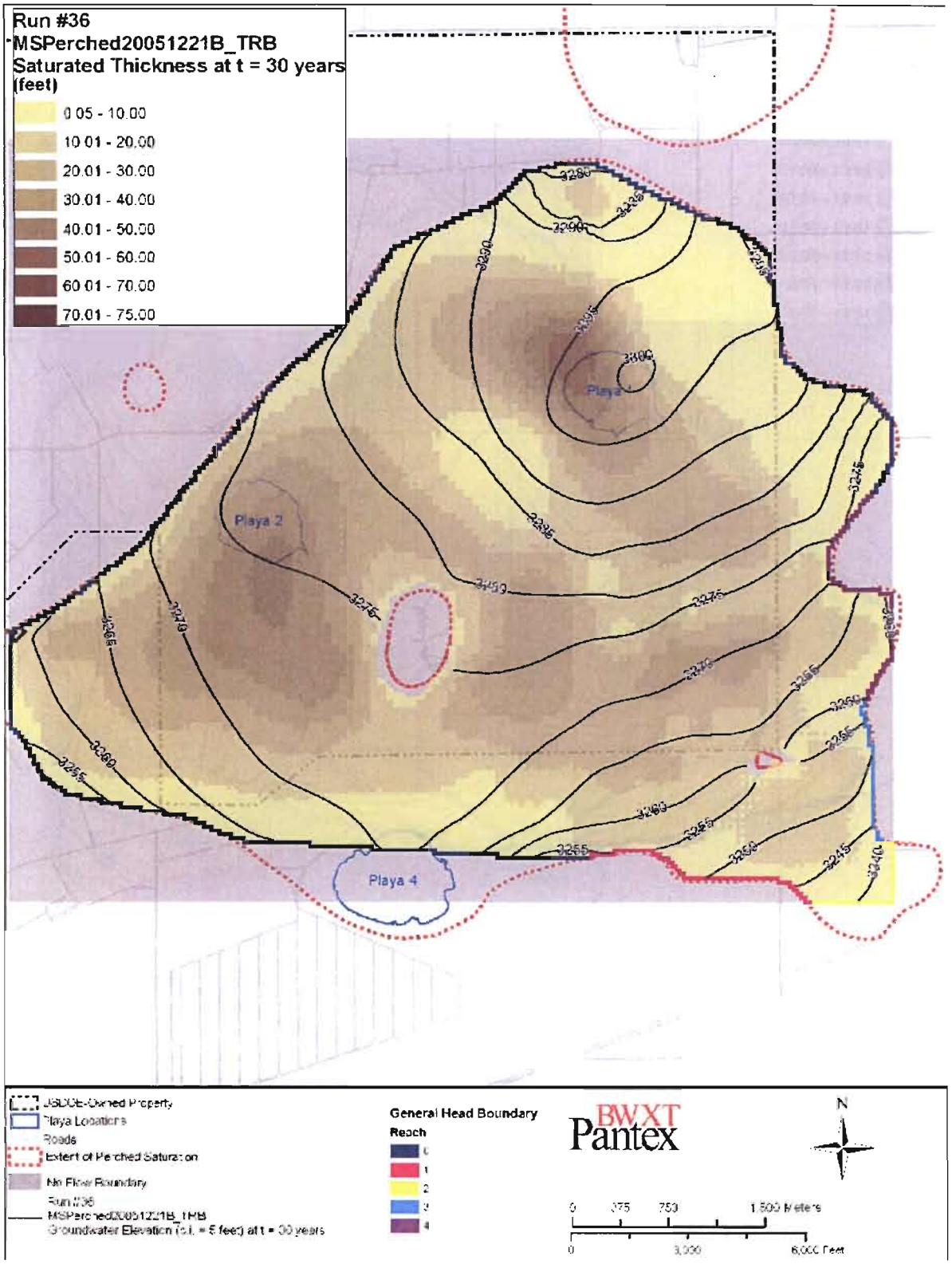

Figure 2A-59. Run 36 Simulated Water Levels and Saturated Thickness at 30 Years

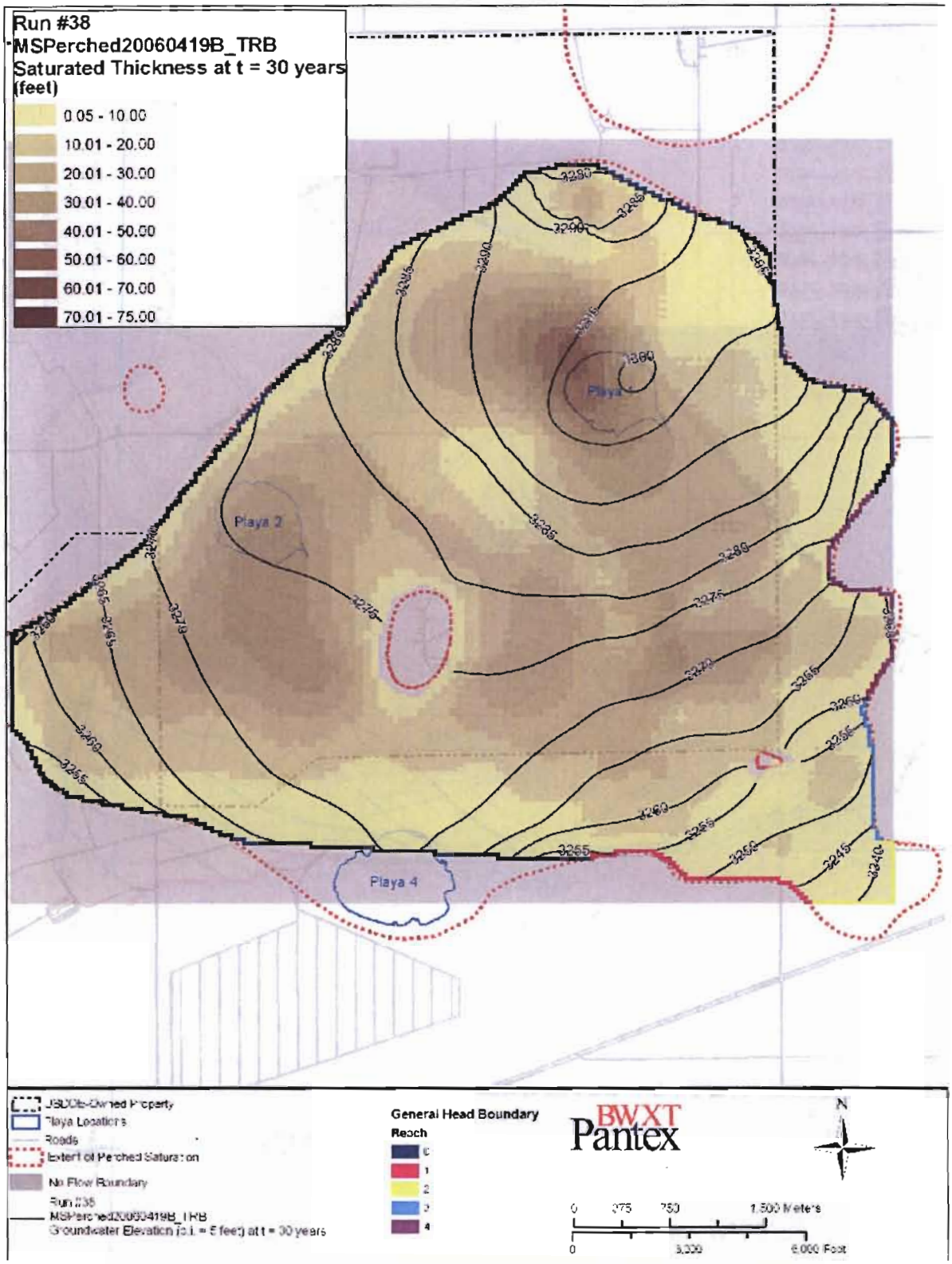

Figure 2A-60. Run 38 Simulated Water Levels and Saturated Thickness at 30 Years

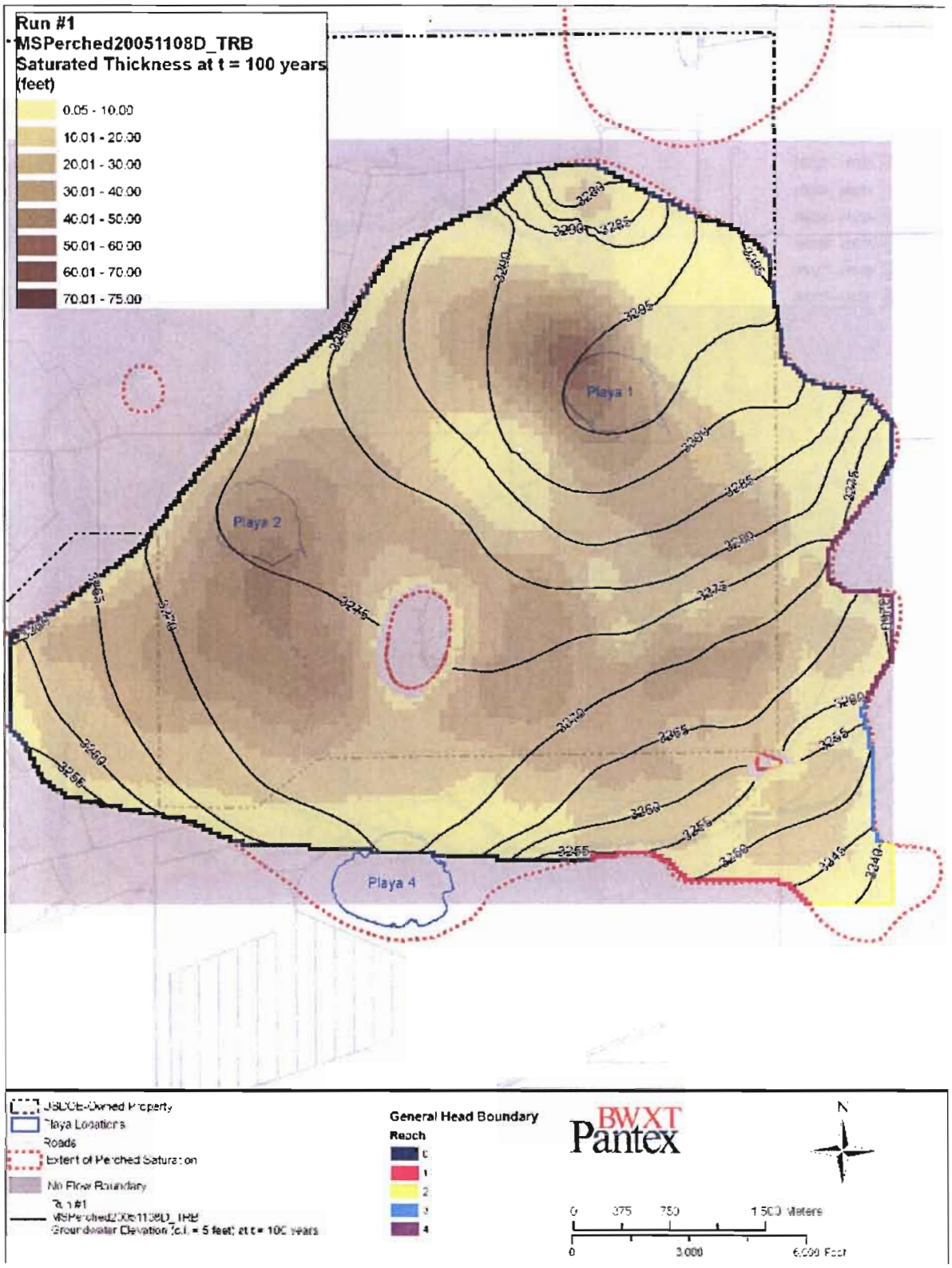

Figure 2A-61. Run 1 Simulated Water Levels and Saturated Thickness at 100 Years

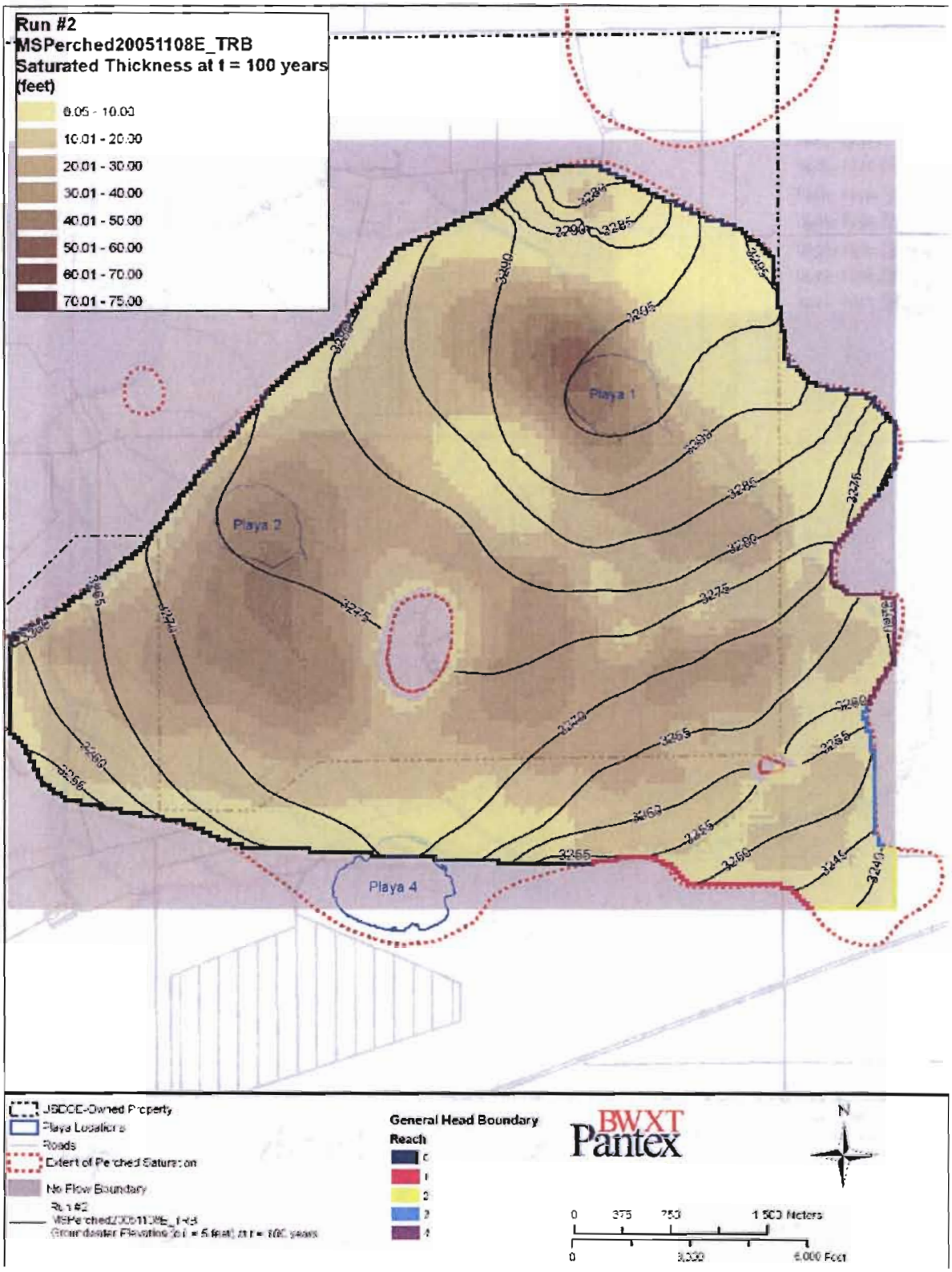

Figure 2A-62. Run 2 Simulated Water Levels and Saturated Thickness at 100 Years

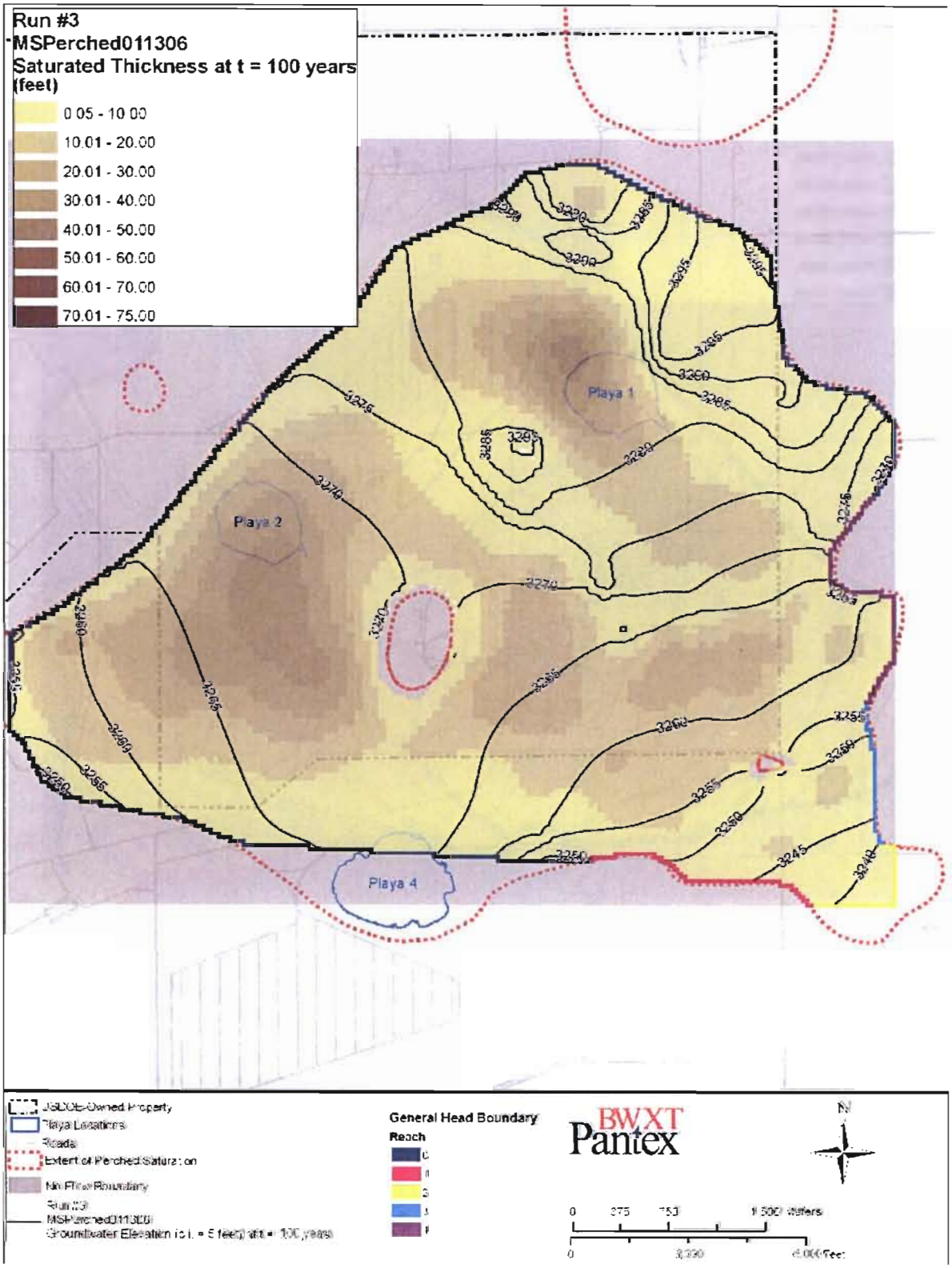

Figure 2A-63. Run 3 Simulated Water Levels and Saturated Thickness at 100 Years

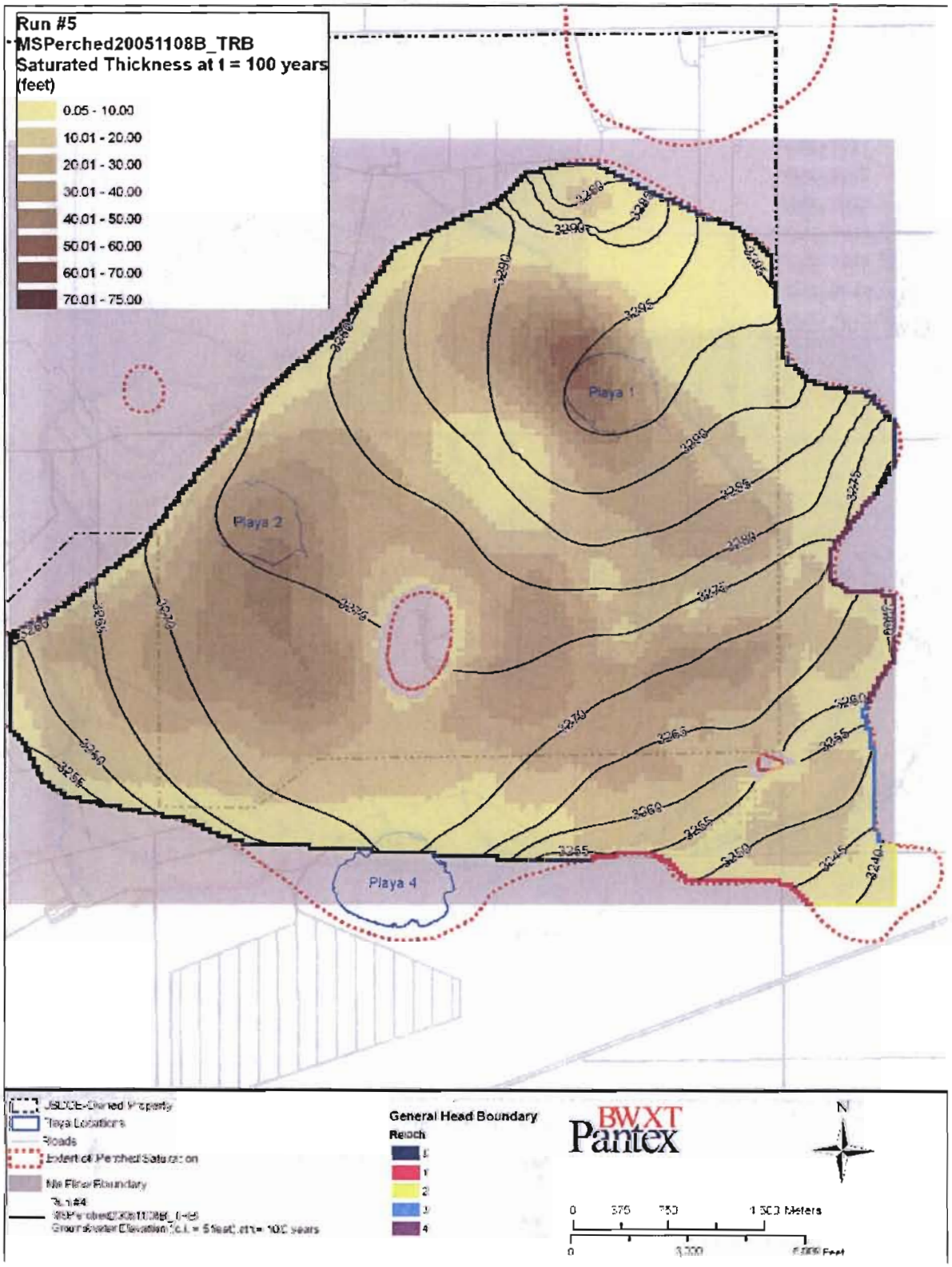

Figure 2A-64. Run 5 Simulated Water Levels and Saturated Thickness at 100 Years

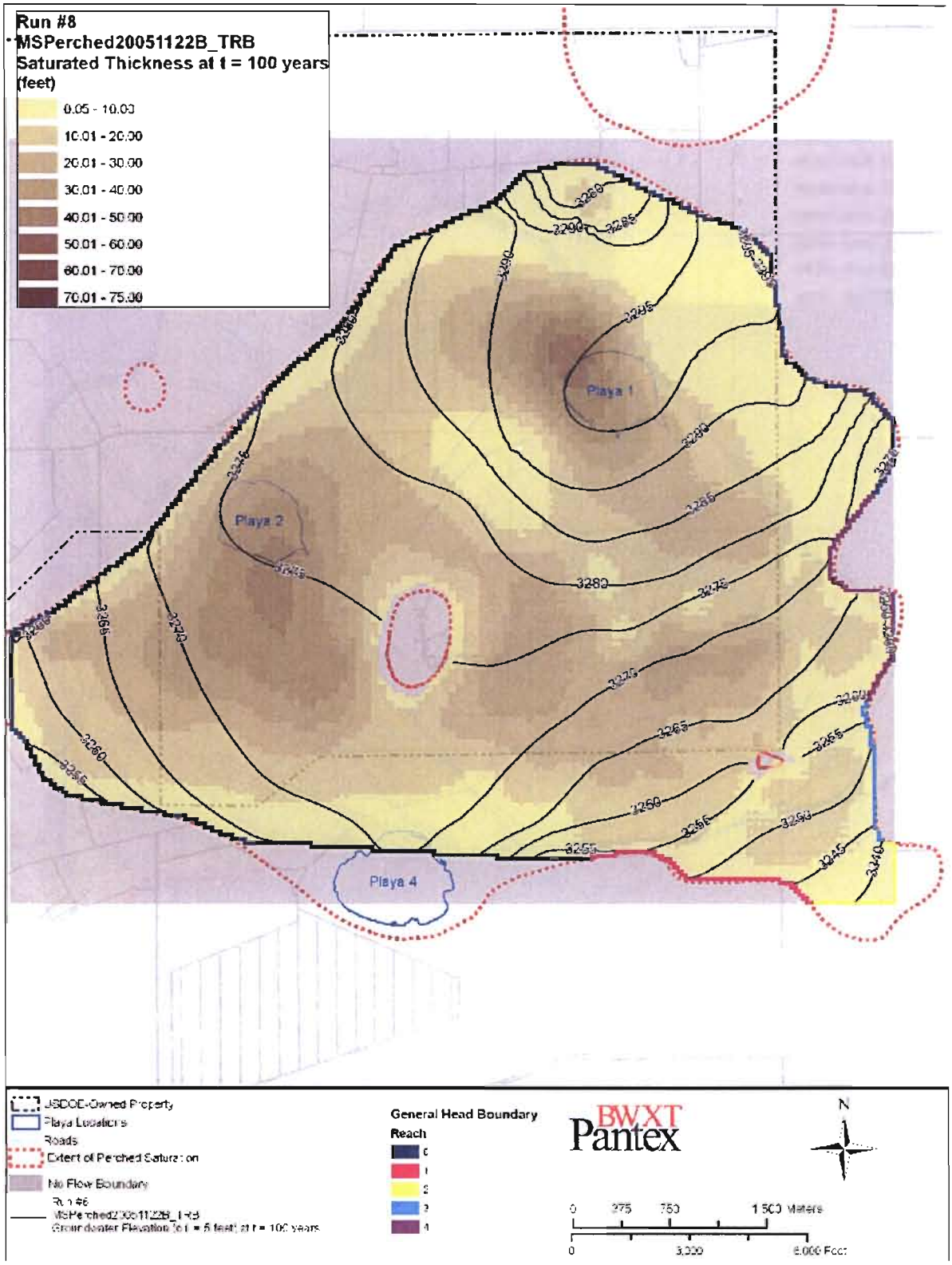

Figure 2A-65. Run 8 Simulated Water Levels and Saturated Thickness at 100 Years

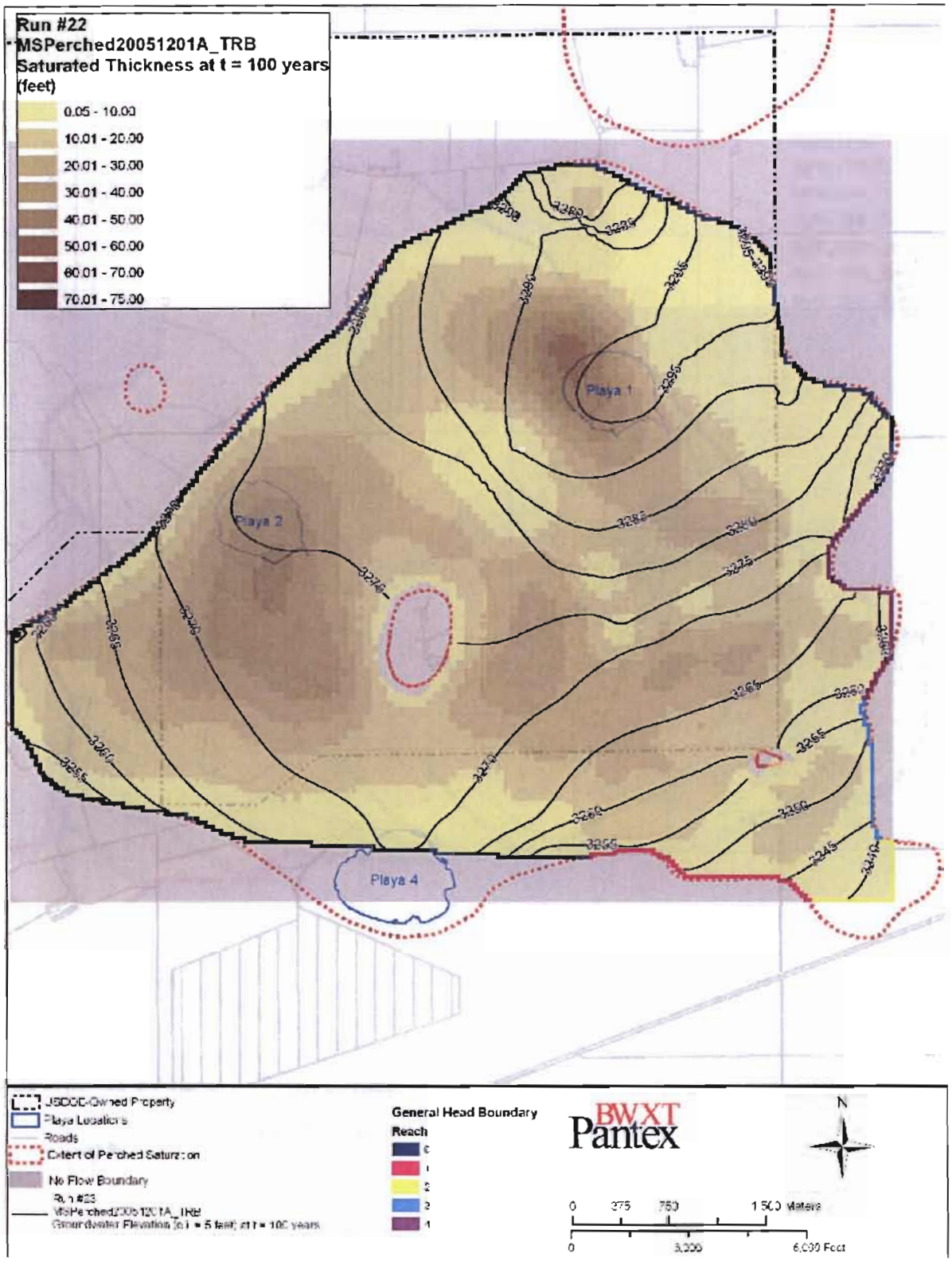

Figure 2A-66. Run 22 Simulated Water Levels and Saturated Thickness at 100 Years

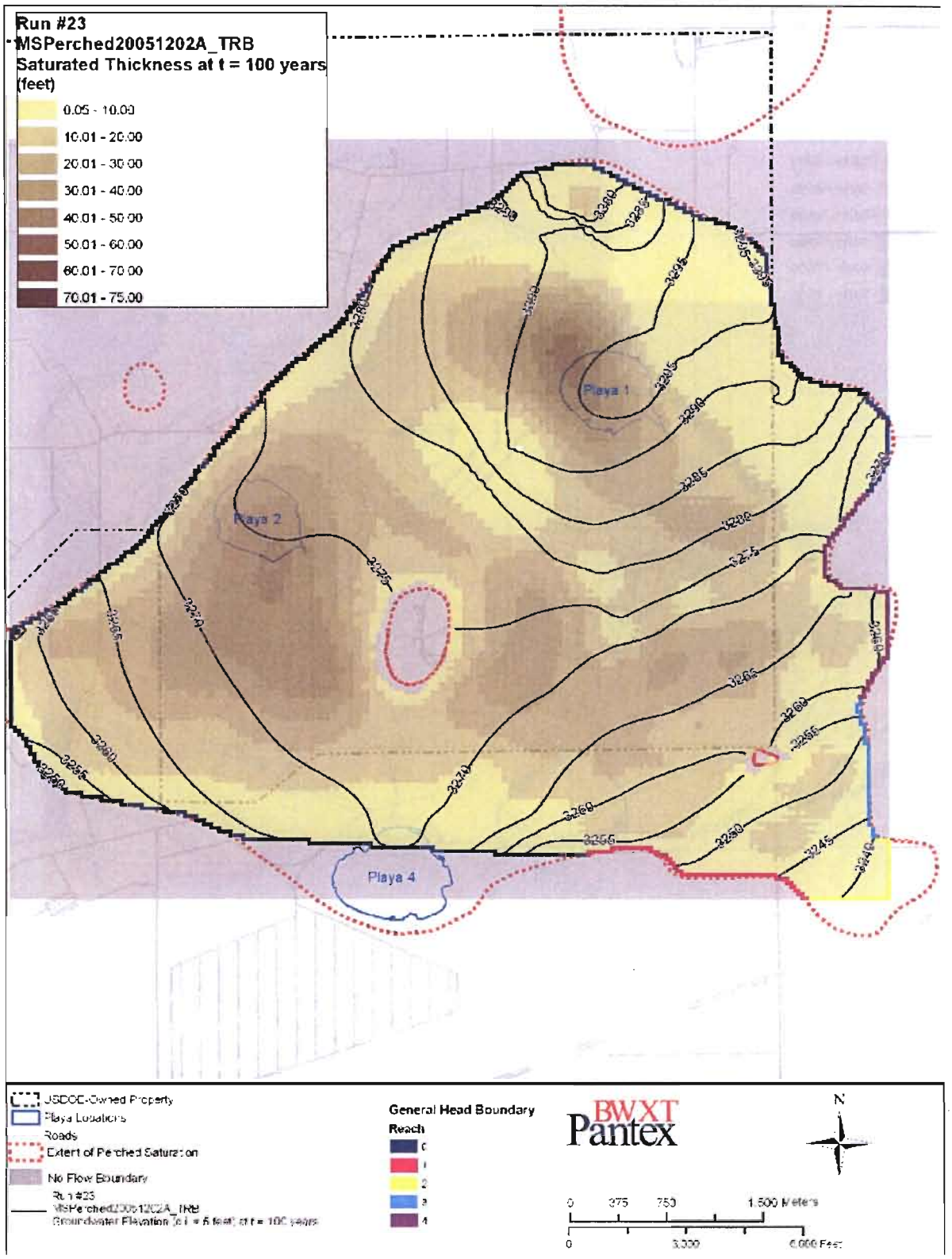

Figure 2A-67. Run 23 Simulated Water Levels and Saturated Thickness at 100 Years

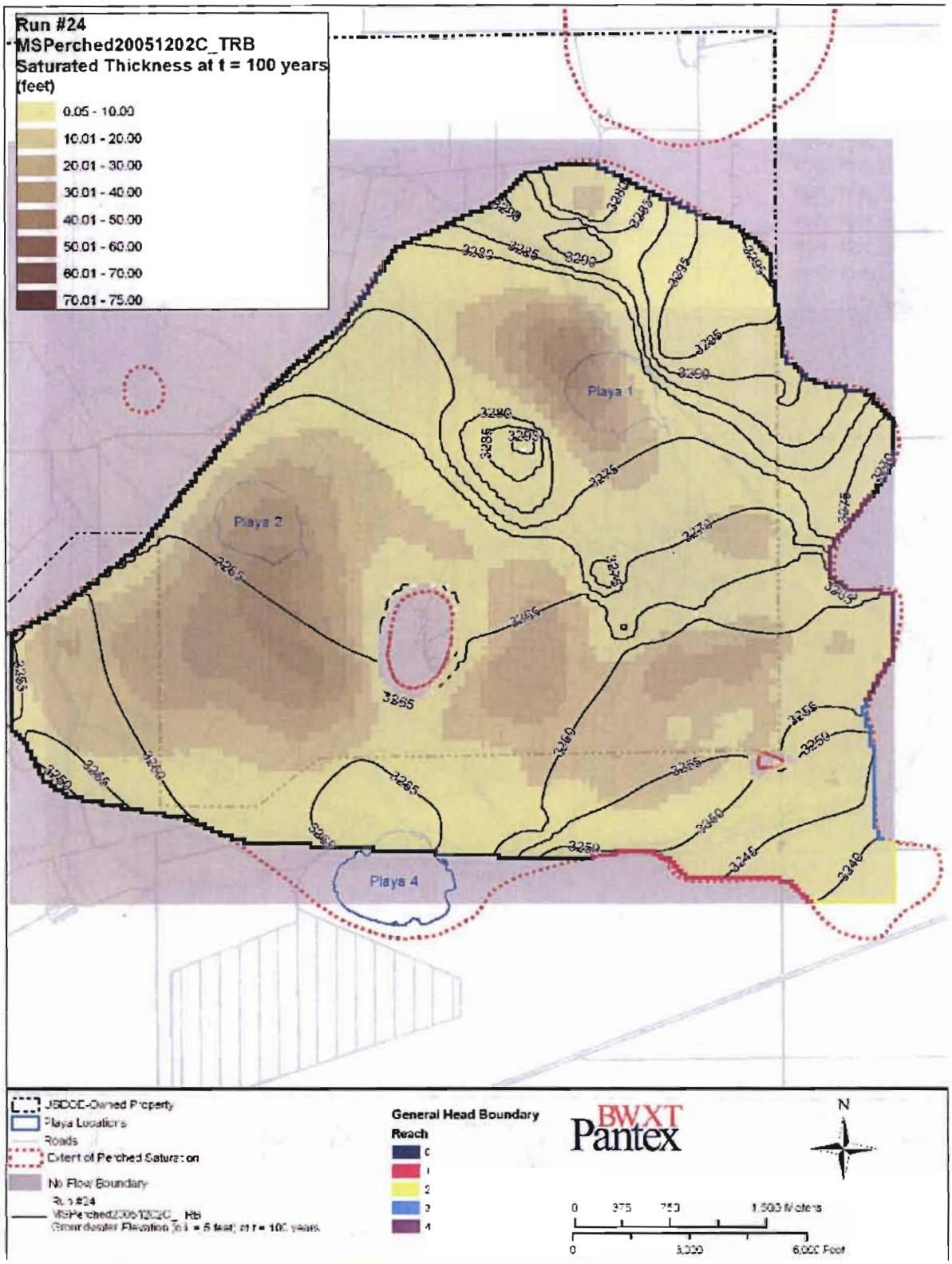

Figure 2A-68. Run 24 Simulated Water Levels and Saturated Thickness at 100 Years

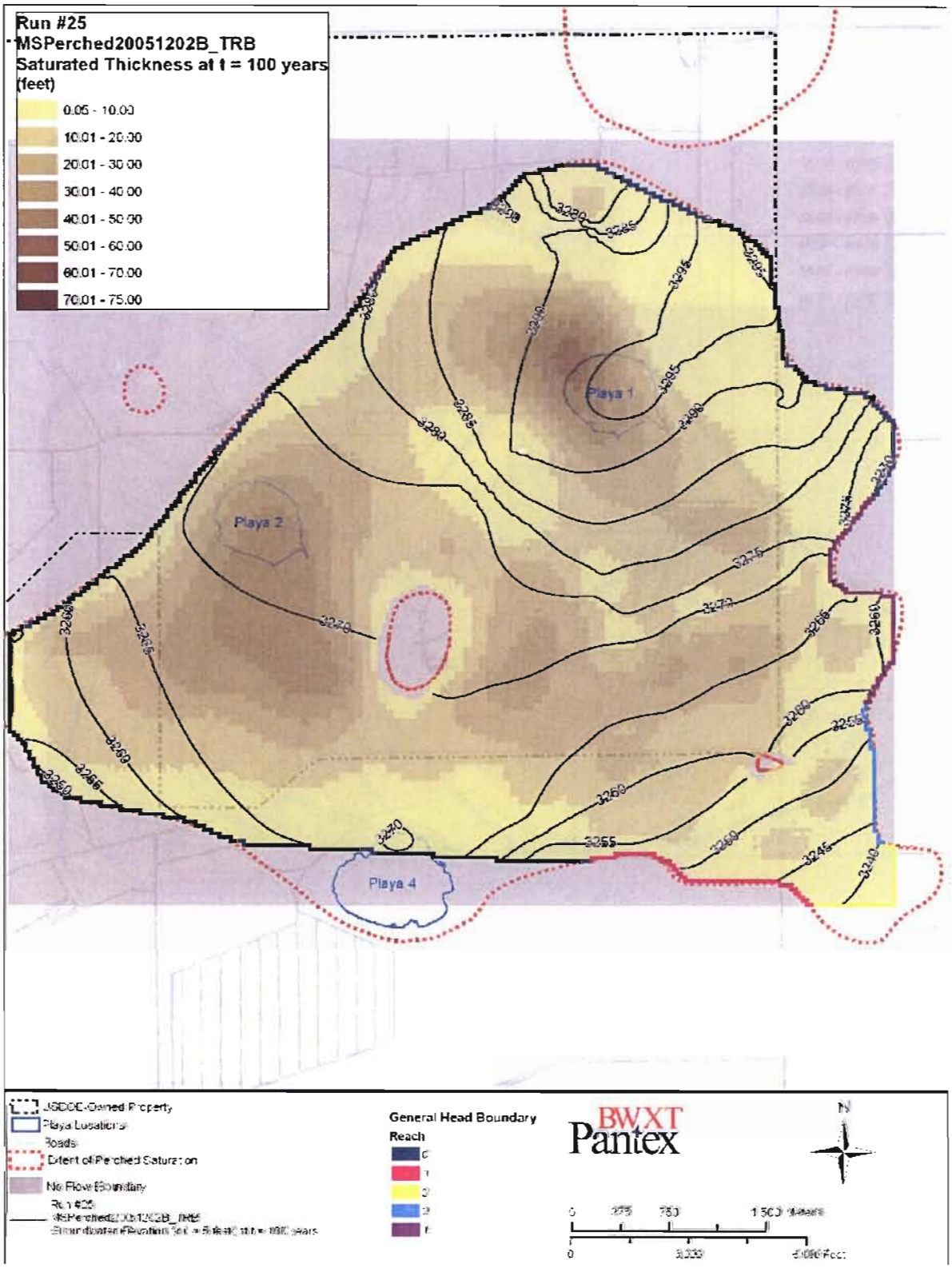

Figure 2A-69. Run 25 Simulated Water Levels and Saturated Thickness at 100 Years

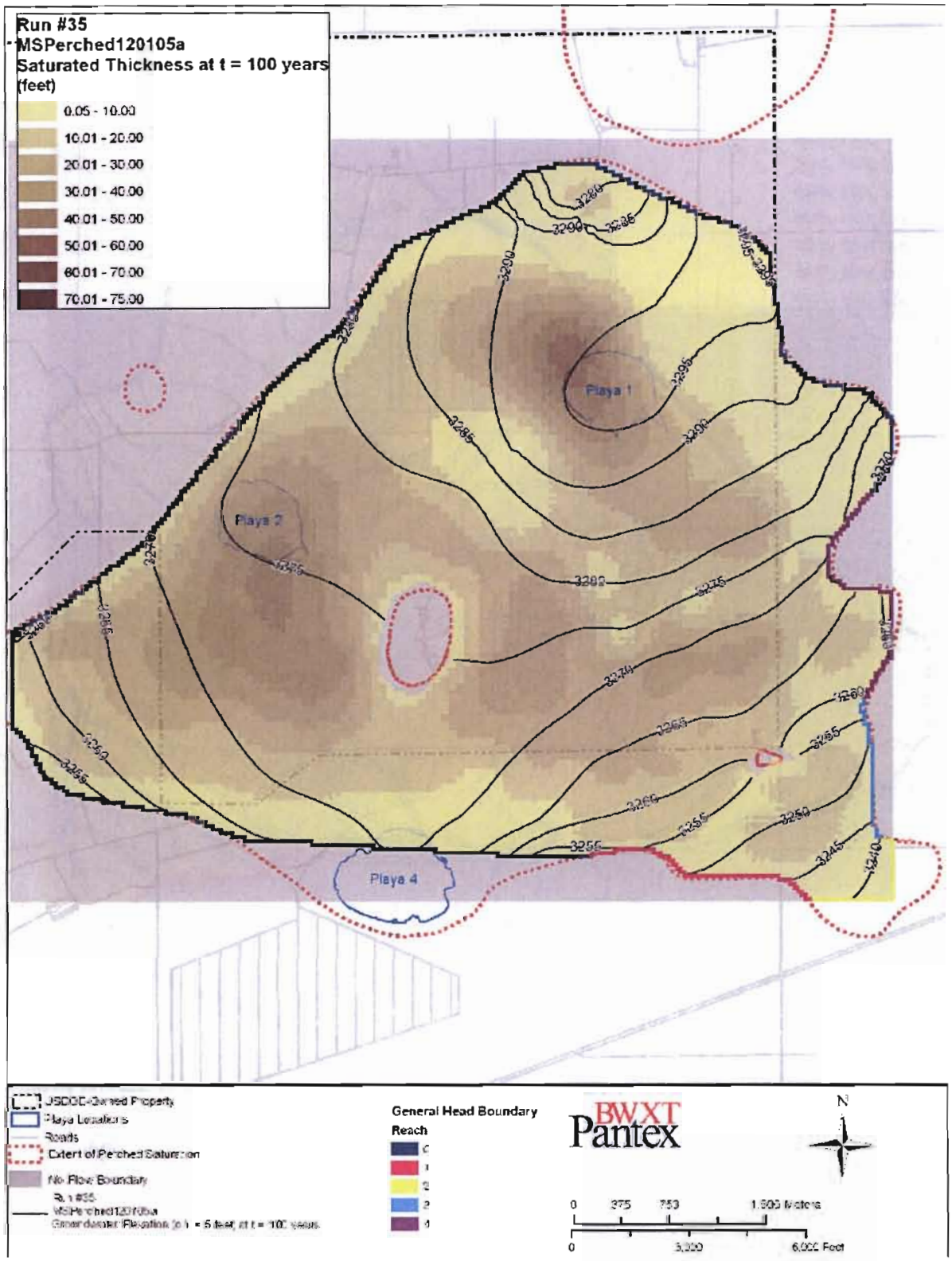

Figure 2A-70. Run 35 Simulated Water Levels and Saturated Thickness at 100 Years

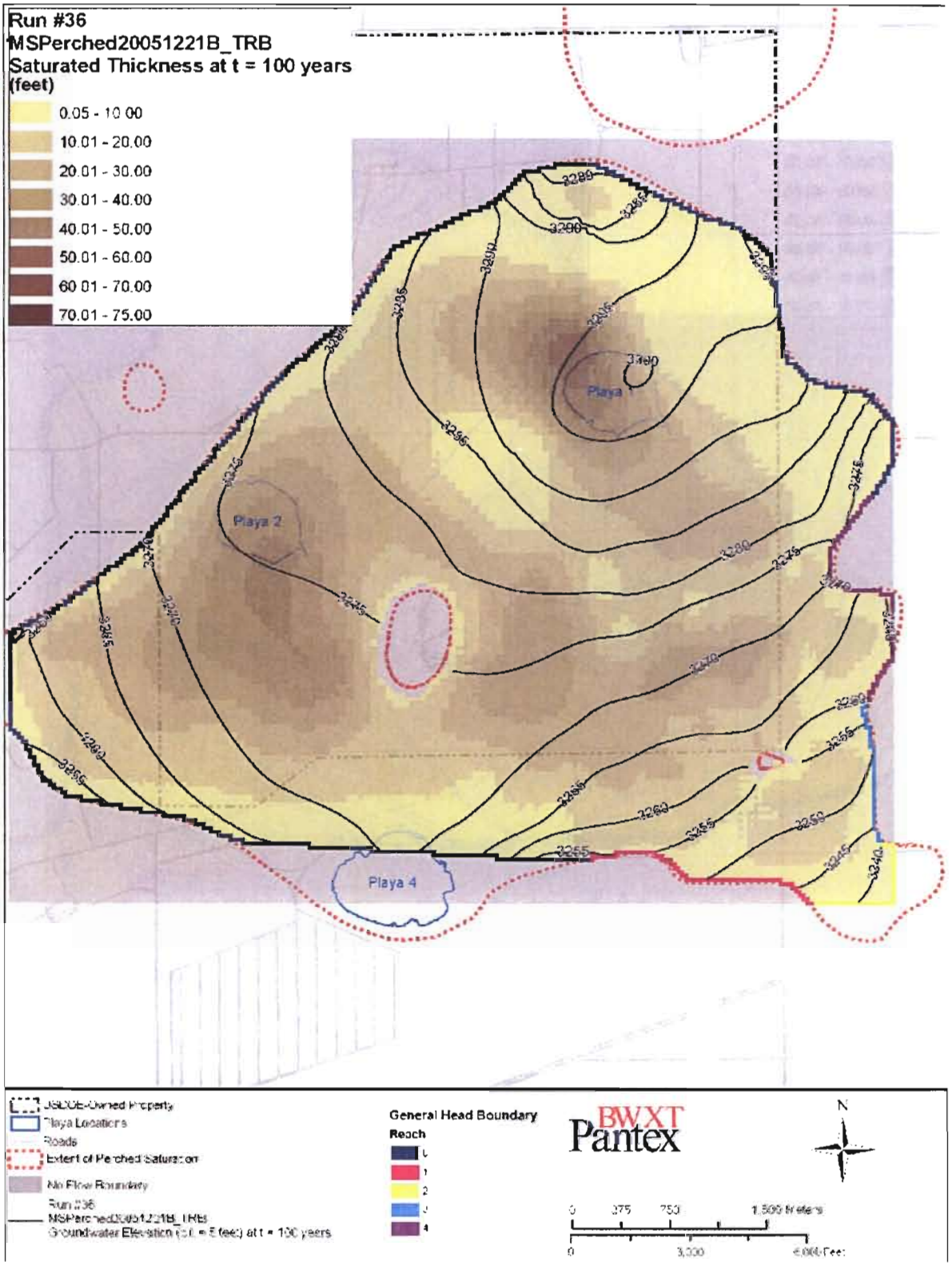

Figure 2A-71. Run 36 Simulated Water Levels and Saturated Thickness at 100 Years

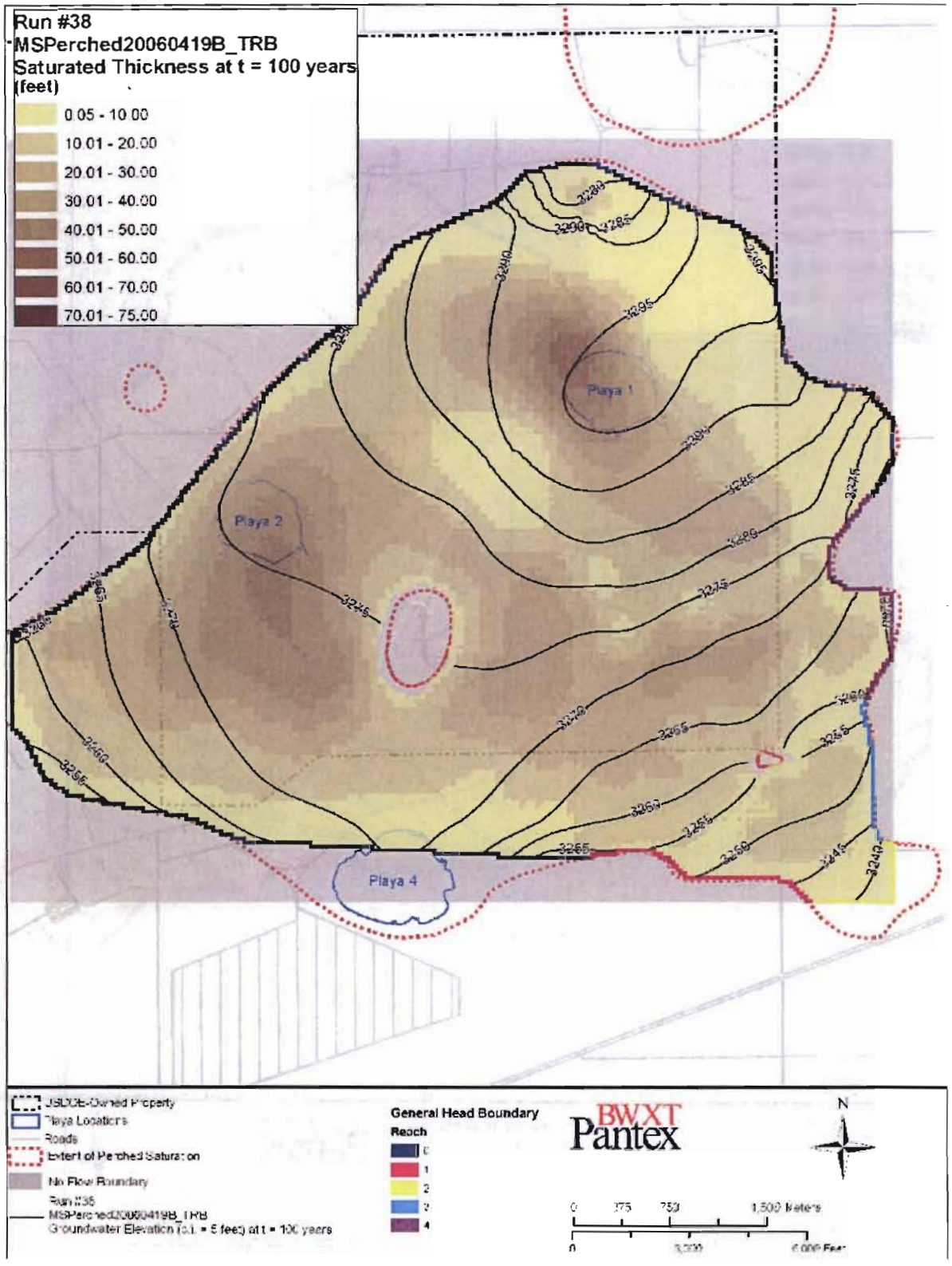

Figure 2A-72. Run 38 Simulated Water Levels and Saturated Thickness at 100 Years