Formerly Utilized Sites
Remedial Action Program
(FUSRAP)

Maywood Chemical Company Superfund Site

ADMINISTRATIVE RECORD

Operable Unit 2 - Groundwater

Document Number

GW-016

US Army Corps
of Engineers®
New York District

FUSRAP
Maywood Superfund Site

Final
Groundwater Feasibility Study Report

Volume 1 of 2

Formerly Utilized Sites Remedial Action Program
Maywood Superfund Site

Prepared by:

US Army Corps
of Engineers®

With Assistance from:

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100 West Hunter Avenue
Maywood, New Jersey 07607

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September 2010

FINAL
GROUNDWATER FEASIBILITY STUDY REPORT
FUSRAP MAYWOOD SUPERFUND SITE
MAYWOOD, NEW JERSEY

SITE-SPECIFIC ENVIRONMENTAL RESTORATION
CONTRACT NO. DACW41-99-D-9001
TASK ORDER 0004
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FINAL
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ABBREVIATIONS AND ACRONYMS

µg/L	micrograms per liter
AEC	Atomic Energy Commission
AOC	Areas of Concern
ARARs	applicable or relevant and appropriate requirements
ATV	acoustic televiewer
AWQC	Ambient Water Quality Criteria
BDAT	best demonstrated available technology
BRA	Baseline Risk Assessment
BTEX	benzene, toluene, ethylbenzene, and xylene
CEA	Classification Exception Area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
cfs	cubic feet per second
cm/s	centimeters per second
COCs	Constituents of Concern
COPCs	Constituents of Potential Concern
CWA	Clean Water Act
DCE	dichloroethene
DOE	Department of Energy
EE/CA	Engineering Evaluation/Cost Analysis
EPA	Environmental Protection Agency
Fe	iron
Fe+2	ferrous iron
Fe+3	ferric iron
FFA	Federal Facility Agreement
f_{oc}	fraction organic carbon
FMSS	FUSRAP Maywood Superfund Site
FS	Feasibility Study
ft	feet
ft/day	feet per day
ft/ft	feet per foot
FUSRAP	Formerly Utilized Sites Remedial Action Program
FW	Fresh Water
g	gram
GAC	granular activated carbon
gpd/ft	gallons per day per foot
GPM	gallons per minute
GWFS	Groundwater Feasibility Study
GWQS	Groundwater Quality Standards
GWRI	Groundwater Remedial Investigation

HI	hazard index
HRC®	Hydrogen Release Compound
ICs	Institutional Controls
K_d	soil distribution coefficient
K_{oc}	carbon adsorption coefficient
LMAS	Leaky Multiple-Unit Aquifer System
LOEL	Lowest Observed Effects Level
LTM	Long-Term Management
LUCs	Land Use Controls
m^3/s	cubic meters per second
MCLs	Maximum Contaminant Levels
MCW	Maywood Chemical Works
MED	Manhattan Engineer District
mg/kg	milligrams per kilogram
mi^2	Square Mile
MISS	Maywood Interim Storage Site
MNA	Monitored Natural Attenuation
Mn	manganese
MRC®	Metals Remediation Compound
MSL	mean sea level
NAD	normalized absolute difference
NCP	National Contingency Plan
NE	northeast
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJGS	New Jersey Geological Survey
NJGWQC	New Jersey Groundwater Quality Criteria
NNE	north-northeast
NNW	north-northwest
NPL	National Priorities List
NRC	Nuclear Regulatory Commission
NW	northwest
NYSW	New York, Susquehanna, and Western Railway Corporation
O&M	Operation and Maintenance
ORC®	Oxygen Release Compound
ORP	oxidation reduction potential
OU	Operable Unit
PCE	tetrachloroethene
pCi/g	picocurie per gram
pCi/L	picocurie per liter
POTW	Publicly Owned Treatment Works
PQL	practical quantitation limit
PRB	Permeable Reactive Barrier
PRGs	Preliminary Remediation Goals
R^2	correlation coefficient
RAOs	remedial action objectives
RCRA	Resource Conservation and Recovery Act

redox	oxidation reduction
REEs	Rare Earth Elements
RI	Remedial Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
Shaw	Shaw Environmental, Inc.
SLERA	screening-level ecological risk assessment
SP	spontaneous potential
SPLP	Synthetic Precipitation Leaching Procedure
SPR	single-point resistance
SSE	south-southeast
SSL	soil screening level
SSW	south-southwest
STSC	Superfund Technical Support Center
SW	southwest
SWQC	Surface Water Quality Criteria
SWQS	Surface Water Quality Standards
TCE	trichloroethene
TEC	Recommended Consensus Based TEC for Freshwater Systems
TOC	total organic carbon
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
UV	ultraviolet
VC	vinyl chloride
VOCs	volatile organic constituents
WNW	west-northwest
WSW	west-southwest
yds	yards

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EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The Maywood Chemical Company Superfund Site in Bergen County, New Jersey is listed on the United States Environmental Protection Agency's (EPA's) Superfund National Priorities List (NPL). The National Superfund Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) identification number is NJD980529762. The Maywood Chemical Company Superfund Site (hereafter referred to as the "Formerly Utilized Sites Remedial Action Program [FUSRAP] Maywood Superfund Site" or "FMSS") consists of property owned by the Federal Government (the Maywood Interim Storage Site [MISS]), the Stepan Company (former location of the Maywood Chemical Works [MCW]), and other government, commercial, and residential properties in Maywood, Lodi, and Rochelle Park, New Jersey, which are also known as the "Vicinity Properties". The interim storage of material removed from previously remediated properties occurred at the MISS.

The FMSS in Bergen County, New Jersey, is being addressed under three separate Remedial Investigation (RI)/Feasibility Study (FS) processes, all coordinated by the EPA. The United States Army Corps of Engineers (USACE) is responsible for two of the RI/FS documents for waste identified as "FUSRAP waste" in the Federal Facilities Agreement (FFA) dated September 17, 1990 between the United States Department of Energy (DOE) and the EPA. The first RI/FS addressed soil/building contamination located on the Federal Government-owned MISS and the Vicinity Properties. The second (the subject of this document) addresses potential groundwater contamination at the MISS and Vicinity Properties related to thorium processing activities and chemical groundwater contamination originating on the MISS. The Stepan Company is responsible for the third RI/FS that addresses non-FUSRAP-related chemical contamination in soils or groundwater related to the areas of the site outside of the MISS.

The USACE was delegated authority for the cleanup of FUSRAP waste associated with thorium processing activities at the MCW by the Energy and Water Development Appropriations Act of 1998, and subsequent reauthorizations of that Act. Other non-FUSRAP-related chemical contamination is being addressed under a separate investigation by the Stepan Company. An FFA for the FMSS was signed in 1991 by the EPA and the DOE to address each party's responsibilities at the FMSS. The FFA also defines FUSRAP waste as it relates to DOE's responsibilities at the FMSS. The DOE was the USACE's predecessor as lead Federal agency for cleanup of FUSRAP waste on the FMSS.

This Groundwater Feasibility Study (GWFS) has been prepared consistent with the *Groundwater Feasibility Study Approach and Initial Screening of Technologies, Interim Submittal* (USACE, 2004a), and addresses those FUSRAP constituents of concern (COCs) in groundwater on the MISS and Vicinity Properties.

The DOE implemented an RI in 1991 (DOE 1992) which identified volatile organic constituents (VOCs), metals, and radionuclides in groundwater. Subsequently, the USACE performed a Groundwater Remedial Investigation (GWRI) at the FMSS to fill data gaps and meet the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The GWRI was completed in 2005. The GWRI identified impacts to groundwater, surface water, and sediment associated with the FMSS.

ES.2 PURPOSE

The purpose of this GWFS is to evaluate the need for, and possible alternatives for, a final remedial action for the groundwater located at the MISS and Vicinity Properties that contains FUSRAP waste as defined by the FFA negotiated between the DOE and EPA Region 2 (effective April 22, 1991).

Under the terms of the FFA, FUSRAP waste was defined as:

- All contamination, both radiological and chemical, whether commingled or not, on the MISS;
- All radiological contamination above cleanup levels related to past thorium processing at the MCW site occurring on any Vicinity Properties; and
- Any chemical or non-radiological contamination on Vicinity Properties that would satisfy either of the following requirements:
    1. The chemical or non-radiological contaminants which are mixed or commingled with radiological contamination above cleanup levels; or
    2. The chemical or non-radiological contaminants that originated at the MISS or were associated with the specific thorium manufacturing or processing activities at the MCW site which resulted in the radiological contamination.

The methodology used in this GWFS employs a step-by-step evaluation of technologies and alternatives. Initially, general qualitative information is used for the identification of applicable technologies. Subsequently, more refined and quantitative information is used to eliminate from consideration infeasible or otherwise unacceptable remedial technologies. Remedial technologies that are not eliminated are then assembled into remedial alternatives and evaluated in detail.

Site Description and History

The FMSS is in a highly developed area of northeastern New Jersey in the boroughs of Maywood and Lodi, and the Township of Rochelle Park. It is located approximately 12 miles north-northwest (NNW) of New York City, and 13 miles northeast (NE) of Newark, New Jersey. The population density of this area is approximately 7,000 people/mi^2. The MISS is an 11.7-acre fenced lot that was previously part of a 30-acre property owned by the Stepan Company. The Federal Government acquired the MISS from the Stepan Company in 1985. The MISS contains two buildings (Building 76 and a Pump House), temporary office trailers, a water reservoir, and two railroad spurs. The water reservoir, Pump House, and one of the railroad spurs are still in use by the Stepan Company. It is bounded on the west by New Jersey State Route 17; on the north by a New York, Susquehanna, & Western Railway (NYSW) line; and on the south and east by the Stepan Company property. Residential properties are located north of the railroad line and within 300 yards (yds) to the north of the MISS. The topography of the MISS ranges in elevation from approximately 51 to 67 feet (ft) above mean sea level (MSL). The highest elevations are in the northeastern portion of the property. The property is enclosed by a chain-link fence, and access to potentially hazardous sites is restricted.

Site-Specific Hydrogeology

Groundwater beneath the FMSS occurs in bedrock and locally in overburden deposits.

Regionally, groundwater in bedrock occurs under confined and unconfined conditions within a network of interconnected bedrock joints (fractures) and open bedding fractures in the Passaic Formation. The permeability of the Passaic Formation is fracture controlled, with the exception of some sandstone aquifer units. Regionally, the Passaic Formation provides a major source of groundwater in the Newark Basin and locally to a number of water districts in Bergen County. The bedrock aquifer is layered (heterogeneous), typically consisting of a series of alternating aquifers and aquitards several tens of feet thick. The water bearing fractures of each aquifer are more or less continuous, but hydraulic connection between individual aquifers is poor. These aquifers generally dip downward for a few hundred feet and are continuous along the strike for thousands of feet. Shallow bedrock, the depth of most interest to the GWFS, generally extends

10 to 35 feet below the bedrock surface. Shallow bedrock monitoring well yields on the FMSS range from 0.5 to 50 gallons per minute (GPM) with most wells producing 0.5 to 2.0 GPM. Shallow bedrock yields have been measured locally in three wells, during short term pumping tests (two to 72 hrs), with average flows of 10.5, 16, and 17 GPM. Long term pumping rates from single wells located on the MISS, based on computer modeling, are expected to be less than 5 GPM. Shallow bedrock groundwater flow at the MISS is predominantly west-southwest (WSW) towards the Saddle River.

Saturated, laterally continuous overburden deposits were mapped in parts of the FMSS, and comprise the local overburden aquifer. Overburden material typically consists of a lower undifferentiated till and gravel unit (on bedrock), which is overlain by gravel, upper undifferentiated till and sand, and an upper sand unit. In most FMSS areas, the sand (unit) is covered by fill of varying thickness. The highest aquifer permeability and porosity (and groundwater yield) is typically encountered in stratified drift (well sorted glacial outwash deposits composed of sand, gravel, silt, and clay laid down by glacial melt water in a river flood plain and in glacial lake deltas and alluvial fans), and is expected in the mapped gravel and sand units. Stratified drift deposits are usually laterally extensive within a paleodrainage, but can vary in composition, permeability, and well yield. The reported yield of stratified deposits in the Hackensack Quadrangle ranges from one to several hundred GPM; however, local wells are expected to yield from 0.5 to 5 GPM. The gravel and/or sand units are mapped in all overburden aquifer areas, and are expected to transmit the majority of groundwater in the overburden aquifer.

Nature and Extent of Groundwater Contamination

In the GWRI report, groundwater data were compared to the lower of the Federal/State Maximum Contaminant Levels (MCLs) or the New Jersey Groundwater Quality Criteria (GWQC). Groundwater Quality Standards (GWQS), as outlined in New Jersey Administrative Code (NJAC) 7:9-6, January 7, 1993 and recodified with amendments, November 7, 2005 (Chapter 7:9c, Groundwater Quality Standards), describes the New Jersey Groundwater Classifications. Groundwater within the FMSS is classified as Class II groundwater.

Class II groundwater has a designated use of potable groundwater with conventional water supply treatment, either at their current water quality (Class II-A) or subsequent to enhancement or restoration of regional water quality, so that the water will be of potable quality with conventional water supply treatment (Class II-B). Both existing and potential potable water uses are included in the designated use.

GWRI-identified impacted media on the FMSS includes the overburden and shallow bedrock groundwater aquifers, surface water, and sediments. The FUSRAP groundwater constituents of potential concern (COPCs) identified in the GWRI included total radium, total uranium, gross alpha, gross beta, arsenic, barium, beryllium, lead, lithium, thallium, benzene, methylene chloride, tetrachloroethene (PCE), toluene, trichloroethene (TCE), and vinyl chloride (VC). These GWRI-identified COPCs were detected in both the overburden and shallow bedrock aquifers. However, PCE, TCE, and VC were determined to be from non-MISS sources.

As part of the GWRI, a well search centered on the MISS indicated the presence of more than 450 wells in a half-mile radius. Of the more than 450 wells identified, ten were listed as domestic use. Of the ten domestic wells, seven did not have specific addresses. These wells are located side gradient from the MISS (Sections 2.13 and 6.6, Table 2-1, Figure 2-1 and Appendix D of the GWRI present detailed domestic well information). An additional 5-mile radius search centered on the MISS was conducted for water allocation permits, which resulted in the identification of only three water allocation permits within a 1-mile radius. One of these permits is for the Stepan Company's surface water withdrawal from the Saddle River. The other two permits are for industrial wells installed in the deeper bedrock aquifer of the Passaic Formation and are located in the opposite direction of groundwater flow at the MISS.

USACE, in implementing land use controls (LUCs), including an aquifer Classification Exemption Area (CEA) (pages 4-4, 4-8, and 4-12), would work with State and local governments and affected property owners to develop and implement appropriate measures intended to restrict the use of groundwater in the area until the COCs no longer exceed cleanup levels. Further investigations would be conducted in the CEA to locate wells to determine specific addresses and to determine the status of any potential groundwater receptors.

A well located at Malt Products Corporation in Maywood was incorrectly identified in the RI as a potential receptor for the MISS. This well is approximately one half mile southeast (SE) of the MISS. A groundwater divide lies between the well and the MISS. The direction of groundwater flow from the MISS is to the west and southwest (SW) which is in the opposite direction to the location of the Malt Products Corporation well. The Malt Products Corporation well is not a potential receptor.

FUSRAP surface water COPCs identified in the GWRI included total radium, arsenic, lead, and thallium. The Soils and Buildings Operable Unit (OU) Record of Decision (ROD) remedy, that includes the replacement or repair of a culvert, would remove the source of surface water radiological and non-radiological contamination. This GW OU would remove the source of remaining surface water non-radiological contamination.

In addition, a 2005 *Baseline Risk Assessment (BRA)* (USACE, 2005a) identified the following predominant contributors to the risk at the FMSS:

- Assuming potable groundwater use by current and future residents - adult
    - Non-cancer health effects: arsenic, benzene, 2-chlorotoluene and lithium
    - Total excess lifetime cancer risk: arsenic, benzene, and VC
- Assuming potable groundwater use by current and future residents - children
    - Non-cancer health effects: arsenic, benzene, 2-chlorotoluene, xylenes, manganese and lithium
    - Total excess lifetime cancer risk: arsenic, benzene, and VC
- Assuming potable groundwater use by current and future workers
    - Non-cancer health effects: arsenic, benzene, and lithium
    - Total excess lifetime cancer risk: arsenic and benzene
- Assuming dermal contact by current and future construction/utility workers (excavation)
    - Non-cancer health effects: benzene and 2-chlorotoluene
    - Total excess lifetime cancer risk: within EPA acceptable range.

In the same way that PCE, TCE and VC were eliminated as COPCs, the BRA chemical constituents 2-chlorotoluene and xylene were not included in the GWRI, since the concentrations found in MISS groundwater were determined to be from a non-MISS source. Manganese was not included as a COPC in the GWRI because the elevated concentrations were attributed to its reduction in conjunction with the degradation of organic constituents such as benzene, chlorotoluene, and chlorinated solvents in groundwater. In addition, the GWRI reported that the COPC lithium exceeded the EPA Region 9 tap water preliminary remediation goals (PRGs), a non-promulgated risk-based remedial goal. However, lithium is not a listed CERCLA hazardous substance. Nevertheless, USACE would address lithium materials remaining on the Federally-owned property in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk. This effort would be confirmed in the

Maywood GW ROD. Since applicable or relevant and appropriate requirements (ARARs) are not available for lithium in groundwater, a risk-based action level was derived for lithium, based upon ingestion of groundwater. A target hazard quotient of 1 was used to derive the lithium risk-based action level of 730 μg/L. In order to achieve this groundwater goal, a soil cleanup number for lithium has been established at 194 milligrams per kilogram (mg/kg).

In addition, the BRA concluded that the radionuclides found in the groundwater at the FMSS contribute relatively little to the total excess lifetime cancer risks. Moreover, the BRA concluded that most of the radiological risks may be due to background levels of the radionuclides.

Based on the evaluation of MISS-related COPCs in the BRA, the primary risk contributors from groundwater, assuming potable use, were determined to be benzene and arsenic.

Probable FUSRAP Areas of Concern (AOCs) were identified in the GWRI for each of the groundwater, sediment, and surface water media (**Figure 1-12**). Groundwater AOCs were defined by the presence of: (1) potential FUSRAP waste(s) in groundwater, and (2) a probable active (ongoing) groundwater contamination source. A total of seven groundwater AOCs were identified in the GWRI for the FMSS study area, as follows:

- AOC 1 – Former Retention Pond A, located within the MISS, was identified as a potential groundwater source area based on arsenic, lithium, lead, and thallium.
- AOC 2 – Former Retention Pond C, located within the MISS, was identified as a potential groundwater source area based on total uranium, arsenic, lithium, barium, beryllium, and benzene. PCE, TCE, and VC were also detected in low concentrations, but were determined to be from non-MISS sources.
- AOC 3 – Nuclear Regulatory Commission (NRC) Burial Pit 1 was identified as a potential groundwater source area based on total uranium.
- AOC 4 - NRC Burial Pit 3 was identified as a potential groundwater source area based on total radium.
- AOC 5 – Well B38W18D (Former Thorium Manufacturing Area), located on the MISS, was identified as a potential groundwater source area, based on total radium, lithium, and arsenic.
- AOC 6 – Probable Benzene (Shallow Bedrock) Source Area, located on the MISS, was identified as a potential groundwater source area based on benzene. Former MCW Building 62, which contained two 20,000-gallon benzene tanks, was located in this area.
- AOC 7 – Probable Overburden Benzene Source Area (Former MCW Chemical Building), located on the MISS, was identified as a potential groundwater source area based on benzene in overburden groundwater.

The GWRI determined MISS soils to contain metals COPCs above the site-specific Soil Screening Levels (SSLs), as summarized in the *Soil Screening Level Technical Memorandum* (USACE, 2004b). These soils were determined to be a potential groundwater metals source.

One sediment/surface water AOC and one surface water AOC were identified based upon sediment and surface water sampling results. Surface water and sediment AOCs were determined to be limited to the stream segment adjacent to an impacted sample and do not include the entire downgradient drainage. The sediment and surface water AOCs were identified as the following:

- AOC 8 – Lodi Brook (sediment and surface water) was identified as a potential source of surface water and sediment contamination to downstream water bodies for total radium, and Ra-226 in surface water, and Th-232 in sediment.
- AOC 9 – Westerly Brook (surface water) was identified as a potential source of down-stream contamination of surface water bodies based on total radium, arsenic, lead, and thallium.

Identification of FUSRAP Groundwater COCs

The following FUSRAP COCs were identified for evaluation in the GWFS due to elevated concentrations of COPCs in groundwater migrating from COPC sources located on the MISS:

- Arsenic
- Benzene
- Lithium

The *Feasibility Study (FS) for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2002a) and the *Record of Decision (ROD) for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2003) did not identify arsenic and benzene as COPCs in the soils. Groundwater was not directly addressed in the soils FS due to ongoing groundwater investigations. The data obtained from the ongoing investigations were evaluated during the development of the BRA and GWFS, which subsequently identified likely MISS source areas for arsenic and benzene in groundwater (see AOC descriptions above). Therefore, arsenic and benzene are considered FUSRAP wastes for the purposes of this GWFS.

Other chemical constituents present in groundwater were not determined to be COCs since they are not FUSRAP wastes. These chemical constituents are from non-MISS related activities, upgradient sources, did not contribute to risk at the FMSS due to limited exceedances, or are the result of biodegradation of the organic constituents in groundwater. They were evaluated in the GWFS for completeness and potential effects on the remedial scenarios. These chemical constituents are:

- PCE
- TCE
- VC
- 2-Chlorotoluene
- Beryllium
- Thallium
- Lithium (non-MISS sources)
- Toluene
- Xylenes (total)
- Arsenic (non-MISS sources)
- Barium
- Lead
- Methylene chloride
- Iron
- Manganese

Isolated occurrences of barium, beryllium, lead, thallium, methylene chloride, and toluene were observed in MISS groundwater, but none of these chemicals were widely distributed in the groundwater (typically detected in five or less wells) with no evidence of a plume. TCE, PCE, VC, xylenes, and 2-chlorotoluene were detected in the groundwater at the MISS. These chemicals were determined to be from an upgradient non-FUSRAP source. Arsenic, which is not related to the MISS, was also detected in off-site monitoring wells. Even though these chemicals do not originate on the MISS, they were evaluated during the GWFS in order to determine their effect on the various remedial alternatives.

Elevated iron and manganese concentrations are attributed to the ongoing degradation of organic constituents (benzene, chlorotoluene, and chlorinated solvents) in groundwater, and utilization (reduction) of these metals as alternate electron acceptors. The highest total iron (Fe) and manganese (Mn) concentrations are detected in monitoring wells impacted with organic constituents and are attributed to the reduction/dissolution of the metals (Fe+2 and Mn+2) from the aquifer matrix. Once the organic constituents are remediated/degraded, iron and manganese (as Fe+3 and Mn+4) would oxidize, become less soluble, and precipitate out of groundwater returning dissolved phase concentrations to background levels since the natural groundwater condition is oxidizing. They will not be included as COCs during the GWFS.

The COPCs total uranium, total radium, gross alpha and gross beta are not included as COCs due to the results of the BRA, which concluded that radionuclides contribute relatively little to the total excess lifetime cancer risks. Furthermore, most of the radiological risks may be due to background levels of the radionuclides. The total radium and total uranium exceedances are localized and isolated to three wells and two wells, respectively. Additionally, the Soils and Buildings OU remediation would remove potential source areas, and the collection and treatment of excavation waters, including groundwater during this effort, would remove water potentially contaminated with radionuclides. As part of the long-term monitoring program designed for this GWFS, radiological constituents would also be monitored in order to ensure protectiveness of the Soils and Buildings OU remediation.

Remedial Action Objectives (RAOs) and Proposed Cleanup Levels

The RAOs for MISS groundwater are based on human health and environmental considerations that drive the formulation and development of response actions. Such objectives are developed based on the criteria outlined in Section 300.430(e)(2) of the NCP. The RAOs for MISS groundwater have been developed such that attainment of these levels would result in the protection of human health, ecological receptors, and the environment.

The following RAOs for the MISS groundwater have been established for the FMSS:

- Comply with Federal and State MCLs or more stringent promulgated NJGWQC that are designated as ARARs for COCs in the groundwater in this GWFS (see **Table 2-1**).
- Eliminate or minimize the source of groundwater contamination associated with MISS non-radiological contaminated soils, to include pond sludge on the MISS, beyond the soils removed during the Soils and Buildings OU remedial action to levels that are protective of groundwater (see **Table 2-2**). Eliminate or minimize the potential for human exposure at unacceptable levels by direct contact or ingestion threat associated with groundwater COCs above cleanup levels established in the GW OU ROD for the COCs during implementation of the remedial action.
- Eliminate or minimize the potential for human exposure at unacceptable levels by direct contact or ingestion threat associated with lithium in groundwater. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

The proposed cleanup levels used for this GWFS are presented in the table below.

GROUNDWATER PROPOSED CLEANUP LEVELS
FUSRAP MAYWOOD SUPERFUND SITE

GWFS Constituent	Groundwater Cleanup Level (micrograms per liter [μg/L])
Arsenic	3[a]
Benzene	1[a]
Lithium	730[b]

a The lowest of Federal MCLs (40 CFR Part 141) or New Jersey Groundwater Quality Criteria (NJGWQC) or higher practical quantitation limit (PQL) (NJAC 7:9C).

b Since ARARs are not available for lithium in groundwater, a risk-based action level was derived for lithium based on ingestion of groundwater.

Development of Remedial Alternatives

Groundwater technology process options were screened based on three factors: implementability, effectiveness, and cost. The term “process option” refers to specific processes within each technology type. The screened technologies and process options were assembled into remedial alternatives based on these criteria. Alternatives were developed from the following groundwater remedial technologies.

- No Action
- Long-Term Management (LTM) - Groundwater Monitoring
- Land Use Controls (LUCs) - Use Restrictions
- Groundwater Extraction
- In-Situ Groundwater Treatment
- Ex-Situ Groundwater Treatment
- Groundwater Discharge
- Soil Excavation
- Off-site Soil Disposal

Soil remediation using excavation and off-site disposal at a licensed facility would be required for removing COC source material of arsenic and lithium on the MISS to include pond sludge on the MISS to protect groundwater (**Sections 2.4** and **2.5**). These soils are located beneath the radiologically contaminated soils that would be remediated under the Soils and Buildings OU ROD, and includes soils both above and below the groundwater table. Soil excavation and off-site disposal at a licensed facility was the selected remedy presented in the Soils and Buildings OU ROD and was reevaluated for use in the GWFS for development of alternatives.

Alternatives can consist of a technology option alone, or several technology options in combination, to address the MISS-specific RAOs.

The following four alternatives are proposed for the groundwater at the MISS:

- Alternative No. 1 – No Action
- Alternative No. 2 – Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation (MNA) of Lithium, Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation on the MISS.
- Alternative No. 3 – Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater, In-Situ Treatment of Arsenic in Overburden Groundwater with Oxidation Reduction (Redox) Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS.
- Alternative No. 4 – Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soil Remediation on the MISS.

These alternatives were evaluated using the groundwater flow and solute transport model constructed for the site (**Appendix C, Volume 2**). Both flow and transport modeling were conducted along with particle tracking analysis. Geochemical evaluations were also performed.

USACE is aware of ongoing investigations by Dixo Company and Stepan Company of groundwater contaminant plumes not originating on the MISS. The existence of these plumes has been considered in the development of remedial alternatives found in this GWFS.

Alternative No. 1 – No Action

The "No Action" alternative was used as the baseline to measure the performance of other alternatives. This alternative is required by the NCP. In this alternative, no remedial systems would be installed or operated, and no LUCs would be used for groundwater. Any improvement of the groundwater would be through natural attenuation including biodegradation, adsorption to aquifer material, outgassing, dispersion, and dilution. An LTM activity, such as groundwater monitoring, would not be conducted. The MISS non-radiological groundwater contamination source soils (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) would not be removed and disposed off site.

Alternative No. 2 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Groundwater and Non-Radiological Contaminated Soil Remediation on the MISS

This alternative would consist of LUCs, such as well restrictions in a groundwater CEA, where groundwater contamination has been identified and construction worker warnings issued regarding dermal exposure; groundwater monitoring for COCs and selected natural attenuation parameters; MISS non-radiological contaminated soils remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) to include pond sludge on the MISS; reporting; and maintenance of the monitoring well system. This alternative has been developed to limit public exposure. The duration of the groundwater monitoring program included in this alternative would be based on the data results which demonstrate that the impacted groundwater has been treated to RAOs. Metals, volatile organics, and natural attenuation parameter analyses would be conducted, as needed, to monitor the change in aquifer conditions and chemical constituent concentrations on the MISS and in groundwater migrating off the MISS. Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA would require that the remedial action be reviewed at least once every five years to ensure protectiveness of the remedy.

Alternative No. 3 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater, In-Situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS

For this alternative, in-situ treatment of arsenic in overburden groundwater is combined with MNA for arsenic, lithium, and benzene in shallow bedrock, in addition to MISS non-radiological contaminated soils remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) to include pond sludge on the MISS, LUCs, groundwater monitoring and natural attenuation as described for Alternative No. 2. The proposed treatment technology is oxidation reduction (redox) alteration which would be used in areas where arsenic in overburden groundwater is above the proposed cleanup level. Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA would require that the remedial action be reviewed at least once every five years to ensure protectiveness of the remedy.

Alternative No. 4 - Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soils Remediation on the MISS

Alternative No. 4 combines groundwater extraction, ex-situ treatment of groundwater; MISS non-radiological contaminated soils remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) to include pond sludge on the MISS, LUCs and groundwater monitoring (as described for Alternative Nos. 2 and 3), and groundwater discharge. Six recovery wells were assumed in this system. The selected treatment system includes an air stripper for VOCs, metals precipitation, reverse osmosis or ion exchange for lithium (lithium is present in site groundwater and would be extracted along with the COCs), and carbon to treat any off-gases from the air stripper. The exact number of wells and locations, and the specific components for the treatment system, would be determined during the system design. Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA would require that the remedial action be reviewed at least once every five years to ensure protectiveness of the remedy.

Detailed Evaluation of Alternatives

The four remedial action alternatives previously presented were compared using a qualitative evaluation. The purpose of the comparative analysis was to weigh the relative performance of each alternative against a particular criterion and to determine which alternative performs consistently well or consistently better in relation to the criterion of interest. The alternatives were evaluated according to the following criteria:

- Threshold criteria:
    - Overall protection of human health and the environment
    - Compliance with ARARs

- Primary balancing criteria:
    - Short-term effectiveness
    - Long-term effectiveness and permanence
    - Reduction in toxicity, mobility, or volume
    - Implementability
    - Cost

In accordance with the *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP, 40 CFR, Part 300), modifying considerations (State acceptance and community acceptance) were not included in the evaluation, since comments from the agencies and the public have not yet been received.

ES.3 THRESHOLD CRITERIA

Overall Protection of Human Health and the Environment

Alternative No. 1 would not protect human health or the environment. Alternative Nos. 2, 3, and 4 would be protective of human health and the environment. In each of these alternatives, groundwater would not be used and future use of impacted groundwater would be controlled through LUCs, such as well restrictions in a groundwater CEA and warnings to construction workers regarding dermal exposure. For all three alternatives, non-radiological contaminated soil source areas would be remediated. Based on the groundwater fate and transport model results, lithium impacted groundwater is predicted to reach the Saddle River. However, due to mixing with surface water, no impact to surface water is expected.

Compliance with ARARs

Alternative No. 1 would not comply with ARARs. Alternative Nos. 2, 3, and 4 would comply with ARARs. Each alternative would meet chemical-specific ARARs for groundwater. The primary difference is the time frame for the ARAR to be achieved. Groundwater monitoring would be a component of each of these alternatives. For Alternative No. 2, MNA would be the primary technology. In Alternative No. 3, after in-situ treatment, groundwater monitoring would be used to track the attenuation of the remaining benzene, arsenic and lithium plumes, and aquifer redox conditions, which could impact COC degradation, fate, and transport. In Alternative No. 4, pumping would be discontinued after concentrations of benzene in groundwater decrease to less than proposed cleanup levels. Groundwater monitoring would be used to evaluate the natural attenuation of arsenic and lithium in the aquifer.

ES.4 PRIMARY BALANCING FACTORS

Short-Term Effectiveness

There would be no additional risk to workers or the community under Alternative No. 1, since the alternative would not involve construction activities. Alternative Nos. 2, 3, and 4 would include non-radiological contaminated soil remediation, drilling, installation and sampling of monitoring wells. Alternative No. 4 would also include construction of a treatment plant. Some of these activities would pose an additional risk to the remedial worker due to work-related hazards and additional risk to the community and environment due to potential hazards related to the transportation and disposal of contaminated soil. Remedial Alternative Nos. 2 and 3 would pose a slightly lower risk, since construction of the treatment plant would not be involved. Alternative No. 3 would include handling of chemicals for in-situ treatment both on and off site which would pose a moderate risk to the remedial worker. All groundwater sampling would pose a moderate risk to the remedial worker and a low risk to the community, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and transported to the site for proper disposal, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

Long-Term Effectiveness

Residual risk would be the same as pre-construction risk for Alternative No. 1. Source areas would not be addressed and there would be no management of residual risk. Under Alternative Nos. 2, 3, and 4, the source areas would be addressed by the remediation of non-radiological contaminated soil, to include pond sludge on the MISS. Under each alternative, groundwater use would be controlled through LUCs, such as well restrictions in a groundwater CEA, and construction workers would be warned about dermal exposure. Based on groundwater modeling and geochemical evaluations, Alternative No. 3 would be the most effective at reducing the timeframe to treat the arsenic contaminant plume (less than one year). Alternative No. 3 would be moderately complex to implement. In-situ treatment would require a large number of chemical injection points. Additionally, the in-situ treatment chemicals would have to be selected based on other contaminants present in the aquifer. In-situ pilot and bench scale studies would have be performed to determine the appropriate chemicals, required concentrations, and injection volumes to use to treat arsenic without mobilizing metals into groundwater from the aquifer matrix. Optimum aquifer conditions would have to be maintained for in-situ treatment or the arsenic would re-dissolve with subsequent downgradient migration. Maintaining optimum aquifer conditions may require additional chemical injections beyond those assumed in the GWFS. Alternative No. 3 does not treat the benzene and arsenic in shallow bedrock plumes which would be allowed to attenuate naturally, and the lithium plume, because it cannot be treated in-situ. Therefore, the time frame for cleanup of the benzene, lithium and arsenic plumes in shallow bedrock is the same as Alternative No. 2. For Alternative Nos. 2 and 4, arsenic concentrations would be expected to be reduced and become less mobile when natural conditions (slightly reducing to oxidizing) are restored in the aquifer and after the benzene biodegrades (**Appendix B** for more details). Once the benzene is no longer in the groundwater system, the attenuation rate for arsenic would be expected to increase. Alternative No. 4 reduces the time frame for the lithium plume by a few years; however, once the pumping is discontinued, this plume is present for a time frame similar to that calculated for Alternative No. 2. Additionally, the active pump and treat technology under Alternative No. 4 could potentially draw off-site non-FUSRAP related contamination into the extraction system. Long-term pumping on the MISS over time, could impact the downgradient Dixo Company chlorinated solvent plume, potentially spreading the contamination over a larger area of the aquifer, increasing concentrations downgradient of the source area (Dixo Company property), and pulling more of the non-FUSRAP contamination onto the MISS.

Reduction of Toxicity, Mobility and Volume

Alternative No. 1 would not reduce contaminant toxicity, mobility, or volume. Both Alternative No. 3 and Alternative No. 4 would include active treatment of groundwater as part of the alternative. Alternative No. 2 would address the contaminant plume through passive treatment. Under Alternative No. 2, toxicity, mobility, and volume of groundwater contamination would be addressed through naturally occurring biodegradation, dispersion, adsorption, and mineral precipitation. The attenuation mechanism for lithium is dispersion. Arsenic concentrations would be reduced through dispersion, adsorption, and mineral precipitation, and benzene by biodegradation. Alternative No. 3 would reduce the toxicity, mobility, and the volume of the groundwater contaminants in the arsenic plume through in-situ treatment. This alternative would not address benzene and arsenic in shallow bedrock, and the lithium plume, since the constituent cannot be treated in-situ. Alternative No. 4 would reduce the toxicity, mobility, and volume of the benzene and arsenic plumes in groundwater through extraction and ex-situ treatment. Groundwater extraction only slightly reduces the projected cleanup time for the lithium plume.

Implementability

Alternative No. 1 would require no implementation. Alternative No. 2 would be easy to implement and would use proven technologies. Alternative No. 3 would be complex to implement, since a large number of chemical injection points would be required. Also, additional chemical injections may be required to implement Alternative No. 3 in order to maintain optimum aquifer redox conditions which may substantially increase costs beyond those developed in this FS. Moreover, the local variable permeabilities of the substrata would impact delivery of the treatment medium under Alternative No. 3. Most activities for Alternative No. 4 would be straightforward; however, selection of the recovery well locations may increase the complexity, since the wells would need to intercept continuous fracture zones. Under all alternatives, implementation of well restrictions in a groundwater CEA would include a small number of off-site, adjacent properties.

Cost

The total present-worth costs are estimated as follows:

- Alternative No. 1 is $0.00
- Alternative No. 2 is $ $30,454,000
- Alternative No. 3 is $35,929,000
- Alternative No. 4 is $122,202,000

Costing assumptions and details are described in Appendix D.

1.0 INTRODUCTION

The Maywood Chemical Company Superfund Site in Bergen County, New Jersey is listed on the United States Environmental Protection Agency's (EPA's) Superfund National Priorities List (NPL). The National Superfund Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) identification number is NJD980529762. The Maywood Chemical Company Superfund Site (hereafter referred to as the "FUSRAP Maywood Superfund Site" or "FMSS") consists of property owned by the Federal Government (the Maywood Interim Storage Site [MISS]), the Stepan Company (former location of the Maywood Chemical Works [MCW]), and other government, commercial, and residential properties in Maywood, Lodi, and Rochelle Park, New Jersey, which are also known as the "Vicinity Properties". The interim storage of material removed from previously remediated properties occurred at the MISS.

The FMSS in Bergen County, New Jersey, is being addressed under three separate Remedial Investigation (RI)/Feasibility Study (FS) processes, all coordinated by the EPA. The United States Army Corps of Engineers (USACE) is responsible for two of the RI/FS documents for waste identified as "FUSRAP waste" in the FFA dated September 17, 1990 between the United States Department of Energy (DOE) and EPA. The first RI/FS addressed soil/building contamination located on the Federal Government-owned MISS and the Vicinity Properties. The second (the subject of this document) addresses potential groundwater contamination at the MISS and Vicinity Properties related to thorium processing activities and chemical groundwater contamination originating on the MISS. The Stepan Company is responsible for the third RI/FS that addresses non-FUSRAP-related chemical contamination in soils or groundwater related to the areas of the site outside of the MISS.

The USACE was delegated authority for the cleanup of FUSRAP waste associated with thorium processing activities at the MCW by the Energy and Water Development Appropriations Act of 1998, and subsequent reauthorizations of that Act; other non-FUSRAP-related chemical contamination is being addressed under a separate investigation by the Stepan Company. A Federal Facility Agreement (FFA) for the FMSS was signed in 1991 by the EPA and the DOE to address each party's responsibilities at the FMSS. The FFA also defines FUSRAP waste as it relates to DOE's responsibilities at the FMSS. The DOE was the USACE's predecessor as lead Federal agency for cleanup of FUSRAP waste on the FMSS.

This Groundwater Feasibility Study (GWFS) addresses those COCs in groundwater (FUSRAP waste) on the MISS and Vicinity Properties. This GWFS has been prepared consistent with the *Groundwater Feasibility Study Approach and Initial Screening of Technologies, Interim Submittal* (USACE, 2004a).

The DOE implemented an RI in 1991 (DOE, 1992) which identified volatile organic constituents (VOCs), metals, and radionuclides in groundwater. Subsequently, the USACE performed a Groundwater Remedial Investigation (GWRI) at the FMSS to fill data gaps and meet the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980. The GWRI was completed in 2005. The GWRI identified impacts to groundwater, surface water, and sediment associated with the FMSS. In addition, the GWRI provided supplemental soils data which were not addressed in the *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2003). Limited additional soils data were collected to further delineate groundwater source areas and to perform batch sorption testing. The supplemental soils data were evaluated under this GWFS. In this GWFS, each of the remaining media are addressed as follows:

- Developing and screening remedial alternatives to address FUSRAP COCs associated with the groundwater located at the MISS;

- Performing an evaluation to determine if the groundwater alternatives will prevent impacts to surface water and sediment from groundwater impacted by the MISS.

This report presents the methodology and results of the GWFS conducted to address these media.

1.1 PURPOSE AND ORGANIZATION

The purpose of this GWFS is to evaluate the need for, and possible alternatives for, a final remedial action for the groundwater located at the MISS and Vicinity Properties that contains FUSRAP waste as defined by the FFA negotiated between the DOE and EPA Region 2 (dated September 17, 1990).

Under the terms of the FFA, FUSRAP waste was defined as:

- All contamination, both radiological and chemical, whether commingled or not, on the MISS;
- All radiological contamination above cleanup levels related to past thorium processing at the MCW site occurring on any Vicinity Properties; and
- Any chemical or non-radiological contamination on Vicinity Properties that would satisfy either of the following requirements:
    1. The chemical or non-radiological contaminants which are mixed or commingled with radiological contamination above cleanup levels; or
    2. The chemical or non-radiological contaminants originated in the MISS or were associated with the specific thorium manufacturing or processing activities at the MCW site which resulted in the radiological contamination.

The methodology used in this GWFS involves the identification and evaluation of technologies and alternatives. Initially, general qualitative information is used for the identification of applicable technologies. Subsequently, more refined and quantitative information is used to eliminate from consideration infeasible or otherwise unacceptable remedial technologies. Remedial technologies that are not eliminated are then assembled into remedial alternatives and evaluated in detail. The documentation of the GWFS is provided in the following report sections.

- **Section 1.0: Introduction**

    Includes a brief description and history of the FMSS and MISS. The nature and extent of the problem, potential risks to human health and the environment, and conclusions of the *Final Groundwater Remedial Investigation Report* (USACE, 2005b) for the FMSS and MISS are repeated only as necessary to summarize findings from the recent investigations and the updated risk assessment, interim remedial actions, updated remedial action objectives (RAOs), and site cleanup levels. Additional details regarding topics discussed in this GWFS can be obtained in the *Final Groundwater Remedial Investigation Report* (USACE, 2005b) and the *Final Baseline Risk Assessment* (USACE, 2005a).

- **Section 2.0: Identification and Screening of Remedial Action Technologies**

    Identifies and screens general response actions and remedial action technologies, which are the key components of remedial alternatives. The process of identifying potentially applicable technologies begins with developing general response actions and RAOs. The potentially applicable remedial technologies associated with each general response action are then screened based on technical feasibility. The most applicable technologies are retained for further consideration.

- **Section 3.0: Screening of Process Options**

  Evaluates remedial technologies and associated process options using the criteria of effectiveness, implementability, and cost. The most applicable technologies/process options representing each general response action are used to develop remedial action alternatives.

- **Section 4.0: Development of Alternatives**

  The technology/process options remaining from the screening performed in **Section 3.0** are combined to provide alternatives for remediation of the MISS to address the RAOs from **Section 2.0**.

- **Section 5.0: Detailed Evaluation of Alternatives**

  Remedial action alternatives developed in **Section 4.0** are evaluated according to seven of the nine remedy selection criteria specified in the NCP. The criteria are established by the NCP as follows: overall protection of human health and the environment; compliance with ARARs; short-term effectiveness; long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; implementability; cost. State acceptance and community acceptance would be evaluated after the Proposed Plan is issued and comments are received from the State and the public.

- **Section 6.0: Ranking of Alternatives and Recommendation**

  Compares the alternatives against each other with respect to the seven evaluation criteria listed below. The result of this comparison leads to the selection of the recommended remedial alternative in the proposed plan.

  - Threshold factors
    - Overall protection of human health and the environment
    - Compliance with ARARs

  - Primary balancing factors
    - Short-term effectiveness
    - Long-term effectiveness and permanence
    - Reduction in toxicity, mobility, or volume
    - Implementability
    - Cost

- **Section 7.0: References**

  Lists the references used in this report.

- **Appendices**

  GWFS supporting and evaluation activities are documented in **Appendices A-D**.

  - **Appendix A** contains a summary of historical groundwater trends.

  - **Appendix B** provides transport parameters and in-situ remediation methods for groundwater.

  - **Appendix C**, Volume 2 provides groundwater flow and solute transport modeling results.

  - **Appendix D** provides detailed cost summaries.

Potential remedial actions for groundwater and groundwater impacts to surface water and sediment are addressed in this GWFS.

1.2 SITE DESCRIPTION AND HISTORY

A brief summary of the FMSS description and history is presented below. This discussion is based on the *Final GWRI* (USACE 2005b). Additional FMSS details can be obtained by reviewing the GWRI. A more detailed description of the FMSS is also provided in the *Feasibility Study for Soils and Buildings at the FUSRAP Maywood Superfund Site* and *Proposed Plan for Soils and Buildings at FUSRAP Maywood Superfund Site* (USACE, 2002 a and b).

1.2.1 Description

The FMSS is in a highly developed area of northeastern New Jersey in the boroughs of Maywood and Lodi, and the Township of Rochelle Park. It is located approximately 12 miles north-northwest (NNW) of New York City, and 13 miles northeast (NE) of Newark, New Jersey. The population density of this area is approximately 7,000 people/mi^2. The FMSS consists of 88 properties owned by the Federal Government, the Stepan Company, and other government, commercial, and private entities/individuals in the municipalities of Maywood, Lodi, and Rochelle Park, New Jersey **(Figure 1-1 and Figure 1-2)**. The MISS and associated retention ponds, adjacent burial pits, and water courses are located within the FMSS (**Figure 1-1**). Of the 88 FMSS properties, 64 Phase I properties (including all municipal and residential properties) have been cleaned up by the DOE or the USACE. During cleanup actions on these properties, additional properties were remediated if contamination was found to extend onto an adjacent undesignated property.

1.2.1.1 MISS

The MISS is an 11.7-acre fenced lot that was previously part of a 30-acre property owned by the Stepan Company. The Federal Government acquired the MISS from the Stepan Company in 1985. The MISS contains two buildings (Building 76 and a Pump House), temporary office trailers, a water reservoir, and two railroad spurs. The water reservoir, Pump House, and one of the railroad spurs are still in use by the Stepan Company. It is bounded on the west by New Jersey State Route 17; on the north by a New York, Susquehanna, & Western Railway (NYSW) line; and on the south and east by the Stepan Company property. Residential properties are located north of the railroad line and within 300 yards (yds) to the north of the MISS. The topography of the MISS ranges in elevation from approximately 51 to 67 feet (ft) above mean sea level (MSL). The highest elevations are in the northeastern portion of the property. The property is enclosed by a chain-link fence, and access to potentially hazardous site areas is restricted.

1.2.1.2 Stepan Company Property

The Stepan Company, a pharmaceutical and chemical manufacturer that purchased the former MCW property in 1959, is located adjacent to and east of the MISS at 100 West Hunter Avenue in the Borough of Maywood. The property covers 18.2 acres. The topography of the property has been modified into a series of terraces to accommodate construction of the operating facility. Topographic relief from the highest terrace at the north side to the lowest terrace at the south side of the property is about 25 ft. Approximately two-thirds of the property contains buildings, some in or near the locations where the MCW thorium processing operations occurred. A chain-link fence encloses the property (excluding the main office and parking area), and access is restricted within the fenced area. Three Nuclear Regulatory Commission (NRC) licensed burial pits are located on the property. Each burial pit is covered, and these locations are currently used as a lawn, parking lot, and building site. The burial pits will be remediated by the USACE, and are addressed further in the *Feasibility Study for Soils and Buildings at the FUSRAP Maywood Superfund Site* and *Proposed Plan for Soils and Buildings at FUSRAP Maywood Superfund Site* (USACE, 2002a and USACE, 2002b).

1.2.1.3 Vicinity Properties

There are 59 designated residential Vicinity Properties and 27 commercial/government properties at the FMSS, located in the Boroughs of Maywood and Lodi, and the Township of Rochelle Park. The DOE identified these properties through surveys performed by Oak Ridge National Laboratory. Two commercial and one government property were originally part of the MCW, and were used for waste storage and burial. The remaining commercial, government, and residential properties were contaminated by transport of soil by surface water runoff along former stream channels, or by use of contaminated material as fill and mulch.

1.2.2 Site History

The original plant, which became known as the MCW after incorporation on December 24, 1918 under the laws of the State of New Jersey, was constructed in 1895. The principal products manufactured by the MCW were chemicals used in the pharmaceutical, food, glass, soap, and metals industries. Starting in 1916, portions of the plant were used to extract thorium and rare earth metals from monazite sands for use in manufacturing industrial products, such as mantles for gas lanterns. Thorium and rare earth metals were extracted from the monazite sands using an acidic separation process. The wastes from this process were pumped as slurry to holding ponds.

Process wastes from the thorium extraction operations were pumped into two areas surrounded by earthen dikes on property west of the plant. In 1932, the disposal areas were partially covered by the construction of New Jersey State Route 17. Waste retention ponds existed on portions of the MCW that now comprise 96 Park Way, MISS, and 149-151 Maywood Avenue.

The MCW also produced detergents, alkaloids, essential oils, and lithiated compounds, including lithium chloride, lithium fluoride, and lithium hydroxide. The MCW owned and operated mining properties in the vicinity of Keystone, South Dakota, which produced lithium ore that was transported to the MCW and processed. Lithium wastes were believed to have been disposed in diked areas on the MCW. Protein extraction from leather digestion was also performed on the MCW. Leather wastes are believed to have been buried in two primary shallow disposal areas on the Stepan Company property, just east of the MISS property boundary.

Process wastes from these manufacturing processes were generally stored in open piles and retention ponds on the MCW property. Some of the process wastes were removed for use as mulch and fill on nearby properties, thereby contaminating those properties with radioactive thorium. Although the fill consisted primarily of tea and cocoa leaves from other MCW processes, these materials were apparently contaminated with the thorium-processing wastes.

Additional waste migrated off the property via natural drainage associated with the former Lodi Brook. Historical photographs and maps indicate that the former course of the Brook, which originated on the MCW property in the area that is now 149-151 Maywood Avenue, generally coincides with the distribution of contaminated properties in the Borough of Lodi. Most of the open stream channel in Lodi was replaced by a storm-drain system that was completed in the 1960s.

The MCW stopped extracting thorium in 1956, after approximately 40 years of production. The property was subsequently sold to the Stepan Company in 1959.

Corrective measures conducted by the Stepan Company in the 1960s on the former MCW plant property included relocation and burial of approximately 19,100 yd^3 of excavated waste materials. The Stepan Company sold the portion of the original plant property located west of New Jersey State Route 17, now known as 96 Park Way, after relocation of the waste materials. The Stepan Company currently holds an NRC license for the storage of thorium-bearing materials in Burial Pits 1, 2, and 3.

1.2.3 Summary of Previous Investigations and Interim Removal Actions

Numerous soil and groundwater investigations have been conducted by various Federal and State governmental agencies at the FMSS.

The DOE began investigating the FMSS and the surrounding area in 1983; and during 1984 through 1985 cleaned up 25 residential properties and a portion of one commercially zoned property. The DOE conducted radiological surveys throughout the FMSS from 1984 through 1987. The DOE conducted an RI at the FMSS from 1989 through to 1991 covering the Stepan Company property, the MISS, eight residential properties, and five commercial/governmental properties. Primary and secondary sources of identified soil contamination were subsequently documented.

The DOE RI Report (DOE, 1992) concluded that the delineation of the nature and extent of groundwater contamination was incomplete. Further RI activities were proposed, including the completion of a Baseline Risk Assessment (BRA), and a more detailed radiological survey of the Stepan Company buildings.

Due to the limited commercial disposal capacity for radiological wastes, the excavated materials from cleanup efforts in the 1980's were stored on property that was a part of the original MCW processing site. The DOE acquired this property from the Stepan Company and named it the Maywood Interim Storage Site. During a cleanup action conducted by the DOE in 1995 and 1996, these stored materials were removed from the MISS and sent to a licensed, permanent, off-site commercial disposal facility. Also during 1995, the cleanup of the remaining residential properties, four municipal properties (three parks and a fire station), and one commercially zoned property (96 Park Way) was initiated. These interim property cleanups were implemented as removal actions as described in the DOE's September 1995 Engineering Evaluation/Cost Analysis (EE/CA) under CERCLA. These interim cleanup actions were completed in 2000 by the USACE.

A time-critical removal action was completed by the USACE during the winter of 2000 to remove contaminated sediments from portions of Lodi Brook and a swale located at the terminus of West Howcroft Road. The removal action re-established the hydraulic grade of the Brook and swale, prevented additional flooding, and prevented the transport or migration of contaminated soil by flood water.

In July 2001, the USACE published the *Engineering Evaluation/Cost Analysis for a Removal Action in Support of NJDOT Roadway Improvement Projects at the FUSRAP Maywood Superfund Site (FMSS)* for public comment. The Action Memorandum was approved in November 2001. The removal action was initiated in January 2002.

The *Feasibility Study for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2002a) was completed and submitted for public comment, along with the *Proposed Plan for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2002b) in August 2002. The *Record of Decision (ROD) for Soils and Buildings at the FUSRAP Maywood Superfund Site* (USACE, 2003) was completed in 2003. The final remedy for the Soils and Buildings OU documented in the ROD is: (1) excavation/removal of soils with contamination at concentrations greater than the cleanup levels; (2) physical separation to sort materials for disposal as mixed waste, other bulk waste, and radioactive waste; (3) institutional land-use controls (deed notices, easements, covenants, zoning controls); (4) off-site disposal of FUSRAP materials; (5) decontamination and demolition of buildings, as necessary; and (6) environmental monitoring of the effectiveness of the remedy. With the implementation of the Soils and Buildings OU ROD, the removal action was transitioned into the final remedy. Several Soils and Buildings OU properties addressed by the soils ROD were previously remediated through the EE/CA. The soils to be removed on the MISS in accordance with the Soils and Buildings OU ROD are not the same soils to be evaluated for removal in the GW OU remedial action. The Soils and Buildings OU ROD did not identify all FUSRAP wastes. Groundwater was not directly addressed in the Soils FS due to ongoing groundwater investigations. The data obtained from the ongoing investigations were evaluated during the development of the BRA, GWRI, and this GWFS to determine any remaining FUSRAP wastes that would impact groundwater.

A Phase I groundwater RI field program was conducted by the USACE during 1999 to 2000. The Phase I groundwater RI involved the following elements.

- Review and research FMSS history and processes.
- Geoprobe® soil and groundwater investigation.
- Existing well inventory.
- Sample USACE overburden and groundwater wells.
- Groundwater level measurements.
- Surface geophysics and borehole geophysics survey.
- In-situ permeability tests.
- Video inspection of the Westerly Brook and Lodi Brook culverts.

A Phase II groundwater RI field program was conducted by the USACE during 2000, 2001, and 2002. The Phase II groundwater RI involved the following elements.

- Area water purveyor and well search.
- Soil and groundwater Geoprobe® investigation.
- Overburden and bedrock monitoring well installation.
- Overburden and bedrock aquifer testing.
- Borehole geophysics survey on newly installed bedrock wells.
- In-situ permeability testing of newly installed overburden wells.
- Survey of all existing and newly installed USACE wells, and Stepan Company wells.
- Groundwater sampling of USACE and Stepan Company wells.
- Sediment and surface water sampling.
- Groundwater level measurements.
- Batch Sorption Soil Distribution Coefficient (K_d) testing.

Additional work was conducted by the USACE to investigate the source and downgradient extent of a bedrock groundwater benzene plume that was partially delineated on the MISS. A Supplemental Groundwater Investigation field program included the following elements.

- Evaluate existing soil and groundwater benzene data on the MISS.
- Install additional bedrock wells to delineate the benzene plume.
- Conduct permeability testing at newly installed wells.
- Perform groundwater VOC sampling at 38 bedrock wells.
- Perform biogeochemical sampling at selected wells to characterize biodegradation in the bedrock groundwater aquifer.

- Measure water levels in shallow and deep bedrock wells over the study area.
- Conduct borehole geophysics at selected newly installed wells.

The Phase I, II, and supplemental activities were documented in the *Final GWRI Report* (USACE, 2005b).

Stepan Company

Investigative activities conducted by the Stepan Company included a Focused RI/FS and a Groundwater Remediation Pilot Test, which are described below.

RI/FS activities included the advancement of soil borings, performance of a surface geophysical survey, installation of overburden and bedrock monitoring wells, aquifer testing, and the collection of soil, surface water, sediment, and groundwater samples. Analytical results generated from the RI indicated the presence of elevated levels of benzene in the soils and groundwater, as well as the presence of buried containers of organic residue and aromatic hydrocarbons, ketones, and/or chlorinated solvents on the 149-151 Maywood Avenue property. Chlorinated hydrocarbons were detected in the bedrock groundwater, and elevated radiological readings were detected in soil samples collected throughout the study area and in unfiltered groundwater samples.

During the Focused RI, test pits were dug near the southwest (SW) corner of the Stepan Company property to further delineate the horizontal and vertical extent of buried tanned leather hides. Samples associated with the former leather processing operation indicated that the area was the source of metals (chromium) contamination in soils and groundwater.

Three separate BTEX (benzene, toluene, ethylbenzene, and xylene) plumes were documented in the groundwater beneath the Stepan Company property. The first plume is located at the former Aromatic and Essential Oils Manufacturing Area (Aromatics Area); the second plume is located northwest (NW) of the Aromatics Area plume; and the third plume is located at the former Central Tank Farm Area.

Approximately 2.4 million gallons per day of non-contact cooling water, scrubber water, cooling water, cooling tower blow down, and storm water are discharged to Lodi Brook from the Stepan Company. However, several spills have occurred and were noted as being discharged into Lodi Brook. During on-site New Jersey Department of Environmental Protection (NJDEP) investigations, observations were made of waste product being washed down the storm sewer leading to Lodi Brook.

Dixo Company

The Dixo Company is located north of the MISS at 158 West Central Avenue, Rochelle Park, and is involved in the packaging of industrial adhesives.

The Dixo Company reported soil and groundwater contamination originating from their property (Dixo Company, 2002). The high concentrations of chlorinated solvents detected in the overburden and bedrock groundwater on the property are potential sources of solvents detected in FMSS monitoring wells to the west of the MISS. Groundwater samples collected by the NJDEP "confirmed the release of tetrachloroethene (PCE) to the underlying aquifer as a result of operations at the Dixo Company facility" and confirmed that the Dixo Company facility was the likely source of PCE contamination in downgradient wells in Rochelle Park (NJDEP, 2002). The NJDEP also detected PCE at USACE well clusters MW-7 and MW-8 during sampling in 2001, and noted that these wells are located "hydraulically downgradient of the Dixo Company facility".

1.2.4 Geology and Hydrogeology

Regional Bedrock Geology

The FMSS is located in the Piedmont Physiographic Province within the U. S. Geological Survey (USGS) Hackensack Quadrangle. The Piedmont Province in New Jersey is located within the Newark Basin, a NE trending half graben which extends SW from the Hudson River Valley in New York to southeastern Pennsylvania.

The Newark Basin is primarily composed of a sequence of sedimentary rocks and intrusive igneous rocks, commonly referred to as the Brunswick Group. The sedimentary rocks within the Brunswick Group consist of sandstones, shales, mudstones, and conglomerates having strike orientations ranging from N20E to N35E, and dipping between 7 and 15 degrees to the NW.

The sedimentary rocks of the Brunswick Group are divided into three formations: a lower unit, the Stockton Formation; a middle unit, the Lockatong Formation; and an upper unit, the Passaic Formation. The FMSS is underlain by the Passaic Formation Sandstone Member which is described as an interbedded grayish red to brownish red, medium to fine grained, medium to thick bedded sandstone and brownish to purplish red, coarse grained siltstone; the unit is planar to ripple cross laminated, fissile, locally calcareous, containing desiccation cracks and root casts. Upward fining cycles are 6 to 15 ft thick. Maximum thickness is approximately 3,600 ft.

Regional Unconsolidated Deposits (Overburden) Geology

Bedrock within the USGS Hackensack Quadrangle is generally overlain by unconsolidated overburden deposits consisting of recent alluvial, wetland, estuarine and stream terrace post glacial deposits, and stratified and unstratified glacial deposits. Stratified glacial deposits are generally well-sorted and include sand and gravel outwash laid down by glacial meltwater in a river plain, and in glacial lake deltas and fans.

In the study area, stratified drift (well sorted glacial outwash deposits composed of sand, gravel, silt, and clay laid down by glacial melt water in a river flood plain, and in glacial lake deltas and alluvial fans) consists of glaciolacustrine and glaciofluvial outwash deposits associated with glacial lakes Hackensack and Paramus, and is comprised of well-sorted sands, gravels, silts, and clays. Unstratified glacial deposits (e.g., till) consist of poorly sorted, non-stratified sediment-containing gravel clasts and boulders deposited directly from glacial ice. Till is locally described as a dense, poorly sorted, heterogeneous mixture of sand, gravel, silt, and clay with occasional boulders and cobbles.

New Jersey Geological Survey (NJGS) borings in the FMSS show that most areas mapped with stratified drift and filled areas are underlain by a thin, dense layer of till. Till overlies weathered bedrock in the vast majority of NJGS-logged wells.

Site-Specific Geology

Bedrock: Top of bedrock elevations generally decrease from the high in the NE corner of the FMSS to the west and south. The maximum bedrock elevation of 70 ft MSL is located along a north-south trending ridge in Lodi, which outcrops at Route 80. A second bedrock high is noted at the intersection of Essex Street and New Jersey State Route 17 in Lodi. The lowest bedrock elevation (-5.0 ft MSL) is mapped at the southern extent of the FMSS at well MW-16D in Lodi. The bedrock has a maximum relief of 75.0 ft on the FMSS, and shows maximum local relief along the trace of Westerly and Lodi Brook.

The bedrock surface at the MISS and Stepan Company properties shows that bedrock elevations decrease to the west with a maximum 20-foot relief.

Bedrock of the Passaic Formation is generally described as a dark red brown, medium to thick bedded, fine to medium grained sandstone and coarse grained siltstone, with occasional thin shale interbeds. The large outcrop located at the rail line cut at Summit Avenue (Hackensack) features a massive (15 ft thick) coarse grained sandstone, which was interbedded with thick to medium bedded sandstones, coarse siltstones, and thin beds of siltstone and shale. At all locations, thin bedded, fine grain rocks showed prominent bedding plane partings and were heavily jointed/fractured. The density of bedding plane partings, joints, and other fractures was observed to generally diminish with increased grain size and bedding thickness.

Bedrock core descriptions are consistent with the Passaic Formation seen in outcrops. The top 10 to 15 ft of cores were highly weathered and showed dense fracturing, with several fractures noted per foot. Weathering and fracture density decreased with depth. Fracturing and apparent water bearing zones were most prevalent in siltstone bedrock, and least developed in thick sandstone units. The vast majority of fractures at all depths is low angle, and probably represents open bed partings. A high angle set of fractures was also noted in most cores, and appears to strike in the same direction as the primary bedding plane fractures.

Borehole geophysical logging was conducted at five existing bedrock wells as part of the Phase I program, and 25 newly installed wells as part of the Phase II program. The logging suite included caliper, single-point resistance (SPR), spontaneous potential (SP), natural gamma, fluid temperature, fluid resistivity, acoustic televiewer (ATV), and heat pulse flowmeter logging. Borehole fractures were identified, which were used to determine fracture dip angles and down dip azimuths.

The prevalent fracture strike orientation is north-northeast (NNE) to south-southwest (SSW), with the dip Rose Plot showing a prevalent west-northwest (WNW) and NW direction. The summary conductive (water bearing) Rose Diagrams also show a dominant NNE to SSW to NE to SW strike orientation, and WNW to NW dip direction. The total fracture and water conducting fracture stereo plots indicate that the majority of fractures dip between 5 and 20 degrees to the WNW. Borehole fracture data is fairly consistent throughout the FMSS study area. An increased number of steeply dipping fractures are observed in wells located along the northern boundary of the FMSS. The borehole geophysical data is consistent with the geologic mapping and local outcrop data.

Fracture density with depth was evaluated by counting the average number of open fractures in 24 shallow wells per 5-foot interval of depth. The greatest fracture density was measured in the upper 0 to 5 ft (2.3 fractures) and 5 to 10 ft (2.9 fractures) of open borehole. Average fracture density was observed to decrease with depth. This finding is consistent with pilot borings (cores) and well logs showing decreasing fracture density with depth from the bedrock surface.

Overburden: Five separate stratigraphic units are present at the FMSS. The units are fill, sand, upper undifferentiated silty sand/clay/gravel (upper undifferentiated unit), gravel and lower undifferentiated unit. Thin, discontinuous layers of peat/meadow mat deposits were also encountered, but were not included as a stratigraphic unit due to their limited extent.

A lower undifferentiated unit overlies bedrock in most FMSS areas and is locally absent. The lower unit is an unsorted mixture of dense till, weathered rock fragments and gravel, sand, silt, and clay. The lower unit is distinguished from the upper undifferentiated unit by the presence of dense till and/or coarse bedrock fragments and gravel. The lower undifferentiated unit reaches a maximum thickness of 12 ft; however, it is generally less than 5 ft thick in most locations and absent in some areas.

The gravel unit overlies the lower undifferentiated unit at most locations and consists of a fine gravel and medium to coarse sand. The gravel is generally poor to moderately well sorted, and contains bedrock fragments. The gravel unit is frequently absent in borings, where the upper undifferentiated unit, or less common sand unit, lies directly on the lower unit or bedrock. The gravel unit reaches a maximum thickness of 12 ft. Thick gravel units are also observed in the vicinity of Lodi and Westerly Brooks.

The upper undifferentiated unit (upper unit) overlies gravel at most locations and consists of unsorted mixtures of silt, sand, clayey sands, and clayey gravel. The upper undifferentiated unit reaches a maximum 12 ft thickness and is locally absent. This unit generally has low permeability. The sand unit is laterally extensive and overlies the undifferentiated (till) unit. The sand unit consists of fine to medium sand and gravel, and reaches a maximum thickness of 13 ft. The sand unit generally has moderate permeability.

Fill overlies the sand unit in most locations on the FMSS. The fill is highly variable in composition, and consists of clay, sand, and gravel with brick fragments, black to blue gray to white mottled “clayey” material (encountered in MISS area), concrete chips, wood chips, and other miscellaneous materials. Fill deposits are thickest in the area of former retention ponds located on the MISS.

The overburden in the FMSS reaches a maximum thickness of 36 ft at the southern extent of the FMSS. Overburden deposits are shown to thin against bedrock highs located south-southeast (SSE) of the MISS, along the northeastern boundary of the MISS, and SW of the MISS.

Site-Specific Hydrogeology

Bedrock Hydrogeology: Regionally, groundwater occurs under confined and unconfined conditions in a network of interconnected bedrock joints (fractures) and open bedding fractures in the Passaic Formation. The permeability of the Passaic Formation is fracture controlled, with the exception of some sandstone aquifer units. Regionally, the Passaic Formation provides a major source of groundwater in the Newark Basin and locally to a number of water districts in Bergen County.

In this report, the term shallow bedrock is used to describe the open bedrock interval investigated by shallow bedrock wells, and would typically extend 10 to 35 ft below the top of bedrock. The shallow bedrock is a weathered and fractured zone. The degree of fracturing is greater both in openings and density than deeper bedrock. Deep bedrock is likewise described as open bedrock interval in deep bedrock wells, and would extend from approximately 45 to 70 ft below the bedrock surface.

The bedrock aquifer is layered (heterogeneous), typically consisting of a series of alternating aquifers and aquitards several tens of feet thick. The water-bearing fractures of each aquifer are more or less continuous, but hydraulic connection between individual aquifers is poor. These aquifers generally dip downward for a few hundred feet and are continuous along the strike for thousands of feet. Under pumping conditions, the deeper bedrock typically exhibits directional rather than isotropic hydraulic behavior, with maximum permeability along the bedrock strike. The shallow bedrock exhibits more isotropic conditions due to more extensive and open fractures, and weathering.

GWRI and pumping test results predominantly support the Leaky Multiple-Unit Aquifer System (LMAS) groundwater flow conceptual model (with a weathered shallow zone and significant component of the near vertical joints). Field data, including outcrop descriptions/measurements, cores, and drilling logs, show that the shallow open bedrock fractures are primarily along bed partings. Shallow bedrock borehole geophysics data also shows that water bearing, or conductive fractures, are also primarily oriented along bedrock strike. Measured fracture density was greatest in the upper 10 ft of the borehole, and decreased with depth to 25 ft, below which the fracture density remained the same. Shallow bedrock well yields on the FMSS range from 0.2 to 50 GPM, with most wells producing 0.5 to 2.0 GPM. Shallow bedrock yields have been measured locally in three wells, during short term pumping tests (two to 72 hrs), with average flows of 10.5, 16, and 17 GPM. Long term pumping rates from single wells located on the MISS, based on computer modeling, are expected to be less than 5 GPM.

A prominent set of high angle, NNE striking joints (fractures) were also observed in outcrop, cores, and borehole geophysical logs. Well and borehole logs indicate that these fractures are the principal source of groundwater in deep monitoring wells and piezometers. Fracture density data suggest that the bedrock permeability and amount of groundwater flow along bedding plane fractures would diminish with depth (and degree of weathering), and that a greater proportion or component of flow is expected along the high angle fractures in the deep bedrock aquifer. The shallow and deep bedrock zones are typically hydraulically connected by a network of discontinuous, but interconnected bedding plane and high angle joint fractures, and show unconfined conditions in overburden and shallow/deep bedrock cluster wells. The conceptual bedrock hydrogeologic model for the FMSS is shown on **Figure 1-3**.

The geologic literature and field investigations indicate that the Passaic Formation is systemically fractured, and that the bedding plane fractures and principle joint fractures are regionally prevalent and are observed throughout the rock section. The shallow bedrock aquifer is densely to moderately fractured in the FMSS, and is characterized as an equivalent porous media. Deeper fractured bedrock may exhibit anisotropy, or varying directional permeability, depending on the orientation of the fractures. In the FMSS, principle water bearing fractures (bedding plane and high angle joints) strike NNE, and increased bedrock permeability is possible along a NNE to SSW trending direction.

Overburden Hydrogeology: Saturated, laterally-continuous overburden deposits were mapped in parts of the FMSS, and comprise the local overburden aquifer. The thickest overburden aquifer sediments were recorded in the southern FMSS area, along Westerly Brook, and on the MISS in the area of Former Retention Ponds A, B, and C. The overburden aquifer locally thins and pinches out against bedrock highs.

Overburden material typically consists of a lower undifferentiated till and gravel unit (on bedrock), which is overlain by gravel, upper undifferentiated till and sand, and an upper sand unit. In most areas, the sand (unit) is covered by fill of varying thickness. The highest aquifer permeability and porosity (and groundwater yield) is typically encountered in stratified drift, and is expected in the mapped gravel and sand units. Stratified drift deposits are usually laterally extensive within a paleodrainage, and can exhibit anisotropy. The reported yield of stratified deposits in the Hackensack quadrangle ranges from one to several hundred GPM; however, local monitoring wells are expected to yield from 0.5 to 5 GPM. The gravel and/or sand units are mapped in all overburden aquifer areas, and are expected to transmit the majority of groundwater in the overburden aquifer.

The mapped lower and upper unconsolidated (till) units are typical of unstratified glacial deposits and would characteristically display low hydraulic conductivity. Typical monitoring well yields in till are expected to range from 0.1 to 1 GPM. Although the upper and lower undifferentiated units are widely distributed in the FMSS, the till deposits are poorly sorted and may show varying permeability over short distances. Till units may act as an aquiclude to more permeable stratified drift deposits or bedrock aquifer and result in local confined conditions.

Site-Specific Groundwater Flow Conditions

Groundwater beneath the FMSS occurs in bedrock and locally in overburden deposits. The FMSS bedrock hydrogeology discussion presented below includes groundwater flow direction, packer testing, aquifer testing, and the linear groundwater seepage velocity. The FMSS overburden hydrogeology discussion presented below includes groundwater flow direction, permeability testing, aquifer testing, and linear groundwater seepage flow. Vertical groundwater flow between the bedrock and overburden aquifer are also discussed.

Bedrock Groundwater Flow Direction: A shallow bedrock potentiometric surface map for the FMSS and MISS is shown on **Figure 1-4**. Shallow bedrock groundwater flow at the MISS is generally towards the west and the Saddle River. However, some groundwater flows to the NW and SW due to influence of a bedrock high to the east of the MISS. Flow arrows, showing the varying flow directions, are also shown on **Figure 1-4**. The varying direction of groundwater flow across the MISS is a result of a bedrock high to the east on Stepan Company property.

Bedrock Groundwater Gradients: The July 2001 groundwater data were used to determine groundwater gradients in various directions across the study area. Shallow bedrock groundwater flow in the westerly direction across the site had an average horizontal gradient of 0.0075 feet per foot (ft/ft); in the southwesterly direction the average horizontal gradient ranged from 0.0082 ft/ft to 0.0109 ft/ft.

The deep groundwater flow direction varies from west to SW, with an average gradient of 0.0027 ft/ft. Shallow/deep bedrock and overburden groundwater levels are generally similar within the FMSS, indicating unconfined bedrock aquifer conditions.

Bedrock Packer Testing: The calculated hydraulic conductivity range of the upper portion of the boreholes ranged from 1.34 x 10^{-5} centimeters per second (cm/s) to 1.97 x 10^{-2} cm/s, with a geometric mean of 4.27 x 10^{-4} cm/s. The lower zone hydraulic conductivity ranged from 1.29 x 10^{-5} cm/s to 2.49 x 10^{-3} cm/s, with a geometric mean of 3.71 x 10^{-4}cm/s. The upper and lower zone results are consistent, and do not show any trend with depth. The geometric mean of all shallow bedrock wells was 6.9 x 10^{-4} cm/s.

Bedrock Short Term Aquifer Tests: A bedrock test well and nine piezometers were developed and pumped at a constant rate for two to three hours on the MISS. Wells were pumped at an average rate of 17 GPM, with measurement of water levels and discharge during pumping. The well-specific capacity and transmissivity were estimated for each well.

Transmissivity (and hydraulic conductivity) estimates based upon these results ranged from a low of 140 gallons per day per foot (gpd/ft) (1.94 x 10^{-4} cm/s) to 8,600 gpd/ft (4.56 x 10^{-3} cm/s). The geometric and arithmetic mean of the transmissivity of the shallow bedrock determined within these wells via these tests are 1,300 gpd/ft (1.63 x 10^{-3} cm/s) and 2,580 gpd/ft (1.48 x 10^{-3} cm/s). The nine tested wells show a significant variance (one order of magnitude) in transmissivity within a 150 ft area, indicating a high degree of aquifer heterogeneity.

The estimated MISS transmissivity values were also compared to the existing 1993 Stepan Company aquifer test data. Separate bedrock pumping tests were conducted on the adjacent Stepan Company and 149-151 Maywood Avenue properties to determine aquifer characteristics at each location. A 72-hour constant discharge test was conducted on the Stepan Company property at an average pumping rate of 16 GPM. Calculated aquifer transmissivity (hydraulic conductivity) was reported in the range of 1,310 to 1,528 gpd/ft (2.1 x 10^{-3} cm/s to 1.7 x 10^{-3} cm/s, estimated). A second 72-hour constant discharge test was conducted on the 149-151 Maywood Avenue property at an average pumping rate of 10.5 GPM. The calculated range of transmissivity (hydraulic conductivity) from these wells is 1,310 to 4,075 gpd/ft (2.1 x 10^{-3} cm/s to 4.6 x 10^{-3} cm/s, estimated).

The median 1,300 gpd/ft (1.63 x 10^{-3} cm/s) and mean 2,580 gpd/ft (1.48 x10^{-3} cm/s) transmissivity (hydraulic conductivity) values estimated from short term bedrock testing (specific capacity) of MISS wells is very similar to those obtained during testing of wells on the adjacent Stepan Company and 149-151 Maywood Avenue properties.

Bedrock Groundwater Seepage Velocity: The shallow bedrock seepage velocity was calculated by applying the measured shallow bedrock hydraulic gradient of 0.0109 ft/ft, the estimated effective porosity of 0.05, and range of mean hydraulic conductivity values calculated for the packer tests (6.9 x 10^{-4} cm/s) and short term specific capacity aquifer tests (1.63 x 10^{-3} cm/s). The shallow bedrock seepage velocity is estimated in the range of 0.43 to 1.01 feet per day (ft/day).

Overburden Groundwater Flow Direction: **Figure 1-5** shows that MISS overburden groundwater elevation contours bend around the bedrock high on the adjacent Stepan Company property resulting in radial groundwater flow off the high and a NW to SW range of flow directions on the MISS. Groundwater flow arrows on **Figure 1-5** show northwest MISS overburden groundwater flow along the eastern portion of the northern boundary, a westerly groundwater flow direction towards the Saddle River in the center portion of the MISS, and a SW groundwater flow direction at the southern end of the MISS.

Overburden Aquifer Extent: The overburden aquifer is absent in areas of the FMSS and Vicinity Properties. The overburden aquifer underlies the MISS and parts of the adjacent Stepan Company property, is also mapped downgradient of the MISS, and extends west to the Saddle River. The overburden aquifer ranges in thickness from 0 to 36 ft, and pinches out or is seasonally absent in some FMSS and surrounding areas.

Overburden Groundwater Gradients: The July 2001 groundwater data were used to determine the overburden groundwater gradients. Overburden groundwater flow to the west has an average horizontal gradient of 0.0076 ft/ft; in the SW direction the average horizontal gradient ranges from 0.0079 ft/ft to 0.0111 ft/ft. The general direction of overburden groundwater flow and gradient along Lodi Brook in Lodi is SSW at an average horizontal gradient of 0.0076 ft/ft.

Overburden Aquifer Slug Tests: The calculated hydraulic conductivity in the overburden aquifer ranges from a minimum average (rising and falling head) value of 1.5 x 10^{-4} cm/s to a maximum average value of 1.05 x 10^{-2} cm/s. The highest average hydraulic conductivity values were obtained in wells installed in the gravel unit (1.37 x 10^{-3} cm/s) and lower undifferentiated unit (1.84 x 10^{-3} cm/s). Lower average values were observed in wells installed in the fill (9.21 x 10^{-4} cm/s), sand (6.06 x 10^{-4} cm/s), and the upper undifferentiated unit (4.61 x 10^{-4} cm/s). The geometric mean hydraulic conductivity of the overburden aquifer is 8.7 x 10^{-4} cm/s.

Overburden Aquifer Pumping Test: An overburden test well was pumped at a constant discharge of 3.14 GPM for 72 hours, and was followed by a 72-hour monitored recovery period. During the testing periods, groundwater level measurements were obtained from 30 monitoring wells. All drawdown data was corrected for the background decline in water levels during the test. Aquifer test results for the "north-south" array are summarized as follows: the geometric mean overburden hydraulic conductivity was 6.48 x 10^{-3} cm/s; and the range of decline in groundwater levels observed in the "north-south" array wells was approximately 0.75 to 2.0 ft.

Aquifer test results for the "east-west" array are summarized as follows: the geometric mean of the hydraulic conductivity was 6.48 x 10^{-3} cm/s; and the range in decline in groundwater levels observed in the "east-west" array wells was approximately 0.5 to 2.0 ft.

The pumping test data were also compared to the results of the Stepan Company overburden aquifer pumping test. The Stepan Company test reported a transmissivity (hydraulic conductivity) value of 32 ft^2/day (1.4 x 10^{-3} cm/s).

A comparison of the aquifer test hydraulic conductivity values to the average FMSS slug test value of 8.7 x 10^{-4}cm/s shows that the aquifer test data are an order of magnitude higher. This discrepancy is attributed in part to the large number of overburden monitoring wells that are installed in low permeability clay, silt, and till deposits. It is also noted that most of the overburden monitoring wells do not fully penetrate the aquifer and may not be installed into the more permeable sand substratum (stratified drift).

Overburden Seepage Velocity: A range of overburden seepage groundwater velocities are calculated based on average gradient, range of the average slug test and aquifer test hydraulic conductivity, and total aquifer porosity. The applied hydraulic gradient is 0.0085 ft/ft and total porosity value of 0.20 for overburden on the MISS. The applied slug test and aquifer test mean hydraulic conductivities are 8.7 x 10^{-4} cm/s and 6.0 x 10^{-3} cm/s, respectively. The calculated groundwater seepage velocities range from 0.11 ft/day to 0.72 ft/day.

Vertical Groundwater Flow: A number of cluster locations show consistent vertical gradients between overburden and bedrock over time. Net downward groundwater gradients were measured on the MISS at cluster wells MISS 01, MISS 02, MISS 03, MISS 04, MISS 07, B38W19, B38W25, MW-20, MW-25, and PW-1S/BRPZ-9. Net upward gradients are measured in Rochelle Park at well clusters B38W14, B38W15, MW-4, and MW-5. A net upward gradient was also noted in Lodi well clusters MW-15, MW-16, MW-17, and MW-18.

Groundwater elevation data was also evaluated in shallow and deep bedrock monitoring well clusters. All clusters except PT-1DA/PT-1DB show weak and/or inconsistent vertical gradients. The Stepan Company well cluster PT-1DA/1DB has a consistent downward vertical gradient.

Groundwater Surface Water Interaction

The interaction between groundwater and surface water are discussed below.

Westerly Brook: The upstream portion of Westerly Brook is conveyed by culvert pipe under the MISS and 96 Park Way, Rochelle Park and opens to a channel at St. Ann Place in Rochelle Park. The video survey found that both the north-south and east-west sections of the Westerly Brook culvert leak heavily at open and cracked joints. Invert elevations for the Westerly Brook culvert pipe show that the culvert pipe is partially below the seasonal low groundwater table, and in some locations was installed on the top of bedrock. These data suggest that groundwater from the MISS is infiltrating into Westerly Brook through open joints in the culvert pipe.

Lodi Brook: Lodi Brook originates on the 149-151 Maywood Avenue property, and flows approximately 1,400 ft as an open channel through the 149-151 Maywood Avenue property to New Jersey State Route 17. At New Jersey State Route 17, Lodi Brook is principally routed into a culvert pipe and flows south to the Saddle River.

Lodi Brook is a continuously-fed or perennial stream, with an estimated base flow of 0.06 cubic meters per second (m^3/s) (2 cubic feet per second [cfs]) (DOE, 1992). Lodi Brook originates in the low marshy areas on 149-151 Maywood Avenue, and is probably fed by shallow groundwater at the two headwater tributaries; however, the main channel does not appear to be a major groundwater discharge point. Lodi Brook also receives intermittent stormwater runoff from local residential and commercial areas (via storm drains) during wet weather. Seasonal groundwater and surface water interaction is expected during prolonged dry and wet periods.

The GWRI indicates that the base flow rate estimates were based on the *Remedial Investigation Report for the Maywood Site* (DOE, 1992). The DOE report indicates that there is no available stream gauge flow data for Lodi and Westerly Brooks, and that flow rates were “visually” estimated to provide “order of magnitude” estimates.

1.2.5 Nature and Extent of Contamination

Groundwater, surface water, and sediment analytical data from the GWRI are summarized in the following sections.

1.2.5.1 Groundwater

In Sections 4.1 to 4.6 of the GWRI, groundwater data were compared to the lower of the Federal/State Maximum Contaminant Levels (MCLs) or the New Jersey Groundwater Quality Criteria (NJGWQC). Groundwater Quality Standards (GWQS), as outlined in New Jersey Administrative Code (NJAC) 7:9-6, January 7, 1993 and recodified with amendments, November 7, 2005 (Chapter 7:9c, Groundwater Quality Standards), describe the New Jersey Groundwater Classifications. Groundwater within the FMSS is classified as Class II groundwater.

Class II groundwater has a designated use of potable groundwater with conventional water supply treatment, either at their current water quality (Class II-A) or subsequent to enhancement or restoration of regional water quality, so that the water will be of potable quality with conventional water supply treatment (Class II-B). Both existing and potential potable water uses are included in the designated use.

Class II-A groundwater consists of all groundwater of the State, except for groundwater designated in Classes I, II-B, or III. The primary designated use for Class II-A groundwater is potable water and conversion (through conventional water supply treatment, mixing, or other similar technique) to potable water. Class II-A secondary designated use includes agricultural water and industrial water. NJDEP GWQS for Class II-A water was presented in the GWRI.

As part of the GWRI, a well search centered on the MISS indicated the presence of more than 450 wells in a half-mile radius. Of the more than 450 wells identified, ten were listed as domestic use. Of the ten domestic wells, seven did not have specific addresses. These wells are located side gradient from the MISS (Sections 2.11 and 6.6, Table 2-1, Figure 2-1 and Appendix D of the GWRI present detailed domestic well information). An additional 5-mile radius search centered on the MISS was conducted for water allocation permits, which resulted in the identification of only three water allocation permits within a 1-mile radius. One of these permits is for the Stepan Company's surface water withdrawal from the Saddle River. The other two permits are for industrial wells installed in the deeper bedrock aquifer of the Passaic Formation and are located in the opposite direction of groundwater flow at the MISS.

USACE, in implementing Land Use Controls (LUCs), including an aquifer Classification Exception Area (CEA) (pages 4-4, 4-8, and 4-12), would work with State and local governments, and affected property owners to develop and implement appropriate measures intended to restrict the use of groundwater in the area until the COCs no longer exceed cleanup levels. Further investigations would be conducted in the CEA to locate wells to determine specific addresses and to determine the status of any potential groundwater receptors.

A well located at Malt Products Corporation in Maywood was incorrectly identified in the RI as a potential receptor for the MISS. This well is approximately one half mile southeast of the MISS. A groundwater divide lies between the well and the MISS. The direction of groundwater flow from the MISS is to the west and SW which is in the opposite direction to the location of the Malt Products Corporation well. The Malt Products Corporation well is not a potential receptor.

Phase I Radiological Results

Groundwater samples obtained from Geoprobe® (overburden) samples were analyzed for Ra-226, Ra-228, Th-228, Th-230, Th-232, U-234, U-235 and U-238. Radium, thorium, and uranium isotopes were detected in unfiltered groundwater samples collected from Geoprobe® borings located throughout the FMSS.

- Forty-two (42) of 88 Geoprobe® samples contained total radium at a concentration exceeding the Federal/State MCL of 5 pCi/L (picocurie per liter).

- Fifteen (15) of 88 Geoprobe® samples contained total uranium exceeding the proposed Federal/ State MCL of 30 micrograms per liter (µg/L).
- Total thorium results were evaluated in relationship to the Federal/State MCL of 15 pCi/L for gross alpha, since there is no individual or total thorium MCL. Fifteen (15) of 88 Geoprobe® samples had total thorium concentrations greater than 15 pCi/L.

Groundwater samples collected from monitoring wells detected a total of three radiological exceedances. The groundwater sample collected from monitoring well B38W18D had total radium exceedances, and two uranium exceedances were present in samples collected from wells B38W12A and MISS-5A. Thorium concentrations detected in the monitoring well samples did not exceed the Federal/State gross alpha MCL of 15 pCi/L (used for comparison since there is no individual or total thorium MCL).

Phase I Non-Radiological Results

Non-radiological parameters included VOCs, metals, and FMSS-related Rare Earth Elements (REEs) - cerium, dysprosium, lanthanum, neodymium, and yttrium. These REEs are components of monazite sand and remain in the sands after thorium extraction. In addition, the MCW performed some processing of monazite to extract specific REEs such as cerium and lanthanum. (Pages 1-6 through 1-7 of the GWRI describe REEs in more detail).

- Elevated levels of PCE (exceeding NJGWQC of 1 µg/L) were detected in 7 of 29 Geoprobe® groundwater samples. The source of PCE contamination at these sample locations does not originate on the MISS.
- Elevated levels of benzene (exceeding NJGWQC of 1 µg/L) were detected in four groundwater samples collected from Geoprobe® borings advanced on the MISS.
- Arsenic, chromium, and lead were detected at elevated concentrations (exceeding NJGWQC of 8 µg/L [now 3 µg/L], 100 µg/L, and 10 µg/L, respectively) in groundwater samples collected from Geoprobe® borings and overburden and bedrock monitoring wells located throughout the FMSS. However, only those originating on the MISS will be addressed in this GWFS.
- All five REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in groundwater samples collected throughout the FMSS; however, there are no MCLs or NJGWQCs for these REEs. These REEs are components of monazite sand and remain in the sands after thorium extraction. (Pages 1-6 through 1-7 of the GWRI describe REEs in more detail).

Phase II Radiological Results

Radium, thorium, and uranium isotopes were detected in unfiltered and filtered groundwater samples collected from Geoprobe® borings, overburden monitoring wells, and bedrock monitoring wells located throughout the FMSS. Total radium was detected in 139 of 151 groundwater samples with concentrations ranging from 0.12 to 19.4 pCi/L. Six of the samples (02b001 unfiltered, 07a002 unfiltered/filtered, OBMW10, MW-9S, B38W18D) contained total radium at a concentration exceeding the Federal/State MCL of 5 pCi/L. The normalized absolute difference (NAD) analysis for the total radium indicates that 4 of 10 unfiltered/filtered sample pairs show increased total radium concentrations that are not statistically attributable to measurement error. The elevated activity in these four samples may have been caused by the high sediment concentrations in the unfiltered samples.

Total uranium was detected in 133 of 151 groundwater samples with concentrations ranging from 0.01 to 110.2 µg/L. Two of the samples (MISS 5A, well 5) contained total uranium at a concentration exceeding the Federal/State MCL of 30 µg/L. The NAD analysis for the total uranium indicates that one unfiltered/filtered sample pair shows increased total uranium concentrations that are not statistically attributable to measurement error. The elevated activity in this sample may have been caused by the high sediment concentrations in the unfiltered samples.

Phase II total thorium results are discussed in relationship to the Federal/State MCL of 15 pCi/L for gross alpha, since there is no individual or total thorium MCL. Total thorium was detected in 129 of 151 groundwater samples with concentrations ranging from 0.36 to 16.14 pCi/L. One of the samples (B38W18D) contained total thorium at a concentration exceeding the Federal/State MCL of 15 pCi/L for gross alpha. The NAD analysis for total thorium indicates that one unfiltered/filtered sample pair shows increased total thorium concentrations that are not statistically attributable to measurement error. The elevated activity in these samples may have been caused by the high sediment concentrations in the unfiltered samples.

Gross alpha was detected in 76 of 98 overburden and bedrock groundwater samples with concentrations ranging from non-detect to 288.99 pCi/L. Four of the samples (OBMW10, BRPZ-5, BRPZ-2RE, MW-3D) contained gross alpha at a concentration exceeding the Federal/State MCL of 15 pCi/L.

Gross beta was detected in 78 of 99 overburden and bedrock groundwater samples with concentrations ranging from 0.03 to 168.02 pCi/L. Four of the samples (BRPZ-2RE, BRPZ-5, MW-26D, MW-13D) contained gross beta at a concentration exceeding the screening level of 50 pCi/L.

Phase II Non-Radiological Results

Figure 1-6 through **Figure 1-11** present the lithium, benzene, and arsenic concentrations in overburden and shallow bedrock groundwater. These groundwater plume maps depict the most widespread solute plumes in groundwater beneath the FMSS. Non-radiological contamination not originating at the MISS nor associated with specific thorium manufacturing or processing activities at the MCW will not be addressed in this GWFS.

REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in groundwater, surface water, and sediment samples collected throughout the FMSS; however, there are no regulatory standards for these REEs. (Pages 1-6 through 1-7 of the GWRI describe REEs in more detail).

Arsenic, barium, chromium (total), lead, and thallium were detected at concentrations exceeding regulatory levels in groundwater samples collected from overburden and bedrock monitoring wells, while lithium was detected in groundwater from both types of wells at concentrations exceeding the EPA Region 9 Preliminary Remediation Goals (PRGs), a non-promulgated risk-based remedial goal, (**Figures 1-6** and **1-7**). Many of the exceedances were found in wells located in/near Former Retention Pond C on the MISS. Other exceedances were detected in/near Former Retention Pond A, on the NYSW property, on the Stepan Company property, and properties located at 149-151 Maywood Avenue, 96 Park Way, and 99 Essex Street. Twenty (20) of 32 lithium exceedances in bedrock wells were collected from the MISS.

Benzene exceedances were detected in overburden and bedrock wells (**Figures 1-8** and **1-9**). The maximum concentration, 9,500 µg/L, was detected during the Supplemental Investigation in the sample obtained from monitoring well BRPZ-5, located within Former Retention Pond C on the MISS. The plotted benzene plume extends approximately 1,075 ft and is oriented NNE-SSW along the plume axis. Historical data from downgradient and sidegradient plume wells show that the benzene plume was limited in extent and stable due to benzene attenuation in the aquifer (Pages 5-5, 5-10, 5-31, and 5-32 of the GWRI present the historical data findings). A comparison of Phase II (2000-2001) and Supplemental Investigation (2002-2003) benzene data show a substantial decline in 5 of 12 bedrock monitoring wells, and may be attributable to natural attenuation. Other exceedances were detected in overburden monitoring wells at locations on the Stepan Company property and are being addressed in the Stepan RI/FS.

Two small arsenic plumes were plotted in the overburden aquifer, and are probably derived from MISS Former Retention Pond A (on the MISS) and NRC Burial Pit 3 (non-MISS location). The distribution of arsenic in overburden groundwater is shown on **Figure 1-10**. The highest concentrations of arsenic in overburden groundwater were detected on the MISS at well MISS 02A, with lower concentrations detected at adjacent non-MISS monitoring well MW-20S. Arsenic exceedances were also detected at downgradient non-MISS monitoring well MW-3S. Arsenic was not detected in groundwater at an adjacent non-MISS monitoring well (B38W01S) and in soils at an adjacent vicinity property (142 West Central Avenue, Maywood) (USACE, 1999). Arsenic groundwater data presented on **Figure 1-10** shows that MISS Former Retention Pond A is the probable source, and forms a plume that extends to the NW, along the projected direction of groundwater flow.

One arsenic plume was plotted in the bedrock aquifer, and probably originates from Former Retention Pond C (on the MISS) (**Figure 1-11**). Overburden and bedrock lithium plumes have been plotted from Former Retention Pond A and Former Retention Pond C source areas, and with the exception of the Former Retention Pond A overburden lithium plume, extend off site from the MISS.

PCE and trichloroethene (TCE) exceedances were also detected in bedrock wells. The maximum concentrations were detected in samples obtained from monitoring well MW-7D, located on the 141 West Central Avenue, Rochelle Park property. Additional PCE and TCE exceedances were detected in overburden monitoring wells and Geoprobe® samples at locations on the 141 West Central Avenue property and the 96 Park Way property, Rochelle Park. Overburden and bedrock PCE, TCE, and dichloroethene (DCE) plumes are present in Maywood and Rochelle Park, and in the NW portion of the MISS. Other VOCs detected in overburden and/or bedrock wells include 1,2-DCE, 1,1-DCE, toluene, vinyl chloride (VC), and xylenes. The probable source of both the overburden and bedrock plumes is upgradient of the MISS. According to the GWRI, xylenes were attributed to the Stepan Company and are being addressed by the Stepan Company as part of an ongoing remedial action (USACE, 2005b).

1.2.5.2 Surface Water and Sediments

As part of the GWRI, a total of 21 surface water samples were obtained from Westerly Brook, Lodi Brook, Coles Brook, and the Saddle River. Surface water samples were analyzed for Ra-226, Ra-228, isotopic thorium, isotopic uranium, TAL metals, lithium, and REEs.

Surface water results were compared to the more stringent of the New Jersey Surface Water Quality Criteria (SWQC) and the Federal Freshwater Ambient Water Quality Criteria (AWQC). The New Jersey SWQC is human health based; whereas, the AWQC are ecological based standards. There are no surface water radiological criteria; therefore, Federal/State drinking water standards were used for comparison. There are also no lithium or boron Federal/State surface water standards; therefore, results were compared to the calculated risk-based value. There are also no State or Federal regulatory standards for REEs.

Sediment results (GWRI Section 4.8) were compared to the more stringent of the NJDEP Lowest Observed Effects Level (LOEL) or the EPA Recommended Consensus Based TEC for Freshwater Systems (TEC). A large majority of sediment metal exceedances fall within the reported range of average metal concentrations for sediments in seven New Jersey watersheds, and probably represent background metal concentrations.

The NJAC sets forth Surface Water Quality Standards (SWQS) which designate uses, classifications, and water quality criteria. The Saddle River, which is a discharge area for groundwater, is classified as Fresh Water 2 (FW2). “FW2” indicates the general surface water classification applied to those fresh waters not designated as FW1 (exceptional recreational and/or water supply significance, or exceptional fisheries resource) or Pinelands Waters.

Results for the surface water samples are as follows.

Westerly Brook (5 samples)

- Two samples, WB-1 (5.1 pCi/L) and WB-2 (5.58 pCi/L), contained total radium concentrations exceeding the Federal/State MCL of 5 pCi/L. Samples WB-1 and WB-2 are located west of the MISS and Former Remediated Retention Ponds D and E. None of the samples contained total uranium or total thorium at concentrations exceeding their respective Federal/State MCLs.
- Six metals were detected at concentrations exceeding the AWQC or SWQC: aluminum, arsenic, lead, silver, thallium, and zinc. Arsenic, which originates on the MISS, will be addressed in this GWFS. Lead and thallium, which do not contribute to risk due to limited exceedances, are not addressed in the GWFS. The other metals are not MISS-related, and are not addressed in this GWFS.
- Lanthanum was the only REE detected in a surface water sample. This sample was obtained from a location upstream of the MISS, and the result was slightly above the laboratory instrument detection limit.

Lodi Brook (7 samples)

- Three samples, LB-3 (5.48 pCi/L), LB-5 (9.25 pCi/L), and LB-7 (6.07 pCi/L), contained total radium concentrations exceeding the Federal/State MCL of 5 pCi/L. LB-3 was collected from Property No. 6c, 167 New Jersey State Route 17; and LB-7 was collected adjacent to Property No. 2d, 8 Mill Street, Lodi. None of the samples contained total uranium or total thorium at concentrations exceeding their respective Federal/State MCLs.
- Five metals were detected at concentrations exceeding the AWQC or SWQC: aluminum, arsenic, copper, lead, and thallium. The sources of the metals impacting Lodi Brook are not migrating from the MISS or are not MISS-related, and will not be addressed in this GWFS.
- Lanthanum, an REE, was detected in sample LB-3 (38.4 µg/L), which is located north of New Jersey State Route 17 on Property No. 6c, 167 New Jersey State Route 17 North. This concentration is slightly above the instrument detection limit of 33.8 µg/L. There is no NJDEP SWQC or Federal AWQC for lanthanum.

Coles Brook (4 samples)

- None of the samples contained total radium, total uranium, or total thorium at concentrations exceeding their respective Federal/State MCLs.
- There were no exceedances of NJDEP SWQC or Federal Freshwater AWQC Acute/Chronic criteria for the TAL metals, lithium, or boron in the samples collected.
- Dysprosium, an REE, was detected in samples CB-4 (5 µg/L) and CB-5 (4.8 µg/L). These samples were collected downstream (north) of the 111 Essex Street Property, Maywood. Dysprosium concentrations were below the EPA Region 9 tap water PRG. There is no NJDEP SWQC or Federal AWQC for Dysprosium.

Saddle River (5 samples)

- None of the samples contained total radium, total uranium, or total thorium at concentrations exceeding their respective Federal/State MCLs.
- Three metals were present at concentrations exceeding SWQC, including arsenic, copper, and lead.
- REEs were not detected.

Results for the sediment samples are as follows.

Westerly Brook and Drainage Ditch (6 samples)

- None of the samples contained Ra-226 and Th-232 at a concentration exceeding the soil cleanup criteria of 5 picocurie per gram (pCi/g). Uranium-238 results did not exceed the proposed soil cleanup standard of 50 pCi/g.
- Metals exceeding the most stringent of the sediment criteria include: cadmium, chromium, copper, lead, nickel, and zinc.
- All five REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in sediments, but there are no sediment quality criteria. These REEs were detected at comparable concentrations both upstream and downstream of the MISS.

Lodi Brook (6 samples)

- One sample, LB-1 (31.89 pCi/g), contained Ra-226 and Th-232 concentrations exceeding the Federal/State MCL of 5 pCi/g. Sample LB-1 was obtained from the eastern tributary at the headwater of Lodi Brook on the 149-151 Maywood Avenue property, Maywood. Uranium-238 results did not exceed the proposed soil cleanup standard of 50 pCi/g.
- Metals exceeding the most stringent of the sediment criteria include: arsenic, cadmium, chromium, copper, lead, nickel, and zinc.
- All five REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in sediments, but there are no sediment quality criteria. Detected concentrations generally decreased in the downstream direction with yttrium concentrations generally remaining constant.

Coles Brook (5 samples)

- None of the samples contained Ra-226 and Th-232 at a concentration exceeding the soil cleanup criteria of 5 pCi/g. Uranium-238 results did not exceed the proposed soil cleanup standard of 50 pCi/g.
- Metals exceeding the most stringent of the sediment criteria include: arsenic, chromium, copper, lead, nickel, and zinc.
- All five REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in sediments, but there are no sediment quality criteria.

Saddle River (5 samples)

- None of the samples contained Ra-226 and Th-232 at a concentration exceeding the soil cleanup criteria of 5 pCi/g. Uranium-238 results did not exceed the proposed soil cleanup standard of 50 pCi/g.

- Metals exceeding the most stringent of the sediment criteria include: arsenic, copper, lead, and zinc.
- All five REEs (cerium, dysprosium, lanthanum, neodymium, and yttrium) were detected in sediments, but there are no sediment quality criteria.

1.2.6 Final GW Baseline Risk Assessment (BRA) July 2005 Summary

The *Final Groundwater Baseline Risk Assessment (BRA)* for the FMSS was issued in July 2005 (USACE, 2005a). The purpose of the BRA was to present an evaluation of human health and ecological risks associated with radiological and chemical contamination detected in groundwater, surface water, and sediment. The BRA is comprised of a quantitative human health evaluation conducted in conformance with a Pathway Analysis Report, approved by the EPA, Region 2 and a screening-level ecological risk assessment (SLERA), which is based on relevant data from the GWRI conducted for the FMSS.

The objectives of the BRA were to:

- Provide an analysis of potential health risks, currently and in the future, in the absence of any major action to control or mitigate contamination (i.e., baseline risks); and assist in determining the need for and extent of remediation.

The BRA addressed:

- All radiological and chemical constituents detected in groundwater from the GWRI Study Area during Phase II of the GWRI, except for chlorinated solvent constituents from select monitoring wells attributed to a site (Dixo Company) located just north of the GWRI Study Area; and
- All radiological and chemical constituents detected in surface water and sediment from Westerly Brook, Lodi Brook, the Saddle River, and Coles Brook in the vicinity of the GWRI Study Area during Phase II.

However, the focus of this GWFS is the FUSRAP waste as defined in the FFA. This includes:

- All contamination, both radiological and chemical, whether commingled or not, on the MISS;
- All radiological contamination above cleanup levels related to past thorium processing at the MCW site occurring on any Vicinity Properties;
- Any chemical or non-radiological contaminants on Vicinity Properties that would satisfy either of the following requirements:
    1. The chemical or non-radiological contaminants are mixed or commingled with radiological contamination above cleanup levels; or

    2. The chemical or non-radiological contaminants originated in the MISS or were associated with the specific thorium manufacturing or processing activities at the MCW site which resulted in the radiological contamination.

<u>Human Health Evaluation</u>

The human health evaluation followed the typical four step process to assess potential human health risks. The steps were: data evaluation, exposure assessment, toxicity assessment, and risk characterization.

Five categories of human receptors ("potentially exposed populations") were identified and evaluated quantitatively: residents (both adults and children), workers, construction/utility workers, recreationists, and municipal workers. Their potential for exposure was evaluated for a number of current and future use scenarios based on conservative exposure point concentrations developed for the evaluation.

The residential drinking water scenario was used as a reasonably foreseeable use of the contaminated groundwater for purposes of risk assessment and the decisions to be made on remedial actions. However, there is no current human exposure to the groundwater contaminated with FUSRAP waste which is located under the Government-controlled MISS and surrounding commercial properties. Groundwater contaminated with FUSRAP waste is not currently used as drinking water, and a public water supply is available.

The risk characterization indicated the following.

- <u>Current/Future Residents</u>: Evaluation of potential exposure to resident adults assuming potable use of the groundwater resulted in risk estimates that exceed the EPA acceptable cancer risk range and the acceptable level for non-cancer health effects. A total hazard index (HI) of 4E+01 was estimated indicating a potential for adverse, non-cancer health effects; arsenic, benzene, lithium, and 2-chlorotoluene in groundwater are the predominant contributors. A total excess lifetime cancer risk of 6E-03 was estimated; arsenic, benzene, and VC are the predominant contributors to the risk estimates.
- Evaluation of potential exposure to resident children, assuming potable use of the groundwater, resulted in risk estimates that exceed the EPA acceptable cancer risk range and the acceptable level for non-cancer health effects. A total HI of 1E+02 was estimated indicating a potential for adverse, non-cancer health effects; arsenic, benzene, lithium, 2-chlorotoluene, manganese, and xylenes in groundwater are the predominant contributors. A total excess lifetime cancer risk of 2E-03 was estimated; arsenic, benzene, and VC are the predominant contributors to the risk estimates.
- <u>Current/Future Workers</u>: Evaluation of potential exposure to workers assuming potable use of the groundwater resulted in risk estimates that exceed the EPA acceptable cancer risk range and the acceptable level for non-cancer health effects. A total HI of 1E+01 was estimated indicating a potential for adverse, non-cancer health effects; arsenic, benzene, and lithium in groundwater are the predominant contributors. A total excess lifetime cancer risk of 1E-03 was estimated; arsenic and benzene are the predominant contributors to the risk estimates.
- <u>Current/Future Construction/Utility Workers</u>: Evaluation of potential exposure to construction/ utility workers (assuming dermal contact and inhalation of vapors) working in the vicinity of an excavation in which groundwater infiltrates the bottom of the excavation results in risk estimates that exceed the EPA acceptable level for non-cancer health effects. A total HI of 1E+01 was estimated indicating a potential for adverse, non-cancer health effects; benzene and 2-chlorotoluene in groundwater are the predominant contributors. The estimated total excess lifetime cancer risk is within the EPA acceptable risk range.
- <u>Current/Future Recreationists</u>: Evaluation of potential exposure to resident adolescents assuming contact with surface water and sediment while wading and recreating in Westerly Brook, the Saddle River, or Coles Brook did not result in risk estimates in excess of the EPA acceptable cancer risk range or acceptable level for non-carcinogenic health effects. Occasional consumption of sport fish caught in the Saddle River in the study area should not pose health risks to recreationists.
- <u>Current/Future Municipal Workers</u>: Evaluation of potential exposure to municipal workers assuming contact with surface water and sediment while conducting manhole inspection or clean-outs in the culverted sections of Westerly Brook or Lodi Brook did not result in risk

estimates in excess of the EPA acceptable cancer risk range or the acceptable level for non-cancer health effects.

In summary, the human health evaluation indicated a potential for health risks to residents (adults and children) and workers from exposure to groundwater, should groundwater be used for potable purposes, and to construction/utility workers from exposure to groundwater, should shallow groundwater be contacted during activities involving excavation. The non-cancer hazards indices and excess lifetime cancer risks greater than the EPA acceptable levels are predominantly due to arsenic and benzene. VC is also a predominant contributor to the excess lifetime cancer risks greater than the EPA acceptable level. In addition, lithium, manganese, and 2-chlorotoluene are predominant contributors to the non-cancer hazard indices greater than the EPA acceptable level.

The BRA further concluded that the radionuclides contribute relatively little to the total excess lifetime cancer risks. In addition, most of the radiological risks may be due to background levels of the radionuclides.

The BRA was conducted for the FMSS groundwater, thus the risks from MISS groundwater may not be the same as those indicated above.

According to the GWRI, xylenes were detected in four wells only, on or near the Stepan Company property. The xylenes were attributed to the Stepan Company; are being addressed by the Stepan Company as part of an ongoing remedial action; and will not be included as a COC in this GWFS.

According to the groundwater BRA, the elevated manganese concentrations are attributed to the ongoing degradation of organic constituents (benzene, chlorotoluene, and chlorinated solvents) in groundwater, and utilization (reduction) of these metals as alternate electron acceptors. The highest total iron (Fe) and manganese (Mn) concentrations are detected in monitoring wells impacted with organic constituents and are attributed to the reduction/dissolution of the metals (Fe+2 and Mn+2) for the aquifer matrix. Once the organic constituents are remediated/degraded, manganese (as Fe+3 and Mn+4) would oxidize/precipitate in the aquifer and return to background groundwater concentrations. As a result of this degradation process, manganese will not be included as COCs in this GWFS.

The chemical constituent 2-chlorotoluene was detected in groundwater collected from a limited number of monitoring wells installed on and off the MISS. The groundwater BRA evaluation of 2-chlorotoluene showed a non-cancer contribution to the HI. It was not included as a constituent of potential concern (COPC) in the GWRI, since it is from an upgradient/non-MISS source.

Lithium was widely observed in groundwater at the MISS. Since the groundwater BRA evaluation of lithium indicated a significant non-cancer contribution to the total HI, and the GWRI reported that the COPC lithium exceeded the EPA Region 9 tap water PRG, a non-promulgated risk-based remedial goal, USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk. This effort will be confirmed in the Maywood GW ROD. Since ARARs are not available for lithium in groundwater, a risk-based action level was derived for lithium, based upon ingestion of groundwater. Based on agreements between the EPA Region 2 and USACE, a risk-based action level of 730 μg/L was derived using the exposure parameters and the toxicity values used in the baseline risk assessment (provisional oral reference dose 2E-02 mg/k-d, based upon Schou and Vestergaard, 1988, with two uncertainty factors applied to account for sensitive subpopulations and use of the lowest observed adverse effect level

(LOAEL)). The basis for the action level is a hazard quotient of 1. In order to achieve this groundwater goal, a soil cleanup number for lithium has been established at 194 milligrams per kilogram (mg/kg).

A risk assessment was not performed on upgradient groundwater for arsenic. Available information indicates that upgradient groundwater concentrations are below the NJGWQC practical quantitation limit (PQL) of 3μg/L. Background concentrations are discussed in the July 2005 Final GWRI, Volume 1, Section 3.6.2 FMSS Background Groundwater Quality, pages 3-19 and 3-20. The statement in the introductory paragraph states "There are no metals, radionuclides or VOC exceedances in the corresponding upgradient vicinity property overburden and bedrock wells…" At the time of the GWRI the exceedance value for arsenic used in the data screening was 8 μg/L. GWRI measured background (upgradient) arsenic concentrations in groundwater for bedrock were reported to range from 2.3 to 3.2 μg/L and in the overburden from 3.2U (non-detect) to 3.8 μg/L. As presented in Table 3-11 of the GWRI, background concentrations of arsenic in bedrock wells in Bergen County, New Jersey were reported by USGS to average 2.64 μg/L (based on 28 samples with a range of 1 to 10 μg/L) and in Stratified Drift Deposits (overburden) 1.00 μg/L (based on 2 samples).

Non-FUSRAP chemical constituents in groundwater whose impact on the remedial alternatives will be evaluated during the GWFS include: lithium, PCE, TCE, VC, 2-chlorotoluene, iron, manganese, and xylenes.

Screening-Level Ecological Risk Assessment

The SLERA comprised the following.

- Screening-level problem formulation, which included a description of the environmental setting, preliminary COPCs, constituent fate and transport information, a discussion of ecotoxicity and potential receptors and exposure pathways, and a presentation of assessment and measurement endpoints.
- Screening-level ecological effects evaluation.
- Risk calculations (in the form of Hazard Quotients [HQ] and total HIs), using appropriate surface water and sediment screening values for aquatic biota.
- Uncertainty assessment.

The SLERA focused on aquatic biota and did not evaluate the potential risk to higher-level organisms, such as semi-aquatic birds (waterfowl) and mammals, since they have more potential for exposure from surface water and sediments. Fish were considered to be the potential receptors of concern for radiological constituents, since they are more sensitive to radiological exposure than benthic invertebrates. For chemical constituents, fish and benthic invertebrates were the receptors of potential concern, since these organisms have the greatest potential for exposure of the aquatic and semi-aquatic organisms that may utilize the water bodies.

None of the radiological constituents detected in surface water or sediment in any of the water bodies had HQs greater than one. Total hazard indices for radiological constituents in surface water and sediment were less than one for each water body. This indicates that there would be no potential for adverse ecological health effects from the presence of radionuclides in surface water and sediment in water bodies in the vicinity of the FMSS.

A number of chemical constituents detected in surface water and/or sediment in each of the water bodies had HQs greater than one, and therefore, would be chemical constituents of potential concern. In surface water and sediment, these constituents include copper, lead, manganese, silver, and zinc. In surface water, these constituents included aluminum, barium, boron, lanthanum, lithium, and uranium. In sediment, these constituents included antimony, arsenic, cadmium, chromium, and nickel.

However, the potential for adverse ecological health effects may be overstated due to the lack of upstream surface water and sediment samples from the evaluated water bodies. Most of the chemical constituents of potential concern have not been associated with the site and their concentrations in surface water/sediment may be the result of off-site, non-FUSRAP sources and upstream surface water/sediment quality.

There were no apparent differences in the general appearance and ecological health of the upstream and downstream locations based on casual observations made during the visits to the surface water bodies.

There was adequate information to conclude that site-related ecological risks would be negligible with respect to the radiological constituents, and therefore, there would be no need for remediation on the basis of ecological risk.

Some of these constituents may be derived from off-site, non-FUSRAP sources and may reflect upstream surface water/sediment quality. Currently, Lodi Brook and Westerly Brook are predominantly culverted and offer little natural habitat. Coles Brook does not appear to have been impacted by the site.

1.2.7 Summary of Media Identified for Evaluation in the Groundwater FS

GWRI-identified impacted media on the FMSS includes the overburden and shallow bedrock groundwater aquifers, surface water, and sediments. The FUSRAP groundwater COPCs identified in the GWRI included total radium, total uranium, gross alpha, gross beta, arsenic, barium, beryllium, lead, lithium, thallium, benzene, methylene chloride, PCE, toluene, TCE, and VC (GWRI 2000-2002 data [**Table 1-1**]). However, PCE, TCE, and VC were determined to be from a non-MISS source. These COPCs were detected in both the overburden and shallow bedrock aquifers. Historical and GWRI FMSS groundwater data trends were evaluated for these chemical constituents. The results of these evaluations are presented in **Appendix A**.

The FUSRAP surface water COPCs identified in the GWRI included total radium, arsenic, lead, and thallium. The FUSRAP sediment COPCs identified in the GWRI were Ra-226 and Th-232 (**Table 1-2**).

Probable FUSRAP Areas of Concern (AOCs) were identified in the GWRI for each of the groundwater, sediment, and surface water media (**Figure 1-12**). Groundwater AOCs were defined by the presence of: (1) potential FUSRAP waste(s) in groundwater, and (2) a probable active (ongoing) groundwater contamination source. A total of seven groundwater AOCs were identified in the GWRI for the FMSS study area, as follows:

- <u>AOC 1 – Former Retention Pond A</u>, located within the MISS, was identified as a potential groundwater source area based on arsenic, lithium, lead, and thallium.
- <u>AOC 2 – Former Retention Pond C</u>, located within the MISS, was identified as a potential groundwater source area based on total uranium, arsenic, lithium, barium, beryllium, and benzene. PCE, TCE, and VC were also detected at low concentrations, but were determined to be from non-MISS sources.
- <u>AOC 3 – NRC Burial Pit 1</u> was identified as a potential groundwater source area based on total uranium.
- <u>AOC 4 – NRC Burial Pit 3</u> was identified as a potential groundwater source area based on total radium.

TABLE 1-1
GWRI CHEMICAL AND RADIOLOGICAL COPCs(1&2)

Groundwater Constituents Exceeding Criteria (# of Exceedances)											
Total Radium (3) Criteria 5 pCi/L			**Total Uranium (2) Criteria 30 µg/L**			**Adjusted Gross Alpha (4) Criteria pCi/L**			**Adjusted Gross Beta (4) Criteria pCi/L**		
Well	**Value (pCi/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (pCi/L)**	**Source**	**Well**	**Value (pCi/L)**	**Source**
OBMW10	17.50	ASSOC	WELL 5	41.46	ASSOC	MW-3D	18.42	MIG	MW-13D	68.98	ASSOC
MW-9S	6.58	ASSOC	MISS05A	110.20	MISS	BRPZ-2RE	27.00	MISS	BRPZ-2RE	168.02	MISS
B38W18D	19.40	MISS				BRPZ-5	57.47	MISS	BRPZ-5 (45-55’)	53.41	MISS
						OBMW10	288.99	ASSOC	MW-26D	117.51	MISS

Arsenic (10) Criteria 3 µg/L			Barium (1) Criteria 2,000 µg/L			Beryllium (1) Criteria 4 µg/L			Lead (2) Criteria 10 µg/L		
Well	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**
MISS01AA	3.6	MISS	MISS05B	9,750	MISS	BRPZ-5	5.3	MISS	MW-20S	27.7	MIG
MISS02A	2,600	MISS							MW-3D	33.9	MIG
MISS05B	5.9	MISS									
BRPZ-5	3.6	MISS									
MW-3S	831	MIG									
MW-20S	465	MIG									
B38W19S	31.8	MISS									
MISS07B	72.4	MISS									
B38W19D	89.1	MISS									
B38W18D	12.5	MISS									

(1) Federal MCL (40 CFR 141) or NJGWQC (NJAC7:9C)
(2) Lithium value is USEPA Region 9 PRG

MISS	Well located on MISS
MIG	Radiological/Chemical constituent migrated from MISS
ASSOC	Associated with Thorium Processing
NON	Derived from non-MISS source

TABLE 1-1 (Continued)
GWRI CHEMICAL AND RADIOLOGICAL COPCs(1&2)

Groundwater Constituents Exceeding Criteria (# of Exceedances)								
Lithium (32) Criteria 730 µg/L			**Lithium (32) (Continued) Criteria 730 µg/L**			**Benzene (15) Criteria 1 µg/L**		
Well	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**
MISS02A	10,100	MISS	BRPW-1DRE	4,150	MISS	MW-3D	5	MIG
MW-20S	6,560	MIG	BRPW-1D	3,630	MISS	MISS05B	3,500	MISS
OVPW-1S	1,970	MISS	BRPZ-9	4,130	MISS	B38W19D	1	MISS
OVPW-1S	1,740	MISS	BRPZ-7	6,100	MISS	BRPZ-7	210	MISS
B38W19S	1,730	MISS	B38W19D	6,920	MISS	BRPZ-5 (102'-112')	480	MISS
MW-3S	1,650	MIG	MW-23D	2,340	MISS	BRPZ-5 (69'-79')	290	MISS
B38W01S	1,510	MIG	BRPZ-4	2,160	MISS	BRPZ-5 (45'-55')	5,000	MISS
MISS05A	1,130	MISS	BRPZ-3RE	883	MISS	BRPZ-4	890	MISS
MW-3D	5,060	MIG	BRPZ-2RE	1,150	MISS	BRPZ-9	1,500	MISS
MW-20D	13,700	MIG	MW-24DD	5,310	MISS	BRPZ-2RE	850	MISS
MW-23DD	12,800	MISS	MW-24D	3,520	MISS	BRPZ-3RE	200	MISS
MISS05B	7,400	MISS	BRPZ-5 (102'-112')	5,000	MISS	BRPW-1DRE	8	MISS
MISS07B	7,740	MISS	BRPZ-5 (69'-79')	4,770	MISS	MW-24D	78	MISS
B38W18D	2,990	MISS	BRPZ-5 (45'-55')	5,260	MISS	MW-24DD	33	MISS
MISS02B	16,100	MISS	MW-25D	1,310	MISS	MW-26D	520	MISS
B38W25D	1,100	MISS	MW-26D	1,230	MISS			

(1) Federal MCL (40 CFR 141) or NJGWQC (NJAC7:9C)
(2) Lithium value is USEPA Region 9 PRG

MISS	Well located on MISS
MIG	Radiological/Chemical constituent migrated from MISS
ASSOC	Associated with Thorium Processing
NON	Derived from non-MISS source

TABLE 1-1 (Continued)
GWRI CHEMICAL AND RADIOLOGICAL COPCs(1&2)

Thallium (2) Criteria 2 µg/L			**Methylene Chloride (4) Criteria 2 µg/L**			**Tetrachloroethene (5) Criteria 1 µg/L**		
Well	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**
MW-3S	3.9	MIG	BRPZ-7	8	MISS	MISS07B	9	NON
BRPZ-5	4.8	MISS	BRPZ-4	7	MISS	MISS01B	12	NON
			BRPZ-9	340	MISS	BRPZ-5 (102'-112')	1	NON
			BRPZ-3R	360	MISS	BRPZ-4	3	NON
						BRPW-1DRE	4	NON

Toluene (1) Criteria 1,000 µg/L			**Trichloroethene (7) Criteria 1 µg/L**			**Vinyl Chloride (1) Criteria 2 µg/L**		
Well	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**	**Well**	**Value (µg/L)**	**Source**
BRPZ-5 (45'-55')	1,400	MISS	MW-3D	1	NON	BRPZ-2RE	2	NON
			MISS07B	2	NON			
			MISS01B	1	NON			
			BRPZ-4	8	NON			
			BRPZ-2RE	6	NON			
			MW-24D	8	NON			
			MW-24DD	2	NON			

(1) Federal MCL (40 CFR 141) or NJGWQC (NJAC7:9C)
(2) Lithium value is USEPA Region 9 PRG

MISS	Well located on MISS
MIG	Radiological/Chemical constituent migrated from MISS
ASSOC	Associated with Thorium Processing
NON	Derived from non-MISS source

TABLE 1-2
GWRI SURFACE WATER AND SEDIMENT CHEMICAL AND RADIOLOGICAL EXCEEDANCES (1)

Surface Water								
Total Radium (5) Criteria 5 pCi/L			**Arsenic (11) Criteria 0.017 µg/L**			**Lead (3) Criteria 5 µg/L**		
Sample Location	**Value (pCi/L)**	**Source**	**Sample Location**	**Value (µg/L)**	**Source**	**Sample Location**	**Value (µg/L)**	**Source**
LB-3	5.48	ASSOC	LB-2	9.7	NON	LB-2	7.7	NON
LB-5	9.25	ASSOC	LB-4	3.6	NON	SR-2	10.8	NON
LB-7	6.07	ASSOC	LB-5	4	NON	WB-3	5.4	NON
WB-1	5.10	ASSOC	LB-6	3.9	NON			
WB-2	5.58	ASSOC	LB-7	4	NON			
			LB-8	4.6	NON			
			SR-3	8.8	NON			
			WB-1	12	MIG			
			WB-2	18.5	MIG			
			WB-3	48.7	MIG			
			WB-4	3.8	MIG			

Surface Water (Continued)		
Thallium (2) Criteria 1.7 µg/L		
Sample Location	**Value (µg/L)**	**Source**
LB-5	4.3	NON
WB-1	6.1	MIG

Sediment		
Ra-226 + Th-232 (1) Criteria 5 pCi/g		
Sample Location	**Value (pCi/g)**	**Source**
LB-1	31.89	ASSOC

[1] NJSWQC [NJAC7:9B-1.14(c)]

MISS	Well located on MISS
MIG	Radiological/Chemical constituent migrated from MISS
ASSOC	Associated with Thorium Processing
NON	Derived from non-MISS source

- AOC 5 – Well B38W18D (Former Thorium Manufacturing Area), located on the MISS, was identified as a potential groundwater source area, based on total radium, lithium, and arsenic.
- AOC 6 – Probable Benzene (Shallow Bedrock) Source Area, located on the MISS, was identified as a potential groundwater source area based on benzene. Former MCW Building 62, which contained two 20,000-gallon benzene tanks, was located in this area.
- AOC 7 – Probable Overburden Benzene Source Area (Former MCW Chemical Building), located on the MISS, was identified as a potential groundwater source area based on benzene in overburden groundwater.

The GWRI determined MISS soils to contain metals COPCs above the site-specific Soil Screening Levels (SSLs), as summarized in the Soil Screening Level Technical Memorandum (USACE, 2004b). These soils were determined to be a potential groundwater metals source.

One sediment/surface water AOC and one surface water AOC were identified based upon sediment and surface water sampling results. Surface water and sediment AOCs were determined to be limited to the stream segment adjacent to an impacted sample and did not include the entire downgradient drainage. The sediment and surface water AOCs were identified as the following:

- AOC 8 – Lodi Brook (sediment and surface water) was identified as a potential source of surface water and sediment contamination to downstream water bodies for total radium and Ra-226 in surface water, and Th-232 in sediment.
- AOC 9 – Westerly Brook (surface water) was identified as a potential source of down-stream contamination of surface water bodies based on total radium, arsenic, lead, and thallium.

1.2.8 Identification of FUSRAP Waste

The following COCs were identified for evaluation in the GWFS due to elevated concentrations of COPCs in groundwater migrating from COPC sources located on the MISS:

- Arsenic
- Benzene
- Lithium

The *Feasibility Study for Soils and Buildings at the FUSRAP Maywood Superfund Site* (August 2002a) and the *Record of Decision for Soils and Buildings at the FUSRAP Maywood Superfund Site* (August 2003) did not identify arsenic and benzene as FUSRAP wastes. Groundwater was not directly addressed in the soils FS due to ongoing groundwater investigations. The data obtained from the ongoing investigations was evaluated during the development of the BRA and GWFS, which subsequently identified likely MISS source areas for arsenic and benzene in groundwater (see previous AOC description). Therefore, arsenic and benzene are considered FUSRAP wastes for the purposes of this GWFS.

Other chemical constituents present in groundwater were not determined to be COCs since they are not FUSRAP wastes. These chemical constituents are from non-MISS related activities, upgradient sources, did not contribute to risk at FMSS due to limited exceedances, or are the result of biodegradation of the organic constituents in groundwater. They were evaluated in the GWFS for completeness and potential effects on the remedial scenarios. These chemical constituents are:

- PCE
- TCE
- VC
- Xylenes (total)
- Arsenic (non-MISS sources)
- Barium

- 2-Chlorotoluene
- Beryllium
- Thallium
- Lithium (non-MISS sources)
- Toluene
- Lead
- Methylene chloride
- Iron
- Manganese

Isolated occurrences of barium, beryllium, lead, thallium, methylene chloride, and toluene were observed in MISS groundwater, but none of these chemicals were widely distributed in the groundwater (typically detected in five or less wells) with no evidence of a plume. TCE, PCE, VC, xylenes, and 2-chlorotoluene were detected in the groundwater at the MISS. These chemicals were determined to be from an upgradient source. Arsenic was also detected in off-site monitoring wells which are not related to the MISS. Even though these chemicals do not originate on the MISS, they were evaluated during the GWFS in order to determine their effect on the various remedial alternatives.

Elevated iron and manganese concentrations are attributed to the ongoing degradation of organic constituents (benzene, chlorotoluene, and chlorinated solvents) in groundwater, and utilization (reduction) of these metals as alternate electron acceptors. The highest total iron (Fe) and manganese (Mn) concentrations are detected in monitoring wells impacted with organic constituents and are attributed to the reduction/dissolution of the metals (Fe+2 and Mn+2) for the aquifer matrix. Once the organic constituents are remediated/degraded, iron and manganese (as Fe+3 and Mn+4) would oxidize, become less soluble, and precipitate out of groundwater, returning dissolved phase concentrations to background levels since the natural groundwater condition is oxidizing.

Total uranium, total radium, gross alpha, and gross beta are not included as COCs in this GWFS due to the results of the BRA, which concluded that radionuclides contribute relatively little to the total excess lifetime cancer risks. Furthermore, most of the radiological risks may be due to background levels of the radionuclides. The total radium and total uranium exceedances are localized and isolated to three wells and two wells, respectively. Additionally, the Soils and Buildings OU remediation would remove potential source areas, and the collection and treatment of excavation waters, including groundwater, during this effort would remove water potentially contaminated with radionuclides. As part of the long-term monitoring program designed for this GWFS, radiological constituents would also be monitored in order to ensure protectiveness of the Soils and Buildings OU remediation.

2.0 IDENTIFICATION AND SCREENING OF REMEDIAL ACTION TECHNOLOGIES

2.1 INTRODUCTION

Remedial action technologies were identified and screened for possible use at the MISS by following the general approach provided in *Guidance for Conducting Remedial Investigation and Feasibility Studies Under CERCLA* (EPA 1988a). The specific steps were as follows.

- Identification of ARARs considered in the development of RAOs and in the evaluation of remedial alternatives (**Section 2.2**).
- Development of RAOs (**Section 2.3**) for the media, and COCs based on ARARs and policy considerations.
- Identification of general response actions (**Section 2.4**) for the media of concern. These general response actions consist of general classes of remedial activities (e.g., containment and treatment) that can be undertaken to satisfy the RAO for the contaminated areas/medium under consideration. General response actions considered are those that may attain or exceed applicable RAOs by addressing MISS problems, and controlling contaminant releases to the environment or pathways of exposure.
- Identification of MISS-specific remedial technologies and process options (the term "process option" refers to specific processes within each technology type) that are potentially applicable to each general response action, followed by screening based on technical feasibility (**Section 2.5**). The objective of the screening process is to identify those technologies and process options best suited for further consideration in developing remedial alternatives for the MISS. Technologies/process options found to be inapplicable on the basis of waste characteristics and site conditions, or incapable of meeting RAOs, are eliminated from further consideration. **Section 3.0** evaluates the process options that pass this screening process.

The focus of the GWFS is the FUSRAP waste in groundwater, its transport to surface water, and source materials in MISS soils that impact groundwater. FUSRAP wastes have been identified in groundwater based upon the definition provided in the FFA (Section 1.2.8). Under the terms of the FFA, FUSRAP waste is defined as:

- All contamination, both radiological and chemical, whether commingled or not, on the MISS;
- All radiological contamination above cleanup levels related to past thorium processing at the MCW site occurring on any Vicinity Properties;
- Any chemical or non-radiological contamination on Vicinity Properties that would satisfy either of the following requirements:
    (1) The chemical or non-radiological contaminants are mixed or commingled with radiological contamination above cleanup levels; or

    (2) The chemical or non-radiological contaminants originated in the MISS or were associated with the specific thorium manufacturing or processing activities at the MCW site which resulted in the radiological contamination.

The radiological or chemical contaminants are subject to the lowest of the Federal or State drinking water standards, or promulgated groundwater quality criteria when assessing the extent of contamination and determining COCs for the GWFS.

2.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARS)

ARARs that address COCs in the FUSRAP GW OU are identified in this section. ARAR identification is an integral part of the remediation process mandated under Section 121 (d) of CERCLA, as amended by Superfund Amendments and Reauthorization Act (SARA). ARARs are used to develop remedial action cleanup levels used to determine the appropriate extent of site cleanup. In accordance with the NCP and the FFA, the USACE and EPA recognize that ARAR identification is necessarily an iterative process and that ARARs must be re-examined throughout the FS process until a Record of Decision (ROD) is issued.

Remedial actions that “clean up” hazardous substances at CERLCA sites must comply with promulgated Federal environmental, State environmental, and facility siting laws with standards and criteria that are legally applicable to the substance, pollutant, or contaminant, or that are relevant and appropriate under the circumstances of the release [42 U.S.C. 9621(d)(2)(A)]. Furthermore, the more stringent ARAR identified must be complied with (40 C.F.R. 300.5). State requirements, however, must be adopted by formal means (i.e., promulgated) and applied universally throughout the State (i.e., not just to Superfund sites, but to all sites subject to the requirement) [42 U.S.C. 9621(d)(2)(C)(iii)(I)].

In order to be classified as an ARAR, CERCLA provides that a Federal environmental law or regulation or State environmental or facility siting law or regulation must meet one of the following two requirements: (1) applicability or (2) relevance and appropriateness. “Applicable” requirements are “those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental, State environmental, or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site” (40 C.F.R. 300.5). “Relevant and appropriate” requirements are “those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under Federal environmental, State environmental, or facility siting laws that, while not ‘applicable’ to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site” (40 C.F.R. 300.5).

In some instances, promulgated standards or requirements do not exist for a specific situation. In those cases, to-be-considered (TBC) information may be used to help choose response actions. TBCs are non-promulgated advisories or guidance issued by Federal or State governments that are not legally binding and do not have the status of ARARs, but that may assist the lead agency in attaining a desired remedial outcome.

Groundwater ARARs

ARARs for groundwater are highly dependent upon the use, or potential use, of the groundwater as a resource. Specifically, the EPA goal at NPL sites is to return groundwater to its beneficial use within a reasonable period of time. Both the State and Federal Governments recognize the off-site and on-site MISS groundwater as being Class IIA groundwater. The primary designated NJDEP use of Class IIA groundwater is potable water and/or conversion of this groundwater through conventional water supply treatment, mixing, or other similar techniques to potable water to the extent these uses are viable [NJAC 7:9C-1.5(e)]. Class IIA secondary uses include agricultural and industrial water.

Federal drinking water standards have been promulgated in the Safe Drinking Water Act (SDWA), while the State drinking water standards have been promulgated in the New Jersey SDWA. New Jersey has incorporated by reference the Federal MCLs (N.J.A.C. 7:10-5.1). The New Jersey MCLs are identical to the SDWA MCLs, except for the fact that New Jersey has promulgated more stringent MCLs for some VOCs

[N.J.A.C. 7:10-5.2(a)(4)]. Although the MCLs are not applicable to the groundwater at FMSS, they are considered to be relevant and appropriate under the circumstances because the groundwater in the GW OU is a potential drinking water source at some time in the future.

New Jersey also has promulgated ground water quality standards or criteria to aid in the restoration or enhancement of groundwater quality in the State. N.J.A.C. 7:9C-2(c). GWQC for Class IIA groundwater have been established pursuant to N.J.A.C. 7:9C-1.7(c). NJDEP developed the New Jersey groundwater quality criteria based upon the weight of evidence available regarding a constituent's carcinogenicity, toxicity, or organoleptic effects, as appropriate for the protection of potable water for public consumption. These criteria are compared to each individual contaminant's PQL, the lowest level that can be reliably measured within specified limits of precision and accuracy during routine laboratory operations. The overall standard for any contaminant is the higher of that contaminant's quality criterion or the PQL. The NJGWQC are not legally applicable to the groundwater at this Federally-owned site, but are considered to be relevant and appropriate under the circumstances because the nature of the substances, the characteristics of the site, the circumstances of the release to groundwater, and the proposed remedial action are sufficiently similar to that contemplated by the State when promulgating its GWQS. Of the relevant and appropriate promulgated standards, the GWQC are the most stringent, and hence, are ARAR for the site. The various chemical-specific groundwater standards for each FMSS groundwater COC are listed in **Table 2-1**. The ARAR for arsenic is the NJGWQC PQL and the proposed cleanup level is 3 µg/L. The ARAR for benzene is the NJDEP MCL and the proposed cleanup level is 1 µg/L. Since ARARs are not available for lithium in groundwater, a risk-based action level was derived for lithium, based upon ingestion of groundwater. A target hazard quotient of 1 was used to derive the lithium risk-based action level of 730 µg/L. In order to achieve this groundwater goal, a soil cleanup number for lithium has been established at 194 mg/kg. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property, since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

When GWQC are not being met in a localized area, the State may define that area as a CEA for specified constituents (N.J.A.C. 7:9C-1.6). When a CEA is established, the State restricts or requires the restriction of potable groundwater uses within areas where there are exceedances of ground water quality standards. NJAC 7:26E-8.3 lists the information that must be submitted for the State to establish a CEA, such as (1) a list of all contaminants and their concentrations, (2) a description of the fate and transport of the contaminant plume, (3) site maps, (4) information regarding current and projected use of the groundwater in the aquifer, such as master plans or zoning plans, and (5) copies of various notification letters to county and municipal officials. Although there is not presently a CEA for this site, the required information could be gathered without much difficulty.

Soil Cleanup Criteria

There are several Federal guidance documents that pertain to soil cleanup criteria; however, there are no promulgated Federal soil cleanup standards for the groundwater COCs at the FMSS site. Similarly, the State of New Jersey does not have promulgated soil cleanup standards for the groundwater COCs at the FMSS site.

Of the non-promulgated guidance documents, several were reviewed for possible use as tools to assist in the evaluation of soil cleanup levels for the COCs in the groundwater below the FMSS. EPA has developed generic SSLs for 110 chemicals based on a migration to groundwater pathway. The SSL values use a default dilution-attenuation factor of 20 to account for natural processes that reduce contaminant concentrations in the subsurface. Another source of non-promulgated guidance that was reviewed for possible use at FMSS are the PRGs established by EPA Region 9; however, for arsenic and benzene these values are the same as the SSLs. NJDEP has proposed "Cleanup Standards for Contaminated Sites," N.J.A.C. 7:26D, which contains "impact to groundwater soil cleanup criteria" (IGWSCC). Although proposed in 1992, and recently revised and resubmitted for public comment, these standards have not yet been promulgated by the State; therefore, these standards were not retained for further consideration.

The FMSS site has soil source areas that may be continuing to contribute to groundwater contamination. The concentrations of inorganic and organic compounds in MISS soils were evaluated using EPA guidance to determine the potential leaching impacts to groundwater. For arsenic, a MISS-specific calculated cleanup value of 41 mg/kg was determined. Because it is site-specific, it represents a better cleanup target than either of EPA's generic standards (SSLs or PRGs).

With respect to benzene, cleaning to EPA's screening level of 0.03 mg/kg would be adequately protective; however, EPA's standard may be overprotective because EPA's PRG model may substantially over predict the mobility and possible impact of benzene on groundwater. A number of environmental studies indicate that organic contaminants that have been in soil for a long period of time act as though they are much more strongly bound to the soil than indicated by the organic partition coefficient used by EPA's PRG model. (Alexander, 1995; Alexander, 2000; Pignatello and Xing, 1996; Chung and Alexander, 1998; Nudelman et al., 2002). An adequately protective PRG could be higher by two or three orders of magnitude due to this effect. Thus, the PRG is greatly overprotective relative to the amount of migration to groundwater that is likely to occur.

Moreover, the soil source of benzene is located at the former MCW Building 62 on the MISS, the site of two former 20,000 gallon benzene above-ground storage tanks (AOC 6). The highest detection of benzene in MISS soil, 380 mg/kg, is located at area TP5UPER, sample number MISS-0160V. Based on the building and tank pad area of 2,500 ft^2, and radiological soil excavation to 3 feet, the amount of potentially benzene-contaminated soil is estimated at no more than 1,000 cubic yards.

This location is about 600 feet upgradient of the benzene plume and is separated from it by a line of wells, B38W25D, MW-25D, MW-23D, AND B38W24d, with analyses showing either very low or non-detect results for benzene.

Because there is no promulgated site screening level, and because the sampling locations and data suggests that removal of benzene source soils is not likely to affect the levels of benzene in the groundwater, no removal of benzene source soils is proposed. The technical literature further supports this decision, because it indicates that weathered or older benzene is not as mobile as the EPA SSLs would indicate.

Because they are not promulgated, none of the above-referenced soil guidance values are legally enforceable and, hence, cannot be ARARs for the FMSS site. These SSLs or SCCs can be considered (TBC) during the remedial activities at the FMSS site.

2.3 REMEDIAL ACTION OBJECTIVES AND PROPOSED CLEANUP LEVELS

The RAOs for MISS groundwater are based on human health and environmental considerations that drive the formulation and implementation of response actions. Such objectives are developed based on the criteria outlined in 40 CFR 300.430(e)(2)(i).

The RAOs for MISS groundwater have been developed such that attainment of these levels would result in the protection of human health, ecological receptors, and the environment. The RAOs specific to groundwater are not so limited that the choice of remedial technologies is overly restricted.

The proposed RAOs for the MISS groundwater are to restore the aquifer to State or Federal standards including:

- Comply with Federal and State MCLs or more stringent promulgated NJGWQC that are designated as ARARs for COCs in the groundwater in this GWFS (see **Table 2-1**).
- Eliminate or minimize the source of groundwater contamination associated with MISS non-radiological contaminated soils beyond the soils removed during the Soils and Buildings OU remedial action to levels that are protective of groundwater (see **Table 2-2**).
- Eliminate or minimize the potential for human exposure at unacceptable levels by direct contact or ingestion threat associated with groundwater COCs above cleanup levels established in the GW OU ROD for the COCs during implementation of the remedial action.
- Eliminate or minimize the potential for human exposure at unacceptable levels by direct contact or ingestion threat associated with lithium in groundwater. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

TABLE 2-1

GROUNDWATER CHEMICAL-SPECIFIC ARARS AND PROPOSED CLEANUP LEVELS

GWFS Constituent	Groundwater ARARs (μg/L)	Source for Cleanup Level
Arsenic	3[a]	NJGWQC PQL
Benzene	1[a]	NJDEP MCL
Lithium	730	Calculated Value[b]

[a] The lowest of Federal MCLs (40 CFR Part 141) or NJGWQC or higher PQL (NJAC 7:9C).

[b] Since ARARs are not available for lithium in groundwater, a risk-based action level was derived for lithium based on ingestion of groundwater.

TABLE 2-2

SOIL PROPOSED CLEANUP LEVELS TO ATTAIN GROUNDWATER CLEANUP

GWFS Constituent	MISS chemical-specific soil TBC (mg/kg)
Arsenic	41
Lithium	194

The GWRI groundwater COPCs were listed in **Section 1.2.7**. COPCs that are also FUSRAP wastes (MISS-related and exceed an MCL or risk-based value) were identified and listed in **Section 1.2.8**. To avoid confusion with the GWRI COPCs, those COPCs that are also FUSRAP wastes will be referred to as COCs.

- The proposed cleanup levels used for this GWFS for COCs in groundwater are presented in **Table 2-1**. These are the most conservative Federal or State promulgated value or higher PQL. The proposed impact to groundwater based cleanup levels for MISS soils are presented in **Table 2-2**.

2.4 IDENTIFICATION OF GENERAL RESPONSE ACTIONS

General response actions describe the broad approaches of remedial measures that can potentially achieve RAOs. General response actions may encompass many remedial technologies and remedial technology process options. For example, groundwater treatment is a general response action; in- situ treatment is a remedial technology; and air sparging is a remedial technology process option. Remedial technologies that have been considered from the beginning of the GWFS process are included under the general response actions described below.

The general response actions applicable to MISS groundwater are:

<u>No Action</u> – Involves no further actions on the GW OU. The NCP and CERCLA, as amended, require the evaluation of a “No Action” alternative as a baseline for comparison with other remedial alternatives. The “No Action” alternative does not involve any groundwater remedial action; therefore, groundwater at the MISS, or emanating from the MISS, would remain contaminated. Groundwater non-radiological contaminated source soils would not be remediated.

<u>Land Use Controls (LUCs)</u> – LUCs are administrative, legal or physical mechanisms that restrict the use of , or limit access to, contaminated property to reduce risk to human health and the environment. Physical mechanisms encompass a variety of engineered remedies to contain or reduce contamination and physical barriers to limit access to property, such as fences or signs. The legal mechanisms are generally the same as those used for institutional controls (ICs) as discussed in the NCP. ICs are a subset of LUCs and are primarily legal mechanisms imposed to ensure the continued effectiveness of land use restrictions imposed as part of a remedial decision. Legal mechanisms include restrictive covenants, negative easements, and institutional controls or notices. Administrative mechanisms include public notices, adopted local land use plans and ordinances, construction permitting, or other existing land use management systems that may be used to ensure compliance with use restrictions. LUCs can be an effective means of eliminating possible pathways of exposure and restricting access to contaminated media. LUCs do not reduce the toxicity, mobility, or volume of contamination by engineered action, but are implemented to reduce the probability of physical contact with contaminated media while natural processes are occurring. The primary purpose of LUCs for MISS groundwater would be to control the human exposure to contaminated groundwater for drinking purposes for the period of time until the GW OU remedial action cleanup levels have been satisfied according to the GW ROD. LUCs are often used in combination with other general response actions.

The source area (MISS) itself is owned by the United States Government, and use restrictions during United States Government ownership are entirely within Federal agency control. Deed covenants, or negative easements that would prevent drinking water use of the groundwater on the MISS, are readily available to be included in a deed transferring real property out of United States Government ownership. Currently, the MISS is restricted by fencing, and access is controlled. If the property is sold by the United States Government at some future time, provisions to continue implementing land use restrictions or LUCs would have to be made.

<u>Long-Term Management (LTM)</u> – LTM is the term used for environmental monitoring, review of site conditions and maintenance of a remedial action to ensure continued protection as designed. Examples of LTM include environmental monitoring of groundwater, surface water, and sediment; landfill cap maintenance; well and fence monitoring and repair; land use control enforcement; annual site inspections;

and 5-year reviews. This term is generally used until no further environmental restoration remedial or response actions are appropriate or anticipated.

Groundwater Removal – Groundwater removal actions would be used to reduce the amount of contamination in the subsurface, and could also be used to control groundwater migration pathways. Typically, a groundwater extraction system is used to remove contaminated groundwater from the affected aquifer. Removal can be achieved by using extraction wells, French drains, or extraction trenches. Groundwater removal is used in combination with other general response actions. For example, the extracted groundwater is typically treated, and then may be discharged to a surface water body, sewer system, or a Publicly Owned Treatment Works (POTW).

Groundwater Treatment and Disposal – Treatment would be used to reduce the amount of contamination in an aquifer and would reduce the potential risks from exposure. Treatment could either be performed in-situ or ex-situ.

In-situ treatment consists of actions that remove or destroy contaminant mass without being brought to the surface, (usually) resulting in significant cost savings. In-situ treatment, however, generally requires longer time periods to accomplish RAOs. Treatment includes methods that chemically alter or degrade the contaminants in place. In-situ biological treatment is used to degrade the contaminants. In-situ oxidation can be used to alter the chemical state of the contaminant. Natural attenuation physically and biologically degrades the contaminants monitored. Monitored natural attenuation (MNA) tracks the effectiveness of this treatment.

Ex-situ treatment is generally combined with groundwater removal. Treatment can involve physical or chemical processes such as air stripping, carbon adsorption, biological treatment, precipitation/ coprecipitation, ion exchange, or reverse osmosis. Ex-situ treatment is combined with groundwater disposal. The main advantage of ex-situ treatment is that it generally requires shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater. However, ex-situ treatment requires potentially cost intensive material handling activities.

When groundwater is treated ex-situ, it would need to be either disposed (discharged) off site or injected back into the aquifer. Typical disposal methods include reinjection, discharge to a POTW, or direct discharge to a surface water body.

Physical Barriers – Physical barriers would be used to control or reduce the migration of contaminated materials into the surrounding environment. They could also be used to isolate contaminated groundwater and soils to reduce precipitation infiltration and groundwater flow into source materials which would cause additional dissolved contamination and the possibility of increased exposure to the COCs. Containment measures for contaminated groundwater and source soils typically include caps, vertical barriers, and horizontal barriers.

Soil Removal – The bulk removal of contaminated soil would reduce the long-term potential for human and ecological exposure. Excavation of the source material would eliminate the development of dissolved contamination in groundwater. COC source soils would be excavated using conventional earth-moving equipment. Removal of soil by excavation would require the use of dust control and surface runoff measures to ensure worker safety and to protect the general-public and the environment. These measures have been successfully used at the FMSS and at other sites around the country.

Soil Treatment – Soil treatment actions evaluated included in-situ physical, chemical, and biological technologies to be used for reducing or removing contamination from the source soils.

In-situ physical processes considered include stabilization/solidification and soil flushing. Stabilization/ solidification techniques would solidify the soil matrix through in-situ injection of grouting materials. Soil flushing would involve the flushing of contaminants from the soil through injection of water through wells to physically scrub and remove the contaminants.

In-situ chemical treatment processes considered include chemical stabilization and fixation techniques that use chemicals to cause reactions between the stabilizing agent and the COCs to reduce their mobility. Additional chemical processes considered include a variety of operations such as chemical oxidation, neutralization, chelation, and solvent flushing. These processes involve a form of chemical addition for removal of COCs.

In-situ biological treatment involves the use of microbes to degrade the contaminants in the soils to below concentrations which would produce concentrations in groundwater above regulatory limits.

Soil Disposal – Disposal would involve the permanent and final placement of the source soils in a manner that protects human health and the environment. Contaminated soil above cleanup criteria would be disposed off site in accordance with local, State, and Federal regulations. Off-site disposal would use existing permitted and licensed disposal facilities. Off-site soil disposal at a licensed facility is currently being used at the FMSS under the Soils and Building OU.

2.5 IDENTIFICATION AND SCREENING OF REMEDIAL ACTION TECHNOLOGIES

Presented below are general descriptions of potentially applicable technologies for MISS groundwater. The technologies are described generally and may be applicable to more than one response action, such as in-situ treatment combined with access controls. Process options for these technologies will be identified and evaluated in **Section 3.0**. The term "process option" refers to specific processes within each technology type. For example, the in-situ treatment technology category includes process options such as permeable reactive barriers, enhanced bioremediation, chemical oxidation, and MNA. Several broad technology types may be identified for each general response action, and numerous process options may exist for each technology. Even within process options there are additional levels of choice, such as different oxidizing agents for chemical oxidation.

The identification and screening process is performed in accordance with the CERCLA FS guidance document (EPA 1988a), as specified by the NCP (40 CFR Part 300, Subpart E). Initial identification, as potentially applicable, is based primarily on technical feasibility using the following criteria:

- Compatibility with constituent characteristics;
- Compatibility with MISS characteristics;
- Ability to achieve RAO – either alone or as a component of a treatment train;
- Development status – a technology must be developed to the point of field-scale demonstration so that information is available on performance, reliability, and cost.

Based on these criteria, some remedial action technologies were eliminated from further consideration from the universe of technologies. Those considered potentially applicable and relevant to meeting MISS RAO and general response actions are presented in **Table 2-3**.

TABLE 2-3

IDENTIFICATION AND SCREENING OF REMEDIAL ACTION TECHNOLOGIES

General Response Action/ Technology	**Description**	**Comments**
A. No Action	No remedial measures to be taken.	The "No Action" alternative must be fully evaluated according to 40 CFR300.430(e)(6). **Retain**
B. LUCs • Use restrictions-Institutional and Physical Controls	Restrict future resource use and access to prevent unauthorized exposure to contaminated media.	A feasible approach for preventing exposure to contamination. Will not actively address any ecological risks. **Retain**
C. LTM • Environmental monitoring	Ensures that remedy remains protective of human health and the environment.	A routine action that determines whether cleanup levels have been achieved and are not migrating off site. **Retain**
D. Groundwater Removal • Groundwater extraction • Enhanced removal	Remove groundwater from the subsurface using pumps.	A routine procedure using traditional methods such as vertical wells and trenches. Some methods are more complex such as horizontal wells. Combined with on- or off-site treatment technologies. **Retain**
E. Groundwater Treatment • In-situ treatment • Ex-situ treatment	Treat groundwater in place to reduce the contaminant concentrations. Treat extracted groundwater or vapor after removal from the subsurface. Treatment could be either off site or on site. Treated groundwater will be discharged to a permitted discharge facility.	In-situ and ex-situ technologies exist for various FUSRAP COCs. **Retain**

TABLE 2-3 (Continued)

IDENTIFICATION AND SCREENING OF REMEDIAL ACTION TECHNOLOGIES

General Response Action/ Technology	**Description**	**Comments**
F. Physical Barriers • Capping • Vertical Barriers • Horizontal Barriers	Use of physical barriers to control precipitation infiltration and groundwater flow through source materials and the migration of contaminants.	Source soils and groundwater plumes are in areas where existing infrastructures (i.e., utilities, sidewalks, buildings) preclude construction of barriers for infiltration and groundwater controls and to plume migration. Portions of plumes are also in bedrock that would impede construction. **Do not retain**
G. Soil Removal • Excavation	Excavation to remove contaminated soils above cleanup criteria that contribute to COCs in groundwater.	Soil excavation is currently being conducted at the FMSS for removal of contaminated soils under the Soils and Buildings OU. **Retain**
H. Soil Treatment • In-situ physical • In-situ chemical	Treat contaminated soils in place to eliminate or reduce the contaminant concentrations.	In-situ physical and chemical treatment was determined not to be applicable due to Site conditions (high groundwater table, types of COCs, proximity to radiological contaminated soils, incompatibility with concurrent soil excavation under the Soils and Buildings OU) **Do not retain**
I. Soil Disposal • Off-site disposal	Disposal of contaminated soils off site at a permitted facility.	Treatment technology is straight forward and is currently being used at the FMSS for soil disposal under the Soils and Buildings OU. **Retain**

3.0 SCREENING OF PROCESS OPTIONS

3.1 INTRODUCTION

This section contains an evaluation and description of process options for each technology. For technologies with more than one process option, each option is evaluated according to the following criteria.

- Effectiveness – which includes evaluation of the following:
  - Potential effectiveness in handling the estimated areas or volumes of media and in meeting the RAOs.
  - Potential impacts to human health and the environment during the construction and implementation phase.
  - Demonstrated reliability of the process with respect to contaminants and conditions at the site (EPA, 1988a).
- Implementability – which includes both the technical and institutional feasibility of implementing a process option:
  - Technologies passing the initial screen of applicability are screened on the basis of technical feasibility. This criterion means feasibility under site-specific conditions. This evaluation may indicate that although a technology may be generally applicable for the COCs, the specific technology may be unworkable or limited due to site-specific conditions.
  - Institutional feasibility emphasizes the institutional aspects of implementability, such as the ability to obtain permits for off-site actions; the availability of treatment, storage, and disposal services (including capacity); and the availability of equipment and skilled workers to implement the technology (EPA, 1988a).
- Cost – which plays a limited role in the screening of process options. Cost is considered a deciding factor only when two alternatives are found to be equally protective. Ranges or approximations of relative capital, and operation and maintenance (O&M) costs, are used rather than detailed estimates. At this stage in the GWFS process, the cost analysis is made on the basis of prior experience with technologies, readily available information, and engineering judgment. Each process is evaluated relative to other process options of the same technology type, based on a cost range.

Following selection of the most appropriate process options for each technology type, the process options are combined to form remedial alternatives. The remedial alternatives are discussed in **Section 4.0**. Each process option for a given technology provides a basis for developing remedial alternatives and evaluating their costs and attributes. However, the specific process used to implement the remedial action may not be selected until the remedial design phase of the project (EPA, 1988a). Furthermore, pilot or treatability studies conducted prior to, or during, the final design may indicate that the representative technology is not feasible. If this occurs, the next best demonstrated available technology (BDAT) is selected.

3.2 EVALUATION AND SCREENING OF PROCESS OPTIONS

This section evaluates the process options within each technology type with respect to effectiveness, implementability, and cost. The most applicable process options are included in the subsequent development of remedial alternatives. The screening of process options is summarized in **Table 3-1**.

TABLE 3-1

SCREENING OF PROCESS OPTIONS

General Response Actions	Remedial Technology	Process Option	Effectiveness	Implementability	Relative Cost[1]	Screening Results
No Action	None	Not applicable (NA)	Does not achieve remedial action objectives.	Straightforward.	None	Retained[2]
LTM	Environmental Monitoring	Groundwater Monitoring Wells	Useful for documenting Site conditions; alone does not reduce risk.	Straightforward. Services & equipment available.	Low capital Low operation & maintenance (O&M)	Retained
		Surface Water/ Sediment Sampling	Useful for documenting Site conditions; alone does not reduce risk.	Straightforward. Services & equipment available.	Low capital Low O&M	Retained
		Annual Site Inspection; 5-Year Reviews; Enforcement of LUCs	Useful for documenting Site conditions, alone does not reduce risk.	Straightforward. Services & equipment available.	Low capital Low O&M	Retained
LUCs	Use Restrictions-Institutional and Physical Controls	Physical control such as well plugging (non-used domestic wells)	Effective for reducing human health exposure to groundwater; does not protect waters of the State.	Straightforward. Services & equipment available.	Low to medium capital, depending on number of properties involved. Low O&M	Retained
		Legal and administrative controls such as institutional controls or well restrictions in groundwater CEAs. Physical controls such as posting of warning signs for construction worker notification .	Effective for reducing human health exposure to groundwater; does not protect waters of the State.	Straightforward. Services & equipment available.	Low to medium capital, depending on number of properties involved. Low O&M	Retained
Groundwater Removal	Groundwater Extraction	Vertical Wells	Would effectively capture majority of contaminant mass.	Straightforward. Services & equipment available.	Medium capital Medium O&M	Retained
		Horizontal and Inclined Wells	Would effectively capture majority of contaminant mass.	Moderately complex. Difficult to install in bedrock. Services & equipment available.	High capital Medium O&M	Retained

TABLE 3-1 (Continued)

SCREENING OF PROCESS OPTIONS[1]

General Response Actions	Remedial Technology	Process Option	Effectiveness	Implementability	Relative Cost[1]	Screening Results
Groundwater Removal (continued)	Groundwater Extraction (continued)	Interceptor Trench	Would effectively capture majority of contaminant mass.	Moderately complex. Difficult to install in bedrock. Services & equipment available.	High capital Medium O&M	Not retained
Groundwater Treatment	In-Situ Treatment	Permeable Reactive Barriers (PRB)	Would be effective for removal of VOCs and metals.	Complex due to different chemical reactions required for benzene, other VOCs, and metals. PRBs require specialized expertise for installation. Installation can be complex so to assure long term performance. Difficult to install in bedrock.	High capital Medium O&M	Not retained
		Chemical Oxidation	Would be effective for VOCs. Can change oxidation state of metals, but does not remove them.	Moderately complex. Services & equipment available.	Medium capital Low O&M	Retained
		Oxidation-Reduction (Redox) Alteration	Would be effective for metals.	Moderately complex, may require pilot testing. Services & equipment available.	Medium capital Low O&M	Retained
		Monitored Natural Attenuation (MNA)	Effective for predicting and monitoring the potential ongoing and decrease in risk.	Straightforward	Low capital Medium O&M	Retained
		Enhanced Bioremediation	May be effective for VOCs, chlorinated organics, and some metals, depending on Site conditions.	Moderately complex, may require some testing, modeling and development.	Medium capital Medium O&M	Retained
		Phytoremediation	Not effective in bedrock.	Complex due to buildings and infrastructure. Will require off-site access.	Medium capital Medium O&M	Not retained
	Ex-Situ Treatment	Co-precipitation	Effective for metals removal (except lithium).	Straightforward	Medium to high capital Medium to high O&M	Retained
		Ion Exchange	Effective for metals removal.	Straightforward	Medium to high capital Medium to high O&M	Retained
		Reverse Osmosis	Effective for removing metals and VOCs.	Straightforward	Medium to high capital Medium to high O&M	Retained
		Clarification/ Coagulation	Effective for metals removal (except lithium).	Straightforward	Medium to high capital Medium to high O&M	Retained

TABLE 3-1 (Continued)

SCREENING OF PROCESS OPTIONS[1]

General Response Actions	Remedial Technology	Process Option	Effectiveness	Implementability	Relative Cost[1]	Screening Results
Groundwater Treatment (continued)	Ex-Situ Treatment (continued)	Adsorption	Effective for metals removal.	Straightforward	Medium to high capital Medium to high O&M	Retained
		Thermal Oxidation	Effective for VOC air emissions abatement for air stripping option.	Straightforward	Medium capital Medium O&M	Retained
		Granular Activated Carbon Adsorption	Effective for removal of VOCs.	Straightforward	Medium capital Medium O&M	Retained
		Biological Treatment	Effective for destruction of VOCs and removal of some metals.	Straightforward with some testing required.	High capital Medium to high O&M	Retained
		UV Peroxide	Effective for destruction of VOCs.	Straightforward	Medium capital Medium O&M	Retained
		Air Stripping	Effective for VOC removal.	Straightforward for most organic compounds.	Low capital without abatement, medium to high capital with abatement Medium O&M	Retained
		Groundwater Discharge to a Publicly Owned Treatment Works (POTW) Discharge	Expected to be effective for VOC and chlorinated VOC treatment. Metal ions may be reduced and concentrated in sludge or diluted in wastewater.	Straightforward	Low to medium capital Medium to high O&M Overall economics would depend on disposal fees charged by POTW and flow rate.	Retained
		Groundwater Discharge to Surface Water	Effective method to manage properly treated wastewater. Must meet New Jersey Pollutant Discharge Elimination System (NJPDES) requirements.	Implementable when combined with appropriate treatment operations.	Low capital Low O&M	Retained
		Groundwater Discharge via Injection Wells	Effective method to manage properly treated wastewater. Must meet equivalent NJPDES and State permit requirements if injection performed on site.	Groundwater injection would affect local groundwater gradients. Would potentially impact on- and non-MISS groundwater plumes. Injected water may not be compatible with groundwater and aquifer properties causing well and formation plugging.	Medium capital Medium to high O&M due to potential well and formation plugging.	Not Retained.

TABLE 3-1 (Continued)

SCREENING OF PROCESS OPTIONS[1]

General Response Actions	Remedial Technology	Process Option	Effectiveness	Implementability	Relative Cost[1]	Screening Results
Soil Removal	Excavation	Conventional earth moving equipment.	Effective for contaminated soil removal.	Straightforward	High capital Low O&M	Retained
Soil Disposal	Off-site Disposal	Permitted disposal facility.	Effective for contaminated soil disposal.	Straightforward	High capital Low O&M	Retained

(1) Cost is indicated as low, medium, and high relative to other technologies screened.

(2) Required to be considered by NCP.

3.2.1 No Action

Under the "No Action" option, no groundwater remedial measures would be taken at the MISS. Natural processes would be allowed to continue unabated, unenhanced, and unmonitored. Groundwater non-radiological contaminated source soils would not be remediated. All GWRI monitoring wells would remain in place and would not be abandoned. Because the alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA requires that the site be reviewed at least once every five years. No further expenditure of money or labor would be made; the cost of the option is zero. This approach would not achieve the RAOs presented in Section 2.3, and would not comply with ARARs. Nevertheless, under the requirements of the NCP, the "No Action" alternative must be evaluated as an alternative in the detailed analysis of alternatives within this GWFS.

Screening Evaluation for the "No Action" Option

The "No Action" option would not be considered effective for reducing contaminants within a reasonable period of time. This option would not address contaminant migration off site from the MISS, where there are no current restrictions for groundwater use. These factors would result in continued risk to human health and the environment. This option would not meet the ARARs. The "No Action" option would be technically feasible to implement. There would be no associated cost for the "No Action" option. However, deferring potential remedial action under a "No Action" option may ultimately result in increased costs when, or if, an action must be undertaken at some later point in time. The "No Action" option may also result in increased future liability, as the environment may not be protected by long-term attenuation of contaminants at the MISS or in the event of future exposure to site-related contamination.

Screening Decision for the "No Action" Option

The "No Action" option will be retained as required by CERCLA to provide a baseline for evaluating other alternatives.

3.2.2 Land Use Controls (LUCs)

LUCs are administrative, legal, or physical measures that can be taken to control/mitigate potential or actual human health and ecological risk. Human exposure to risks from groundwater or surface water can be controlled through the use of legal LUCs such as institutional controls for groundwater use, and well restrictions in groundwater CEAs. Groundwater within the contaminant plume is not currently utilized; however, formal controls (e.g., use restrictions, institutional controls, deed covenants, well plugging) for groundwater use may be required to meet ARARs for certain alternatives such as groundwater extraction.

An administrative LUC that can be implemented at the MISS is notification of local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Another administrative LUC is project-specific health and safety plans. A physical LUC that can be implemented at the MISS is the posting of warning signs.

LUCs implemented for vicinity properties where inaccessible soils remain above cleanup criteria, as well as where FUSRAP waste concentrations do not allow for unrestricted use, as part of the Soils and Buildings OU ROD include periodic inspections of properties to determine changes in land use; distribution of notification letters that identify locations of FUSRAP waste to property owners, utility companies, government agencies and other commercial entities; and the creation of a website that provides the public with project information including maps that identify areas of FUSRAP waste. The latter two LUCs inform the public to contact the USACE before excavation work is performed in areas where FUSRAP waste remains. In addition, LUCs in the form of deed notices have been and would continue to be proposed, if necessary, on a property-by-property basis. The objectives of these LUCs are to restrict land use to commercial or industrial, prohibit residential or unrestricted use, and to prohibit excavation into designated restricted areas.

The MISS source area is currently restricted by fencing and access is controlled. If the property is sold by the United States Government at some future time, provisions to continue implementing land use restrictions or LUCs would have to be made.

Screening Evaluation for LUCs Option

LUCs involve controlling access to contaminated areas by implementing administrative, legal, and physical mechanisms. LUCs would be required to ensure groundwater within the contaminated plume is not used for potable purposes until contaminant concentrations decrease to safe levels. Additionally, the LUCs associated with work being conducted under the Soils and Buildings ROD would prevent the use of the surface for residential purposes and would eliminate the potential for residential drinking water use of the contaminated groundwater as long as those LUCS remain in place. Governmental controls that may be considered include restricting future property uses involving groundwater for human consumption within contaminated areas and restricting the installation of new drinking water wells. One such legal LUC is the groundwater CEA. The CEA is a State of New Jersey administrated designation of areas that are not potable due to contamination. The State exercises its authority by utilizing a statute that requires permits prior to the construction of any groundwater well. Thus, the drinking water well exposure pathway is administratively controlled by the State for those areas classified as a CEA. A second type of legal LUC is a deed restriction or land use designation. These types of restrictions are typically implemented and enforced by the property owners or local planning or zoning departments or other municipal agencies. Designation of a CEA is preferable over institutional controls, since the Federal Government does not own all of the affected property. An agreement with each land owner would be required to implement this type of restriction. An administrative LUC that may be considered is notification of local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Another administrative LUC is project-specific health and safety plans. Posting of warning signs on the MISS, a physical LUC, may also be considered as a means to control access to site-related groundwater contaminants.

On-site LUCs would be implementable and easy to maintain while the government remains in control of the MISS. Off-site LUCs on groundwater and surface water may be difficult to implement if deed restrictions are attempted on off-site properties. Enforcement on the use of groundwater under a CEA would become the obligation of the local government or the NJDEP through issuance of well permits or zoning. Maintaining ongoing funding for enforcement, and a mechanism for performing the required maintenance of controls, would be the major requirement to assure continued implementability.

The typical cost for enforcement and maintenance of LUCs is usually minimal compared to remediation costs.

Screening Decision for LUCs Option

Legal and administrative LUCs are retained for consideration during the development of alternatives.

3.2.3 Long-Term Management (LTM)

LTM programs are intended to ensure that the remedy remains protective of human health and the environment. They are an essential part of the environmental restoration process where waste remains in place. LTM actions include environmental monitoring of groundwater, surface water, soil and sediment in order to determine that cleanup levels have been achieved and are not migrating from the site at levels harmful to public health and the environment. Additional LTM actions that ensure continued remedy performance include annual site inspections, 5-year reviews, and enforcement of LUCs.

At the FMSS and MISS, groundwater sampling and analysis, annual site inspections, 5-year reviews, and enforcement of LUCs can be implemented as LTM actions.

Screening Evaluation for LTM Option (Groundwater Monitoring)

Long-term environmental monitoring of groundwater, the primary component of this option, is conducted periodically until appropriate media-specific ARARs have been achieved. Groundwater monitoring, both along the plume's flow path and cross-gradient to the flow, allows for effective groundwater contaminant tracking. Groundwater monitoring is required as long as contaminated groundwater remains at the site above cleanup levels in a majority of the wells. Monitoring at hazardous waste sites is usually conducted to determine whether contaminant concentrations have decreased to safe levels. The typical cost for implementing monitoring is usually minimal compared to remediation costs.

Screening Decision for the LTM Option (Groundwater Monitoring)

Groundwater monitoring is retained for consideration in the alternatives development.

3.2.4 Groundwater Removal

Common groundwater extraction process options include vertical wells, horizontal and inclined wells, and interceptor trenches. These process options are used to remove contaminant mass from the subsurface. These technologies alone do not provide treatment of the contaminated media, but may be used to reduce the volume of contaminants in the aquifer. Additionally, the pumping of groundwater may produce a cone of depression around the wells and reverse the hydraulic gradient, effectively containing the groundwater contaminant plume.

Screening Evaluation of Groundwater Removal Option

Groundwater extraction can be used to remove contaminated groundwater. If the system is properly designed, extraction options can effectively contain and capture the majority of the contaminant mass. The effectiveness at the MISS would be influenced by the size of the plume, and variable subsurface permeabilities that would dictate the number and/or size of wells required. Groundwater extraction does not directly reduce the toxicity of the extracted contaminated groundwater and must be used in combination with other treatment technologies.

Installation and operation of vertical wells at the MISS are straightforward. The technology is well documented and there are no subsurface features to interfere with installation. Horizontal and inclined wells are more complex to implement due to design, equipment, and installation requirements. Installation of interceptor trenches is complicated by the presence of bedrock and the depth of the contaminant plume.

Relative costs for these process options are well documented. Capital costs for vertical wells are medium compared to other process options. Horizontal/inclined wells and interceptor trenches have high capital costs due to design and installation requirements. Operation and maintenance costs are medium and involve operation of pumps, and the maintenance and periodic replacement/refurbishment of the system. Use of an interceptor trench at the MISS would require the removal of 20 to 40 feet of bedrock, which would make this option cost prohibitive.

Screening Decision for the Groundwater Removal Option

Interceptor trenches are not retained as a removal option. Each of the remaining removal options are retained for further consideration.

3.2.5 Groundwater Treatment

Remedial technologies associated with groundwater treatment include in-situ treatment and ex-situ treatment technologies. Common in-situ treatment options in groundwater include permeable reactive barriers, such as iron filing walls, enhanced bioremediation, chemical oxidation, and MNA. The effectiveness of in-situ treatment technologies is dependent on the contaminant, as well as the chemical and physical characteristics of the aquifer and subsurface soils. Ex-situ treatments, which may be applicable to the MISS groundwater, would require construction of a treatment facility. Common techniques include ion exchange, co-precipitation, reverse osmosis, adsorption, thermal oxidation, and air stripping.

As discussed in **Section 2.2.3.1**, the FUSRAP groundwater COCs include arsenic, benzene and lithium. These FUSRAP COCs were detected in both the overburden and shallow bedrock aquifers. Groundwater plumes associated with the MISS are observed for arsenic, benzene, and lithium. Isolated chemical and radiological exceedances were detected in wells at AOCs 1, 2, 3, 4, and 5, and at other locations on the MISS. Non-FUSRAP contaminants detected on the MISS above MCLs and from upgradient, non-MISS sources are PCE, TCE, and VC. . Lithium is also present upgradient of the MISS. These and any additional chemical constituents found in site and local groundwater would have to be accounted for in designing both in-situ and ex-situ groundwater treatment systems.

3.2.5.1 In-Situ Treatment

The main advantage of in-situ treatment is that it allows groundwater to be treated without being brought to the surface, usually resulting in significant cost savings. In-situ treatment, however, generally requires longer time periods, and there is less certainty about the uniformity of treatment. Verification of the attainment of treatment levels is typically more difficult because of the variability in aquifer characteristics, and because samples are collected from discrete locations rather than thoroughly mixed groundwater.

A detailed discussion of in-situ treatment is provided in **Appendix B**. In-situ treatments that are viable to treat the benzene plume include air sparging, chemical oxidation, MNA, enhanced bioremediation, and phytoremediation. The oxidation reduction (redox) alteration is the viable treatment technology for metals. A brief discussion of each technology is provided below.

Screening Evaluation for Permeable Reactive Barriers (PRB)

PRB consist of a reactive medium installed in a trench constructed across the groundwater flow path. The PRB allows passage of groundwater while treating contaminants. Zero-valent iron is the most common reactive medium used in PRB, which would not be effective for the COC benzene. Two common concerns with the construction of a PRB are that the trench is constructed so that groundwater would continue to flow through the PRB; the second is the longevity of the reactive material.

Design and construction of the PRB at the MISS would be complex. The groundwater contaminants present include benzene, arsenic, and lithium. A reactive medium would need to be selected that would take into account the complex chemical reactions which may occur for each of the contaminants. In addition, installation of the PRB would require excavation into 20 to 30 feet of bedrock.

Screening Decision for the PRB Option

PRB is not retained for further evaluation of alternatives.

Screening Evaluation for Chemical Oxidation Option

In-situ chemical oxidation is based on the delivery of chemical oxidants to contaminated media in order to achieve destruction or breakdown into non-toxic products of the VOC. Liquid chemical oxidants are injected into the subsurface through injection wells. The two most commonly applied oxidants include hydrogen peroxide and potassium permanganate. Hydrogen peroxide is commonly added to the groundwater with an iron catalyst in order to create a hydroxyl free radical. The free radicals then act as the oxidizing agent for VOCs including benzene and highly chlorinated compounds. Residual peroxide degrades to water and oxygen. Permanganate also oxidizes VOCs including benzene and chlorinated compounds. Some of the injected oxidant is consumed by total organic carbon (TOC) and minerals. The two additives differ in their oxidation capacity, mechanism of oxidation, rate of reaction, radius of influence, and cost. Both oxidants are readily available and treatment time is rapid, largely decreasing the restoration timeframe of a site. Both oxidants would likely inhibit any natural biological processes within the radius of influence. Chemical oxidation can change the oxidation state of metals, but does not remove them. If chemical oxidation is considered at the MISS, the effect on metals in groundwater would need to be considered, especially for uranium and radium.

Many field applications of the technology have been conducted using both oxidants, and have resulted in a significant reduction in VOC concentrations in groundwater at other sites. Hydrogen peroxide is highly reactive, thus resulting in a smaller radius of influence than permanganate, which would require additional injection points over a given area. In addition, because of its high reactivity, it creates an exothermic reaction, thus generating heat. The heat generated from injecting hydrogen peroxide may interfere with any underground utilities and wells. Potassium permanganate, being less reactive than hydrogen peroxide, has a larger radius of influence and would remain stable in the groundwater for longer periods of time. Since concentrations at the MISS are relatively low compared to other sites in which chemical oxidation was used, material costs should not be the limiting factor in remediation.

Screening Decision for the Chemical Oxidation Option

Chemical oxidation is retained for consideration in the development of alternatives.

Screening Evaluation for Redox Alteration Option

The manipulation of the redox state of the aquifer environment is used as a remediation method to cause the precipitation of metals, the adsorption of metals on mineral surfaces, or the enhancement of aerobic or anaerobic microbiological activity. This option is discussed in detail in **Appendix B** and summarized here. The redox manipulation techniques are most effective for redox-active metals, which are metals that can exist in more than one valence state over the range of Eh, pH, temperature, and pressure conditions that exist in shallow groundwater environments. The different valence states of some of the metals of concern at the site have very different solubilities and/or adsorption affinities, which translate into different mobilities. Microbial enhancement techniques are most effective for in-situ treatment of organic contaminants, but have also been successfully used for metals.

Methods for increasing the redox potential of the aquifer include air sparging, the injection of pure oxygen, ozone, hydrogen peroxide, and oxygen-releasing solid compounds such as magnesium peroxide and proprietary compounds, such as Oxygen Release Compound (ORC®, developed by Regenesis [2004]). More aggressive redox-increasing techniques include the injection of permanganate and persulfate compounds, and Fenton's reagent. These more aggressive techniques rapidly raise the redox potential to very high values in the treated areas.

Chemical techniques used to create reducing conditions include the injection of reducing agents such as calcium polysulfide, sodium thiosulfate, and proprietary compounds, such as Metals Remediation Compound (MRC®, developed by Regenesis [2004]). Biological techniques involve the injection of compounds that provide a bio-available source of organic carbon that stimulates anaerobic activity. Materials such as lactic acid, sodium lactate, molasses, soybean oil, and proprietary compounds, such as Hydrogen Release Compound (HRC®, developed by Regenesis [2004]) have been successfully used for this purpose.

Caution should be exercised with redox manipulation techniques where there is more than one metal of concern, because treatment (immobilization) of one metal may mobilize one or more other metals.

Screening Decision Redox Alteration Option

Redox alteration is retained for consideration in the development of remedial alternatives

Screening Evaluation for Monitored Natural Attenuation (MNA) of Groundwater Option

Natural attenuation includes a variety of natural processes which work together to reduce the concentration of contaminants and their impact on the environment. Attenuation of contaminants occurs whether active remedial measures are implemented or not. However, natural attenuation should not be confused with "No Action." Natural attenuation is a systematic approach of modeling, predicting, monitoring, and measuring the rate at which attenuation of contaminants occur, so as to demonstrate that RAOs are achieved. Natural attenuation includes intrinsic bioremediation and groundwater sorption/dispersion. Contaminant transport modeling has been performed which predicts the downgradient dispersion of the plume. When used as a remedial technique, a formal monitoring program is established and the action is termed "MNA."

Intrinsic bioremediation is a natural biological activity whereby contaminants are degraded. Intrinsic biological activities fall into two classes; aerobic and anaerobic. Aerobic environments tend to be oxidizing and tend to have a higher capacity for degrading hydrocarbons and low-concentration short-chain chlorinated organic compounds. Anaerobic environments tend to be reductive, and generally have a higher capacity to immobilize contaminants such as metals through reduction reactions and sulfide fixation. Anaerobic environments are also sufficiently reducing to dehalogenate the more highly chlorinated, inert, and environmentally persistent organic compounds.

The more highly chlorinated compounds such as PCE and TCE typically degrade under natural conditions via reductive dechlorination, a process that requires both electron acceptors (e.g., Fe +3, Mn+4, sulfate, and possibly chlorinated aliphatic hydrocarbons like PCE and TCE) and an adequate supply of electron donors. Electron donors include fuel hydrocarbons (e.g., benzene) or other types of anthropogenic carbon or natural organic carbon. If the subsurface environment is depleted of electron donors before the chlorinated aliphatic hydrocarbons are degraded or removed, the biological reductive dechlorination would cease, and natural attenuation rates would be dependent on sorption and dispersion. Because of this process, the biodegradation of chlorinated compounds is an electron-donor-limited process.

As discussed in **Appendix B**, strongly anaerobic conditions exist in the area of the benzene plume becoming less strong to oxic outside of the benzene plume. Estimated degradation rates for the primary contaminants are also provided in **Appendix B**. The chemical characteristics for the contaminants at the site would affect the rates at which these processes occur. Depending on the rates, destruction or removal of the contaminants may or may not occur as a result of biodegradation.

A second mechanism for natural attenuation is Groundwater Sorption/Dispersion. Contaminant releases are attenuated within groundwater plumes. Although the movement of these groundwater plumes may be slow, contaminants eventually would attenuate. Attenuation mechanisms include sorption of contaminants onto the soil matrix and dispersion throughout the aquifer. Attenuation may result in precipitation or solubilization, adsorption, preferential retardation, or change in pH within the aquifer. These are the mechanisms which primarily control the natural attenuation of metals and radionuclides in groundwater.

MNA as a technology is well developed and simple to implement. The effectiveness of the technology would be dependent on the rate at which natural attenuation occurs at the site. The costs for this technology are low and are primarily related to groundwater monitoring.

Screening Decision for Monitored Natural Attenuation of Groundwater Option

This technology is retained for further evaluation and possible use in the remedial measures alternative development.

Screening Evaluation for Enhanced Bioremediation Option

As discussed in **Appendix B**, the GWRI Report provides data on the oxidation reduction potential (ORP), as well as the concentrations of various microbial indicators, including dissolved oxygen, nitrate, ammonia, dissolved manganese, dissolved iron, sulfate, sulfide, and methane in samples from benzene-impacted and non-impacted locations. Results from the benzene-impacted locations clearly show oxygen depletion, conversion of nitrate to ammonia, solubilization of manganese and iron, and methane production.

The results indicate that anaerobic conditions are firmly established within the benzene-impacted area. Local benzene degradation rates would be limited by the rates that are specific to these existing anaerobe populations. Remedial methods that supply the system with oxygen by air sparging, ozone injection, hydrogen peroxide injection, and the use of oxygen-releasing compounds such as magnesium peroxide, are standard techniques implemented at benzene, toluene, ethylbenzene, and xylenes (BTEX)-impacted sites. These techniques return the system to oxic conditions under which the faster aerobic degradation processes become re-established. Many sites where these techniques have been implemented have experienced greatly increased BTEX degradation rates.

The biodegradation of benzene under anaerobic conditions is enhanced by the injection of compounds into the aquifer that serve as alternate electron acceptors. Compounds added may be nitrate or sulfate. Oxidation of benzene has been shown to occur under various reducing conditions with the addition of these nutrients at several sites. The end-products produced, when nitrate is added, are nitrogen gas, water, and carbon dioxide. The primary end-product produced, when sulfate is added, is hydrogen sulfide. The compounds can be added through a standard injection well.

Implementation of this technology would require a large number of application points, due to the low and variable permeability of the aquifer in the source areas. However, this technology is effective for benzene and chlorinated organics. Degradation may produce toxic intermediates for short time periods in limited areas before complete degradation. Enhanced bioremediation is a moderate to well demonstrated technology that has been successfully used at other sites. Bioremediation treatment chemicals are readily available to implement the technology. Costs are medium and are dependent upon the number of points and frequency of injection required.

Screening Decision for Enhanced Bioremediation Option

This technology is retained for further evaluation and possible use in the remedial alternatives development.

Screening Evaluation for Phytoremediation Option

In-situ phytoremediation is a process which uses plants to address soil or groundwater contamination. Plants act as hosts to aerobic and anaerobic microorganisms. Plant roots and shoots increase microbial activity in their direct environment by providing additional surface area for microorganisms, increasing readily-degradable carbon substrates. In addition, plant roots uptake some contaminants from the soil and groundwater matrix, and incorporate the contaminants into the biomass.

The effectiveness of phytoremediation is limited by the root structure. Since contamination extends to a depth of up to 60 feet, and is located in bedrock as well as the unconsolidated aquifer, phytoremediation is not considered a viable technology.

Screening Decision Phytoremediation Option

Phytoremediation is not retained for further evaluation in the remedial alternatives development.

3.2.5.2 Ex-Situ Treatment and Disposal

If groundwater is extracted at the MISS, treatment would be necessary prior to disposal (discharge) to reduce concentrations of contaminants. The main advantage of ex-situ treatment is that it generally requires shorter time periods, and there is more certainty about the uniformity of treatment because of the ability to monitor and continuously mix the groundwater. Ex-situ treatment, however, requires pumping of groundwater, leading to increased costs for engineering and equipment, possible permitting, and material handling. Various treatment methods are described below. A summary of chemical constituents addressed by each treatment method is provided in **Table 3-2**. This list of chemicals includes both COCs and non-COCs, since both may be captured during groundwater extraction and require treatment before discharge.

Discharge technologies involve the disposal of treated groundwater into an on-site or off-site POTW, discharge into an on-site or off-site surface water body, or discharge back into groundwater via injection wells. The discharge of treated water must satisfy all effluent limitations.

Screening Evaluation for Precipitation/Coprecipitation Option

This process uses chemicals to transform dissolved contaminants into an insoluble solid. In coprecipitation, the target contaminant may be dissolved, or in a colloidal or suspended form. Precipitation/coprecipitation involves pH adjustment and addition of a chemical precipitant or coagulation. It can also include the addition of an oxidant to reduce the contaminant to a less soluble state. Common chemicals used are ferric salts, ammonium sulfate, aluminum hydroxide, lime softening, manganese sulfate, copper sulfate, and sulfide. (EPA, 2002).

Screening Decision for Precipitation/Coprecipitation Option

This technology is capable of removing the MISS metals and radiological contaminants from an aqueous waste stream. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Ion Exchange Option

Ion exchange is a physical/chemical process in which ions held electrostatically on the surface of a solid are exchanged for ions of a similar charge in a solution. Exchange of cations or anions between the contaminants in the wastewater and the exchange media occurs (EPA, 2002).

TABLE 3-2

EX-SITU TREATMENT PROCESS OPTIONS

Process Option	**Radiological**				**Metals**						**Organics**					
	Adjusted Gross Alpha(2)	Adjusted Gross Beta(2)	Total Radium (2)	Total Uranium (2)	**Arsenic**	Barium(2)	Beryllium(2)	Lead(2)	**Lithium**	Thallium(2)	**Benzene**	Methylene Chloride(2)	Tetrachloroethene(2)	Toluene(2)	Trichloroethene(2)	Vinyl Chloride(2)
Coprecipitation/Precipitation	X	X	X	X	X	X	X	X	X	X						
Ion Exchange	X	X	X	X	X	X	X	X	X	X						
Reverse Osmosis	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Clarification\Coagulation	X	X	X	X	X	X	X	X	X	X						
Adsorption	X	X	X	X	X	X	X	X	X	X						
Thermal Oxidation (1)											X	X	X	X	X	X
Granular Activated Carbon Adsorption											X	X	X	X	X	X
Biological Treatment				X							X	X	X	X	X	X
UV Peroxide											X	X	X	X	X	X
Air Stripping											X	X	X	X	X	X

Note:
(1) For air stripper off-gas treatment.
(2) All chemical and radiological constituents present in groundwater on or near the MISS were considered in the selection of a process option, since they may be extracted during groundwater pumping.

For this treatment, contaminated groundwater is passed through a resin bed where ions are exchanged between the resin and the water. Ion exchange is a proven technology for removing metals and uranium from water. Regeneration of the resin would result in concentrated brine which would need additional treatment and/or disposal.

Screening Decision for Ion Exchange Option

This technology is capable of removing the MISS metals and radiological contaminants from an aqueous waste stream. It is not effective on the organic contaminants. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for the Reverse Osmosis Option

Reverse osmosis is a high pressure process that primarily removes smaller ions by membrane filtration. Efficiency of arsenic removal can be achieved by first oxidizing the wastewater to convert arsenic (III) to arsenic (V). This technology is effective for a wide variety of contaminants and characteristics of the untreated water. Suspended solids, organics, and colloids can cause fouling (EPA, 2002).

Screening Decision for the Reverse Osmosis Option

This technology is more expensive than other ex-situ treatment technologies, but it would treat each of the MISS contaminants. This technology is retained for consideration in the development of the remedial alternatives.

Screening Evaluation for Clarification/Coagulation Option

Clarification is a process whereby suspended particles are removed by settling, filtration, centrifugation, or the addition of flocculants, followed by the addition of ferric chloride in the form of an acidic solution. When the solution mixes with water, the iron hydrolyzes ferric hydroxide which precipitates as a fine flocculant with the scavenged metals. This flocculant is then removed by settling or filtration, often with the aid of a polymer.

Screening Decision for Clarification/Coagulation Option

This technology is capable of removing the MISS metals and radiological contaminants from an aqueous waste stream. It is not effective on the organic contaminants. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Adsorption Option

In this process, an adsorption media such as activated alumina, activated carbon, copper-zinc granules, granular ferric hydroxide, or surfactant-modified zeolite, is packed into a column. Contaminated water is then passed through the column and contaminants are adsorbed. When the adsorption sites become filled, the column must be regenerated or disposed of and replaced with new media (EPA, 2002).

Screening Decision for Adsorption Option

This technology can treat dissolved metals and radiological MISS contaminants. However, the adsorption of organics would reduce the efficiency of the adsorption of metals such as arsenic. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Thermal Oxidation Option

Thermal oxidation is a process whereby emission streams are heated with a mixture of air and combusted at high temperatures. There are three types of thermal oxidizers: direct flame, recuperative, and regenerative. A thermal oxidizer can be used to treat a wide variety of organic emission streams and can achieve 95 to 99 percent efficiency.

Screening Decision for Thermal Oxidation Option

Thermal oxidation is retained for development of the remedial alternative which considers the potential treatment of organic off-gases.

Screening Evaluation for Granular Activated Carbon Option

Liquid phase carbon adsorption is a full scale technology in which groundwater is pumped through a vessel, or series of vessels, containing granular activated carbon (GAC) to which dissolved contaminants adsorb. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the GAC can be regenerated in place, removed and regenerated at an off-site facility, or discarded and replaced. Adsorption by GAC has a long history of use in treating municipal, industrial, and hazardous waste. Carbon adsorption is most efficient for removing organic compounds with a high boiling point, high molecular weight, and low solubility in water.

Carbon adsorption is also effective for polishing water discharges from other remedial technologies to attain regulatory compliance. Carbon adsorption systems can be deployed rapidly, and contaminant removal efficiencies are high. Logistic and economic disadvantages arise from the need to transport and decontaminate spent carbon (Platinum International, 2002).

Screening Decision for GAC Option

GAC treatment is capable of removing the volatile contaminants from an aqueous waste stream. It is not effective for the metals or radiological contaminants. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Biological Treatment Option

A common biological treatment is using a bioreactor. Using this technique, contaminants in groundwater are put in contact with microorganisms in attached or suspended growth bioreactors. In suspended growth systems, contaminated groundwater is circulated in an aeration basin where microbial population aerobically degrades organic matter. In attached growth systems, microorganisms are established on an inert support matrix to aerobically degrade water contaminants (Platinum International, 2002).

Screening Decision for Biological Treatment Option

Biological treatment is capable of removing the MISS volatile organic contaminants from an aqueous waste stream. It is not effective for the metals or most radiological contaminants. Biological treatment is effective for removal of uranium. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for UV Peroxide Option

This technology combines ultraviolet light (UV) with hydrogen peroxide. This is a destruction process that oxidizes organic constituents present in water by the addition of strong oxidizers and irradiation with UV light. The oxidation reaction is achieved 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 CO_2, 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 contaminants are extracted and concentrated in a separate phase. UV oxidation processes can be configured in batch or continuous flow modes, depending on the throughput under consideration. Practically any organic contaminant that is reactive with the hydroxyl radical can potentially be treated. A wide variety of organic and explosive contaminants are susceptible to destruction by UV oxidation, including petroleum hydrocarbons and chlorinated hydrocarbons (Platinum International, 2002).

Screening Decision for UV Peroxide Option

UV peroxide is capable of removing the MISS volatile organic contaminants from an aqueous waste stream. It is not effective on the inorganic or radiological contaminants. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Air Stripping Option

Air stripping is a full scale technology in which volatile organics are separated from groundwater by increasing the surface area of the contaminated water that is exposed to air. Types of aeration methods include: packed towers, diffused aeration, tray aeration, and spray aeration. Air stripping is used to separate VOCs from water. It is ineffective for inorganic contaminants (Platinum International, 2002).

Screening Decision for Air Stripping Option

Air stripping is capable of removing the MISS volatile organic contaminants from an aqueous waste stream. It is not effective on the inorganic or radiological contaminants. This technology is retained for consideration in combination with other technologies in the development of the remedial alternatives.

Screening Evaluation for Discharge to POTW Option

Treated groundwater can be discharged via a sewer system to a POTW. A permit is already in place to discharge groundwater from construction activities to the POTW operated by the Bergen County Utilities Authority. Any wastewater discharged would need to meet the chemical quality of this permit. In addition, a permit revision would be required to increase the quantity of allowable discharge water.

Screening Decision for Discharge to POTW Option

Discharge of treated groundwater is an effective technology when used in conjunction with ex-situ treatment technologies. Discharge of treatment plant effluent to the POTW is retained for consideration in the alternatives assembly.

Screening Evaluation for Discharge to Surface Water Option

For this technology, treated groundwater is discharged to a surface water body such as Westerly Brook. This technology is straightforward to implement, since Westerly Brook is adjacent to the MISS. Surface water discharges would meet State requirements for water quality.

Screening Decision for Discharge to Surface Water Option

Discharge of treated groundwater is an effective technology when used in conjunction with ex-situ treatment technologies. Surface water discharge of treatment plant effluent is retained for consideration in the alternatives assembly.

Screening Evaluation for Discharge to Groundwater Option

For this technology, treated groundwater would be injected into subsurface formations via injection wells. The injection well field would have to be designed to accept the quantity of water extracted, and placed at a location which would not interfere with the extraction system or existing groundwater plumes. The treated water would have to be compatible with the injection formation and groundwater.

Screening Decision for Discharge to Groundwater Option

This technology would be complex to implement due to the potential impacts on the hydrogeologic environment and existing groundwater plumes. The treated water would most likely not be compatible with the injection formation or existing groundwater, potentially causing well plugging. For these reasons, groundwater injection for disposal is not retained.

3.2.6 Soil Removal

Excavation using conventional earth-moving equipment is a common practice for the removal of contaminated soil from a site. Soil excavation is used to remove source materials which are contributing to groundwater contamination from the site. This technology alone does not provide treatment of the contaminated media, but may be used to reduce the volume of contamination on the site.

Screening Evaluation for Soil Excavation Option

Soil excavation can be used to remove contaminant mass from the site. Removal of soil by excavation would require the use of dust control and surface runoff measures to ensure worker safety and to protect the general public and the environment. The technology is currently being utilized at the FMSS for radiological contamination mass removal under the Soils and Buildings OU. The use and cost of the technology is well understood at the FMSS.

Screening Decision for Soil Excavation Option

Soil excavation has been successfully used at the FMSS and at other sites around the country. Soil excavation is retained as a remedial technology.

3.2.7 Soil Disposal

Contaminated soil above cleanup criteria would be disposed off site in accordance with local, State, and Federal regulations. Off-site disposal would use existing permitted and licensed disposal facilities.

Screening Evaluation for Soil Disposal Option

The technology is currently being utilized at the FMSS for radiological contamination mass removal under the Soils and Buildings OU. The use and cost of the technology is well understood at the FMSS.

Screening Decision for Soil Disposal Option

Off-site soil disposal at a licensed facility has been successfully used at the FMSS and at other sites around the country. Off-site soil disposal at a licensed facility is retained as a remedial technology.

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4.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES

4.1 INTRODUCTION

Remedial alternatives are formed by combining the treatment technologies/process options that passed both the initial screening (**Section 2.5**) and the second, more detailed screening (**Section 3.2**). In this section, the proposed remedial alternatives for the MISS are developed. Following development of alternatives, evaluation of each alternative is performed based on the CERCLA criteria. A comparative analysis of all the alternatives is then presented in **Section 5.0**, leading to a recommendation of the preferred alternative as discussed in **Section 6.0**.

Groundwater technology process options were screened in **Section 3.0** based on three factors: implementability, effectiveness, and cost. In this section, the screened technologies and process options are assembled into groundwater remedial alternatives based on the previously-listed criteria. Alternatives were developed from the following remedial technologies.

- No Action
- Land Use Controls – Use Restrictions
- Long-Term Management – Groundwater Monitoring
- Groundwater Extraction
- In-Situ Groundwater Treatment
- Ex-Situ Groundwater Treatment
- Groundwater Discharge
- Soil Excavation
- Off-site Soil Disposal

Soil remediation using excavation and off-site disposal at a licensed facility would be required for removing COC source material for arsenic on the MISS to protect groundwater (**Sections 2.4** and **2.5**). These soils are located beneath the radiologically contaminated soils that would be remediated under the Soils and Buildings OU ROD, and above and below the groundwater table. Soil excavation and off-site disposal at a licensed facility was determined to be the selected remedial technology for the site during the Soils and Buildings OU ROD and was further evaluated for use in the GWFS for development of alternatives. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

Alternatives can consist of a technology option alone, or several technology options in combination, to address the MISS-specific RAOs.

4.2 RATIONALE FOR ASSEMBLY OF ALTERNATIVES

Development of remedial alternatives must conform to the requirements identified in CERCLA, as amended, and to the extent possible, the NCP. Section 300.430 of the NCP specifically refers to ARARs in the development of alternatives. CERCLA Section 121(d) requires that Superfund remedial actions attain ARARs unless specific waivers are granted and the remedial action must also be protective of human health and the environment. Remedial actions must also attain State ARARs that are more stringent than Federal

ARARs to the extent that they are also applicable, or relevant and appropriate, have been timely identified by the States, and otherwise comply with CERCLA and the NCP.

CERCLA Section 121(b) identifies the following statutory preferences when developing and evaluating remedial alternatives.

- Remedial actions involving treatment which permanently and significantly reduces the volume, toxicity, or mobility of the contaminants of hazardous substances are preferred over remedial actions not involving such treatment.
- Off-site transport and disposal of hazardous substances or contaminated materials without treatment is considered to be the least favored remedial action alternative when practical treatment technologies are available.
- Remedial actions using permanent solutions, alternative treatment technologies, or resource recovery technologies shall be assessed.

Based on these statutory preferences and the response objectives developed in **Section 2.0**, remedial alternatives are developed in this section to satisfy the following criteria.

- Remedial alternatives are protective of human health and the environment.
- Remedial alternatives attain chemical-specific ARARs.
- Remedial alternatives that use permanent solutions/treatment technologies to the maximum extent possible.
- Remedial alternatives that are cost-effective.

Several MISS-specific assumptions have been made for the development of the remedial alternatives. These assumptions are as follows.

- For the purpose of the GWFS evaluations, no on-going contaminant releases from contaminated soils were input into the groundwater model. The zero time for each alternative was assumed to be after the soils are remediated. This is appropriate, especially considering current and expected future land use, since any residual soil material left on-site will be diminimis as compared to the current on-site material.
- No wetlands, flood plains, endangered species, or historical areas exist at the MISS that would impede the development and implementation of remedial alternatives.
- Lodi Brook surface water radium exceedances are derived from an off-site overburden soil source, which produces groundwater contamination that flows to the stream, and not from runoff and/or stream sediments. Off-site contaminated soils, contaminated wetlands located in headwater areas, and contaminated stream sediments from upper Lodi Brook (upstream of Route 17), would be excavated on adjacent properties under the Soils and Buildings OU ROD. Surface water radium concentrations are expected to diminish after soil and sediment remediation is complete. No further actions would be required to address radiological source materials.
- Cleanup of chlorinated solvent exceedances on the MISS (PCE, TCE, VC, and 2-chlorotoluene) is not within the scope of the GWFS, as they were determined to be associated with the Dixo Company (NJDEP, 2002) or other non-MISS and upgradient sources. However, the potential impacts of the Dixo Company chlorinated solvent plumes on the selected remedial alternatives (e.g., extracted groundwater needing treatment before discharge) or the impacts of the alternatives on the Dixo Company chlorinated solvent plumes (e.g., groundwater pumping capturing or altering the plume locations or shapes) are evaluated in this GWFS.

- USACE is aware of ongoing investigations by Dixo Company and Stepan Company of groundwater contaminant plumes not originating on the MISS. The existence of these plumes has been considered in the development of remedial alternatives found in this GWFS.
- Uranium, radium, manganese, and non-FUSRAP chemical constituents found in MISS groundwater would be evaluated to determine their impact on the remedial alternatives.

4.3 ASSEMBLY AND PRESENTATION OF ALTERNATIVES

Based on the rationale presented above, and the technology and process options that have been retained based on the evaluations, the following four alternatives are proposed for the groundwater at the MISS.

- Alternative No. 1 – No Action.
- Alternative No. 2 – Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation on the MISS.
- Alternative No. 3 – Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater, and In-Situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS.
- Alternative No. 4 – Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soil Remediation on the MISS.

The alternatives were evaluated using the groundwater flow and solute transport model constructed for the site which is provided in **Appendix C, Volume 2**. Both flow and transport modeling were conducted, along with particle tracking analysis. Flow model results that support the alternative descriptions are presented in this section. Contaminant transport results are provided for each alternative in **Section 5.0**. Additionally, geochemical evaluations were performed for site-related contaminants to support the groundwater flow and solute transport modeling and the in-situ treatment evaluations (**Appendix B**).

4.4 DETAILED DESCRIPTION OF THE ALTERNATIVES

4.4.1 Alternative No. 1 – No Action

The “No Action” alternative would be used as the baseline to measure performance of other alternatives. This alternative is required by the NCP. In this alternative, no groundwater remedial systems are to be installed and no LUCs are to be implemented. No non-radiological contaminated soils, located beyond the soils to be removed during the Soils and Buildings OU remedial action, would be remediated and disposed off site. In addition, existing monitoring wells would remain in place. Any improvement of the groundwater quality would be through natural attenuation including biodegradation, adsorption to aquifer material, mineral precipitation outgassing, dispersion, and dilution. Groundwater monitoring would not be conducted; therefore, any improvement or further degradation of water quality would not be documented. The alternative provides a baseline for comparison of risk reduction achieved by each treatment alternative.

4.4.2 Alternative No. 2 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation on the MISS

Alternative No. 2 has been developed to limit public exposure to the contaminated media while demonstrating reduction of contamination by natural processes. MISS non-radiological contaminated soils located beyond the soils to be removed during the Soils and Buildings OU remedial action would be excavated and disposed off site. The toxicity, mobility, or volume of groundwater contaminants would not be reduced by any engineering process. To document that natural attenuation is occurring, a groundwater monitoring program would be implemented at the site. A long-term groundwater monitoring plan would be submitted to the regulatory agencies for review and approval. For this alternative, it is assumed that monitoring would be accomplished by sampling 21 existing, plus 3 newly installed overburden monitoring wells, and 21 existing, plus 3 newly installed shallow bedrock wells. These additional groundwater monitoring wells would be used to fill data gaps related to the up and down gradient extent of the arsenic and benzene plumes as described on pages 7-5 and 7-6 of Section 7.3 (Nature and Extent of Contamination), in the Final GWRI (USACE, 2005b). All remaining site-related groundwater monitoring wells would be proposed to the regulatory agencies for plugging and abandonment. While the actual duration of the groundwater monitoring program included in this alternative would be based on the data results which demonstrate that the impacted groundwater has been treated to RAOs, the monitoring program was assumed for 30 years in accordance with CERCLA guidance procedures for costing purposes, since the duration of arsenic and lithium in the aquifer at concentrations above MCLs or the risk-based action level is uncertain. Initially, the wells would be sampled quarterly for two years. After the two years, the data would be reviewed to determine whether or not the sampling frequency should be reduced or eliminated for specific wells. Additionally, when a well has been in compliance for all COCs for five consecutive sampling periods, it would be proposed to the regulatory agencies that the well should be retired and not sampled further unless there is reason to suspect that it may become non-compliant again. Therefore, beginning in year three, this alternative assumes the monitoring wells would be sampled on an annual basis. Based on modeling estimates, concentrations of benzene in the groundwater are expected to decrease in less than 10 years to less than proposed cleanup levels. Once benzene is no longer present, attenuation rates for arsenic would be expected to increase as aquifer conditions return to the natural oxidative conditions. The groundwater model predicts that lithium contamination would still be present in both the overburden and shallow bedrock aquifers for 280 years. The implementation of well restrictions in a groundwater CEA would control the use of the groundwater until proposed cleanup levels are achieved. The groundwater sampling locations are shown on **Figure 4-1**. The location and number of monitoring wells would be reviewed on an annual basis. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. In consultation with the regulatory agencies, the need for continuing the long-term monitoring at the location would be evaluated based on existing and expected future groundwater conditions. All water quality results, and the results of the review, would be provided in an annual monitoring report.

The implementation of the remedial alternative would be considered complete once non-radiological source soils are removed from the MISS, and groundwater monitoring indicates that FUSRAP COCs are at or below the cleanup levels in all of the MISS and Vicinity Properties groundwater monitoring well sampling locations.

Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA requires that the site be reviewed at least once every five years to ensure the protectiveness of the remedy.

The following actions are incorporated into this alternative. These alternative details were developed for GWFS technical evaluations and costing purposes only. Actual design details of the remedial action to be implemented would be determined for the selected alternative during the design phase that would be implemented after the ROD is approved.

- Excavate MISS non-radiological contaminated soils, including pond sludge on the MISS, and dispose of them off site. All MISS soils above and below the groundwater table, which are contaminated with arsenic, would be removed. These soils, which have concentrations of COCs above the SSL values (i.e., those that would cause groundwater contamination above the regulatory limits listed in **Table 2-2**), would be removed. Soil disposal would comply with Resource Conservation and Recovery Act (RCRA) hazardous waste identification, evaluation, and disposal requirements. The excavation of MISS non-radiologically impacted soil would be conducted as part of the GW OU ROD concurrently with the removal of MISS radiologically impacted soils being remediated under the Soils and Buildings OU ROD. This includes excavation of impacted soils in the area of MISS groundwater AOCs 1, 2, and 5. The conceptual approach to MISS radiological and non-radiological soil excavation is shown on **Figure 4-2**. The volume of non-radiological arsenic and lithium contaminated soil estimated to be excavated from the MISS is 15,600 cubic yards above and 5,400 cubic yards below the groundwater table. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

- Implement appropriate LUCs, such as well restrictions in a groundwater CEA, deed restriction or land use designation to restrict access to groundwater for use as drinking water in areas where arsenic and benzene exceed groundwater cleanup levels. However, well restrictions in a groundwater CEA are preferable over institutional controls and land use designation, since the Federal Government does not own all of the affected property. USACE would request NJDEP establish a CEA in these areas. USACE would submit the information listed in NJAC 7:26E-8.3 to assist NJDEP in establishing a CEA. In the event the State is unable to designate a CEA, USACE would work with local government authorities and affected property owners to develop and implement appropriate LUCs intended to restrict the human consumption and use of groundwater in these areas until such time as the levels of arsenic and benzene no longer exceed cleanup levels in off-site and MISS wells.
- USACE would notify local utilities and governments of the dermal/inhalation risks from site–related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. These actions would be taken in Year 1 and each time a statutory review report is prepared.
- Develop natural attenuation and groundwater monitoring plans for all AOCs.
- Install three additional overburden and three additional shallow bedrock monitoring wells downgradient of MISS groundwater AOCs 1 and 2 (off the MISS and downgradient of the arsenic plume). These wells would be installed during the first year of the program.
- Monitor the COCs and radiological concentrations in groundwater at 24 overburden wells and 24 shallow bedrock wells (upgradient, downgradient, and within the MISS); quarterly for 2 years, then annually for 28 years.
- Initiate groundwater analytical program. Each well located on the MISS or located in areas off of the MISS, but in locations where potential migration of analytes occurs, would be analyzed for benzene, arsenic, and lithium, and documented in the long term monitoring plan. Natural attenuation parameters would be monitored/analyzed, as needed, to monitor the change in aquifer redox conditions that may impact COC degradation, fate and transport. Natural attenuation parameters include pH, Eh, dissolved oxygen, organic carbon, ferric and ferrous iron, manganese, sulfide, sulfate, nitrate/ammonia, and methane. The limited number of wells to be sampled for selected natural attenuation parameters would be addressed in the long term monitoring plan. Depth to groundwater and groundwater elevations would be determined for each well monitored. Analytical data would be validated upon receipt from the laboratory.

- Prepare a Year 2 report with justification for annual monitoring. Additionally, the analytical program would be reevaluated and the list of chemical parameters reduced as COC concentrations decrease below MCLs.
- Prepare annual monitoring reports.
- Complete a statutory review report every five years in accordance with CERCLA requirements.
- Abandon all unused GWRI monitoring wells during the third year of the program (after the Year 2 Monitoring Report is approved).
- Repair/replace monitoring wells, as needed, at an assumed rate of two overburden and two bedrock wells per year for 30 years, and then abandon all wells.

The time frames provided are estimates, based on the results of the groundwater flow and transport model constructed for the site and used to evaluate each of the alternatives. The model results are provided in **Appendix C, Volume 2**. The model predicts that at Year 30, arsenic may still be present in both the overburden and shallow bedrock aquifer if redox conditions do not change, allowing precipitation to occur, which would remove arsenic as a dissolved contaminant from groundwater. Model predictions indicate that the arsenic would persist for more than 3,000 years under current aquifer geochemical conditions. The groundwater model predicts that by Year 30, lithium contamination would still be present in both the overburden and shallow bedrock aquifers. Therefore, 30 years of monitoring are assumed for this alternative. This is the maximum length of time required by CERCLA for use in evaluating alternatives for costing purposes. Due to the length of the monitoring program, well repairs and replacement have been included in this program for costing purposes. Since the arsenic plume may persist for over 30 years, it is likely that monitoring would continue beyond this time frame.

The monitoring wells selected for this program have been chosen to provide groundwater quality data for the FUSRAP COCs and radiological constituents located upgradient, downgradient, and on the MISS. Wells were chosen to show the extent and concentration trends of the major COC plumes (arsenic, benzene and lithium) based on the groundwater flow conditions as illustrated on the groundwater contour maps (**Figures 6-5** and **6-6, Appendix C, Volume 2**) and particle tracking (**Figures 7-1** and **7-2, Appendix C, Volume 2**). Individual wells where concentrations of contaminants exceeded cleanup levels, but are not indicative of a contaminant plume, are also included. The wells selected for monitoring are shown on **Figure 4-1**. All monitoring well data would be evaluated annually, and adjustments to the sampling program, if required, would be recommended at that time. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. The long-term monitoring would continue until concentrations are below action levels. All water quality results and the results of the review would be provided in an annual monitoring report.

The Groundwater BRA indicated a non-cancer health risk for construction and utility workers due to dermal exposure to groundwater contaminants and inhalation of vapors. The risk would be addressed using LUCs, including notification to local utilities and governments, posted warning signs at the MISS, and by project-specific health and safety plans that would identify the risks to construction workers from dermal exposure to site-related groundwater contaminants.

4.4.3 Alternative No. 3 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater, In-Situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS

Alternative No. 3 combines in-situ treatment of groundwater with MISS non-radiological contaminated soils remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action), including pond sludge on the MISS, in addition to LUCs, groundwater monitoring and monitored natural attenuation, as described for Alternative No. 2. **Appendix B** provides a thorough discussion of potential in-situ treatments for the FUSRAP COCs and **Appendix C, Volume 2** provides the model evaluation of the remedial action durations. No one treatment method would address each of the identified MISS contaminants. In fact, some methods that may treat one contaminant in groundwater could cause other contaminant concentrations to increase. Therefore, treatment methods would need to be selected based on the predominant FUSRAP COC plumes, with consideration to the other contaminants present. The method that was selected for in-situ treatment of arsenic in overburden groundwater was redox alteration. It was assumed that a redox altering treatment would be the selected treatment method in AOCs 1 and 2 where arsenic exceeds 3 μg/L in overburden groundwater (**Figure 1-10**). Benzene and arsenic in shallow bedrock would be allowed to attenuate naturally. Lithium cannot be treated in-situ and would also be allowed to naturally attenuate because there are no standard in-situ treatment methods for this contaminant. Treatment areas for the overburden are shown on **Figure 4-3**. This alternative would be moderately complex to implement. In-situ treatment would require a large number of chemical injection points. Additionally, the in-situ treatment chemicals would have to be selected based on other contaminants present in the aquifer and hazardous chemicals would be used on site to treat the contaminated groundwater. In-situ pilot and bench scale studies would have to be performed to determine the appropriate chemicals, required concentrations, and injection volumes to use to treat arsenic without mobilizing metals into groundwater from the aquifer matrix. Optimum aquifer conditions would have to be maintained for in-situ treatment or the arsenic would re-dissolve with subsequent down gradient migration. Maintaining optimum aquifer conditions may require additional chemical injections beyond those assumed in the GWFS.

A groundwater monitoring program would be included to both monitor the performance of the in-situ treatment, and to monitor the constituents which are not addressed in the treatment program. A Long-Term Groundwater Monitoring Plan would be submitted to the regulatory agencies for review and approval. For this alternative, it is assumed that monitoring would be accomplished by sampling 21 existing, plus 3 newly installed overburden monitoring wells, and 21 existing, plus 3 newly installed shallow bedrock wells. These additional groundwater monitoring wells would be used to fill data gaps related to the up and down gradient extent of the arsenic and benzene plumes as described on pages 7-5 and 7-6 of Section 7.3 (Nature and Extent of Contamination), in the Final GWRI (USACE, 2005b). All remaining site-related groundwater monitoring wells would be proposed to the regulatory agencies for plugging and abandonment. The actual duration of the groundwater monitoring program included in this alternative would be based on the data results which demonstrate that the impacted groundwater has been treated to cleanup levels. Initially, the wells would be sampled quarterly for two years. After the two years, the data would be reviewed to determine whether or not the sampling frequency should be reduced to annual sampling. Additionally, when a well has been in compliance for all COCs for five consecutive sampling periods, it would be proposed to the regulatory agencies that the well should be retired and not sampled further unless there is reason to suspect that it may become non-compliant again. Therefore, beginning in Year 3, this alternative assumes the monitoring wells would be sampled on an annual basis. The arsenic overburden plume is estimated to be below 3 μg/L within the first year after treatment. Groundwater modeling estimates indicate that the remaining arsenic located in shallow bedrock is projected to be attenuated in 180 years. Also based on modeling results, the benzene plume is predicted to be attenuated in 7 years in the overburden aquifer and less than 10 years in shallow bedrock. The groundwater model predicts that the lithium contamination would persist in both the overburden and shallow bedrock aquifers for 280 years. The implementation of well restrictions in a groundwater CEA would control the use of the groundwater until proposed cleanup levels are achieved. The groundwater sampling locations are shown on **Figure 4-1**. All monitoring well data would be evaluated annually, and adjustments to the sampling program, if any, would be proposed to regulators at that time. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. The long-term monitoring would continue until concentrations are below cleanup levels. All water quality results and the results of the review would be provided in an annual monitoring report.

The implementation of the remedial alternative would be considered complete once non-radiological source soils are removed from the MISS, and groundwater monitoring indicates that FUSRAP COCs are at, or below, the cleanup levels in all of the MISS and Vicinity Properties groundwater monitoring well sampling locations.

Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA requires that the site be reviewed at least once every five years to ensure the protectiveness of the remedy.

The following actions are incorporated into this alternative. These alternative details were developed for GWFS technical evaluations and costing purposes only. Actual design details of the remedial action to be implemented would be determined for the selected alternative during the design phase that would be implemented after the ROD is approved.

- Excavate MISS non-radiological contaminated soils and dispose of them off site. All MISS soils above and below the groundwater table, which are contaminated with arsenic, would be removed. These soils, which have concentrations of COCs above the SSL values (i.e., those that would cause groundwater contamination above the regulatory limits listed in **Table 2-2**), would be removed. Soil disposal would comply with RCRA hazardous waste identification, evaluation and disposal requirements. The excavation of MISS non-radiologically impacted soil would be conducted as part of the GW OU ROD concurrently with the removal of MISS radiologically impacted soils being remediated under the Soils and Buildings OU ROD. This includes excavation of impacted soils in the area of MISS groundwater AOCs 1, 2, and 5. The conceptual approach to MISS radiological and non-radiological soil excavation is shown on **Figure 4-2**. The volume of non-radiological arsenic and lithium contaminated soil estimated to be excavated from the MISS is 15,600 cubic yards above and 5,400 cubic yards below the groundwater table. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.
- Develop in-situ treatment plan.
- Perform in-situ pilot and bench scale studies to determine the appropriate chemicals, required concentrations, and injection volumes to use to treat arsenic in the overburden without mobilizing metals into groundwater from the aquifer matrix.
- Design in-situ treatment system including injection point layout, work plan, and health and safety plan.
- Perform procurement, utility survey clearance, site preparation, and surveying.
- Prepare construction and completion reports.

- Treat arsenic in and around AOC 1 and 2 (approximately 4.5 acres) in the overburden aquifer using approximately 660 injection points (Regenesis 2005).
- Treat 100 percent of the total area in Year 1, 30 percent of the area in Year 2, and 10 percent of the area in Year 3 (plus additional treatment for any potential rebound in concentrations or incomplete application).
- Treat arsenic using a redox altering compound (to be confirmed with bench scale and pilot testing).
- Implement appropriate LUCs, such as well restrictions in a groundwater CEA, deed restriction, or land use designation to restrict access to groundwater for use as drinking water in areas where arsenic and benzene exceed groundwater cleanup levels. However, well restrictions in a groundwater CEA are preferable over institutional controls and land use designation, since the Federal Government does not own all of the affected property. USACE would request NJDEP establish a CEA in these areas. USACE would submit the information listed in NJAC 7:26E-8.3 to assist NJDEP in establishing a CEA. In the event the State is unable to designate a CEA, USACE would work with local government authorities and affected property owners to develop and implement appropriate LUCs intended to restrict the use of groundwater in these areas until such time as the levels of arsenic and benzene no longer exceed cleanup levels in off-site and MISS wells.
- USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. These actions would be taken in Year 1 and each time a statutory review report is prepared.
- Develop groundwater monitoring plans for all AOCs.
- Install three additional overburden and three additional shallow bedrock monitoring wells downgradient of MISS groundwater AOCs 1 and 2 (off the MISS and downgradient of the arsenic plume) in Year 1.
- Monitor the COCs and radiological concentrations in groundwater at 24 overburden wells and 24 shallow bedrock wells (upgradient, downgradient, and within the MISS); quarterly for two years, then annually for an additional 28 years due to uncertainties in attenuation projections.
- Initiate groundwater analytical program. Each well located on the MISS or located in areas off the MISS, but in locations where potential migration of analytes occurs, would be analyzed for benzene, arsenic, and lithium, and documented in the long term monitoring plan. Additional aquifer parameters would be monitored/analyzed, as needed, to monitor the change in aquifer conditions that may impact COC degradation, fate and transport. These parameters include pH, Eh, dissolved oxygen, organic carbon, ferric and ferrous iron, manganese, sulfide, sulfate, nitrate/ammonia, and methane. The limited number of wells to be sampled for these additional aquifer parameters would be addressed in the long term monitoring plan. Depth to groundwater and groundwater elevations would be determined for each well monitored. Analytical data would be validated upon receipt from the laboratory.
- Prepare a Year 2 report with justification for annual monitoring. Additionally, the analytical program would be reevaluated, and the list of chemical parameters reduced as COC concentrations decrease below MCLs.
- Prepare annual monitoring reports.
- Complete a statutory review report every five years in accordance with CERCLA requirements.

- Abandon all unused GWRI monitoring wells in Year 3 (after approval of the Year 2 Monitoring Report).
- Repair/replace monitoring wells, as needed, at a rate of two overburden and two bedrock wells per year and then abandon all wells at the end of the remedial program.

The time frames provided are based on the results of the geochemical treatment evaluations (**Appendix B**), and the groundwater flow and transport model constructed for the site. For Alternative No. 3, lithium was not modeled, since there are no standard in-situ treatments. The model results for Alternative Nos. 1 and 2 provide the time frames for attenuation of lithium. The model results are provided in **Appendix C, Volume 2**. The model shows that by Year 30, lithium contamination would still be present in both the overburden and shallow bedrock aquifer. Therefore, 30 years of monitoring are assumed for this alternative. This is the maximum length of time required by CERCLA for use in evaluating alternatives for costing purposes. Due to the length of the monitoring program, well repairs and replacement have been included in this program for costing purposes. Since the plumes are expected to persist beyond 30 years, it is likely that monitoring would continue beyond this time frame.

Treatment media would be injected into the aquifer using a series of well points. A redox altering treatment is assumed to be used in the overburden to treat arsenic at AOCs 1 and 2 (**Figure 4-3**). The effectiveness of the treatment is dependent on the rate of spreading and completeness of coverage of the treatment media. Due to the heterogeneity of the aquifer materials, the actual treatment rate and coverage may vary. Therefore, for costing purposes, it is assumed that multiple treatments would be necessary. The frequency of the additional treatments is provided above.

The monitoring wells selected for this program have been chosen to provide groundwater quality data for the FUSRAP COCs and radiological constituents upgradient, downgradient, and on the MISS. The wells were chosen in source areas so that the impacts of in-situ treatment can be determined, and the extent and concentration trends of the major plumes (arsenic and benzene) can be shown based on the groundwater flow conditions as illustrated on the groundwater contour maps (**Figures 6-5** and **6-6, Appendix C, Volume 2**) and particle tracking (**Figures 7-1** and **7-2, Appendix C, Volume 2**). Individual wells, where concentrations of contaminants exceeded cleanup levels, but are not indicative of a contaminant plume, are also included. The wells selected for monitoring are shown on **Figure 4-1**. The location and number of monitoring wells would be reviewed on an annual basis. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. The long-term monitoring would continue until concentrations are at or below action levels. All water quality results and the results of the review would be provided in an annual monitoring report.

The Groundwater BRA indicated a non-cancer health risk for construction and utility workers due to dermal exposure to groundwater contaminants and inhalation of vapors. The risk would be addressed using LUCs, including notification to local utilities and governments, posted warning signs at the MISS, and by project-specific health and safety plans that would identify the risks to construction workers from dermal exposure to site-related groundwater contaminants.

4.4.4 Alternative No. 4 - Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soil Remediation on the MISS

Alternative No. 4 combines groundwater extraction, ex-situ treatment of groundwater; MISS non-radiological contaminated soils remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action), including pond sludge on the MISS; groundwater monitoring (as described for Alternative Nos. 2 and 3); and groundwater discharge. Six recovery wells are assumed in this system based on the combined results of the individual models for the three major plumes (benzene, arsenic, and lithium). The conceptual locations of the extraction wells, conveyance piping, and treatment plant are shown on **Figure 4-4**. The treatment system selected includes an air stripper for VOCs, metals precipitation, reverse osmosis or ion exchange for lithium and carbon to treat any off-gases from the air stripper. The specific components for the treatment system would be determined during the system design.

For Alternative No. 4, groundwater extraction wells would be installed on the MISS as shown on **Figure 4-4**. The well layouts and expected capture zones in relationship to the benzene (AOCs 6 and 7), arsenic (AOCs 1 and 2), and lithium (AOCs 1 and 2) plumes are provided in **Appendix C, Volume 2**, **Figures 8-3A**, **8-3B**, **8-8A**, **8-8B, 8-13A and 8-13B**. Each of the wells would be installed in shallow bedrock on the MISS to an average depth of approximately 50 feet below land surface. This system would be used to provide both mass removal and hydraulic control of contaminant migration. The extraction system in this alternative was assumed to be in operation for a period of more than 30 years. In order to verify its effectiveness in capturing impacted groundwater from all MISS AOCs, the groundwater modeling was performed for a 30 year pumping period. The results of the groundwater modeling estimates are provided in **Appendix C, Volume 2**. The actual duration of pumping would be affected by any aquifer redox alteration that would cause arsenic to be adsorbed and to precipitate and be removed as a dissolved contaminant in groundwater. The estimated groundwater pumping rate is 10 GPM total for the six pumping wells. Individual recovery well pumping rates would vary from 1 to 4 GPM with a design capacity of 5 GPM. Well construction details and final well field layout would be determined during system design. **Figure 4-5** provides the capture zone for the six recovery wells. As shown, impacted groundwater from all MISS AOCs would be captured. Groundwater from off-site AOCs 3 and 4 would not be captured by the groundwater extraction system.

Groundwater extraction wells would be placed to address the arsenic, benzene, and lithium plumes on the MISS. The capture zone of these extraction wells would be designed to minimize the capture/influence of non-FUSRAP chlorinated solvent or other plumes downgradient of the MISS. Long-term pumping on the MISS over time, could impact the downgradient Dixo Company chlorinated solvent plume, potentially spreading the contamination over a larger area of the aquifer, increasing concentrations downgradient of the source area (Dixo Company property), and pulling more of the non-FUSRAP contamination onto the MISS.

It is assumed that recovered groundwater would be routed to a central treatment facility and discharged to the local POTW.

A groundwater monitoring program is included to both monitor the performance of the treatment, and to monitor the natural attenuation of the constituents which are not addressed in the treatment program. A long-term groundwater monitoring plan would be submitted to the regulatory agencies for review and approval. For this alternative, it is assumed that monitoring would be accomplished by sampling 21 existing, plus 3 newly installed overburden monitoring wells, and 21 existing, plus 3 newly installed shallow bedrock wells for a period of 30 years. These additional groundwater monitoring wells would be used to fill data gaps related to the up and down gradient extent of the arsenic, benzene, and lithium plumes as described on pages 7-5 and 7-6 of Section 7.3 (Nature and Extent of Contamination), in the Final GWRI (USACE, 2005b). All remaining site-related groundwater monitoring wells would be proposed to the regulatory agencies for plugging and abandonment. While the actual duration of the groundwater monitoring program included in this alternative would be based on the data results which demonstrate that the impacted groundwater has been treated to cleanup levels, the monitoring program was assumed for costing purposes for 30 years in accordance with CERCLA guidance procedures, since duration of arsenic in the aquifer at concentrations above MCLs is uncertain. Initially, the wells would be sampled quarterly for two years. After the two years, the data would be reviewed to determine whether or not the sampling frequency should be reduced to annual sampling. Additionally, when a well has been in compliance for all COCs for five consecutive sampling periods, it would be proposed to the regulatory agencies that the well should be retired and not sampled further unless there is reason to suspect that it may become non-compliant again. Therefore, beginning in year three, this alternative assumes the monitoring wells would be sampled on an annual basis. Based on modeling estimates, concentrations of benzene in groundwater are expected to decrease in less than eight years to less than proposed cleanup levels. Once benzene is no longer be present, attenuation rates for arsenic would be expected to increase similar to Alternative No. 2 due to the aquifer returning to the natural oxidative state. The implementation of a groundwater CEA would control the use of the groundwater until proposed cleanup levels are achieved. The groundwater sampling locations are shown on **Figure 4-1**. All monitoring well data would be evaluated annually, and adjustments to the sampling program, if any, would be proposed to regulators at that time. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. The need for continuing the long-term monitoring at the location would be evaluated based on existing and expected future groundwater conditions. All water quality results and the results of the review would be provided in an annual monitoring report.

Based on modeling estimates, concentrations of benzene in groundwater are expected to decrease in less than eight years to less than proposed cleanup levels. Model predictions indicate that the arsenic would persist for more than 2,000 years under current aquifer geochemical conditions. Once benzene is removed, attenuation rates for arsenic would be expected to increase similar to Alternative No. 2. The model predicts that lithium contamination would be present in both the overburden and bedrock aquifers for 275 years. The implementation of a groundwater CEA would control the use of the groundwater until proposed cleanup levels are achieved. The groundwater sampling locations are shown on **Figure 4-1**. All monitoring well data would be evaluated annually, and adjustments to the sampling program, if any, would be proposed to regulators at that time. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to construction or other activities, would be replaced or repaired, as needed. The need for continuing the long-term monitoring at the location would be evaluated based on existing and expected future groundwater conditions. All water quality results and the results of the review would be provided in an annual monitoring report.

The implementation of the remedial alternative would be considered complete once non-radiological source soils are removed from the MISS, and groundwater monitoring indicates that FUSRAP COCs are at or below the cleanup levels in all of the MISS and off-MISS groundwater monitoring well sampling locations.

Because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA requires that the site be reviewed at least once every five years to ensure the protectiveness of the remedy.

The following actions are incorporated into this alternative. These alternative details were developed for GWFS technical evaluations and costing purposes only. Actual design details of the remedial action to be implemented would be determined for the selected alternative during the design phase that would be implemented after the ROD is approved.

- Excavate MISS non-radiological contaminated soils and dispose of them off site. All MISS soils above and below the groundwater table, which are contaminated with benzene, arsenic, and lithium would be removed. These soils, which have concentrations of COCs above the SSL values (i.e., those that would cause groundwater contamination above the regulatory limits listed in **Table 2-2**), would be removed. Soil disposal would comply with RCRA hazardous waste identification, evaluation, and disposal requirements. The excavation of MISS non-radiologically impacted soil would be conducted as part of the GW OU ROD concurrently with the removal of MISS radiologically impacted soils being remediated under the Soils and Buildings OU ROD. This includes excavation of impacted soils in the area of MISS groundwater AOCs 1, 2, and 5. The conceptual approach to MISS radiological and non-radiological soil excavation is shown on

Figure 4-2. The volume of non-radiological arsenic and lithium contaminated soil estimated to be excavated from the MISS is 15,600 cubic yards above and 5,400 cubic yards below the groundwater table. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

- Develop groundwater extraction plan including performance of a well field analysis, complete bench scale study, health and safety plan, and procurement.
- Design groundwater extraction and ex-situ treatment system; 10 GPM system with a groundwater capture zone extending from MISS upgradient with a 30-year expected operational period. All treatment systems would be designed to comply with RCRA hazardous waste treatment, storage, and disposal requirements.
- Apply for off-site permits: treatment plant discharge to POTW, construction, utility survey clearance, site preparation, surveying, and system startup.
- Install six groundwater extraction wells in shallow bedrock.
- Install groundwater collection system: 600 feet of double-walled PVC piping from wells to conveyance headers; 1,200 feet of double-walled PVC piping from conveyance headers to treatment plant; 2,500 feet of single-walled PVC piping from treatment plant to POTW.
- Install groundwater treatment process to include: air stripper for VOCs, metals precipitation, reverse osmosis or ion exchange for lithium. Disposition of wastes generated would comply with RCRA hazardous waste identification and disposal requirements.
- Install carbon unit to be used for air stripper off-gas treatment.
- Prepare as-built drawings, construction report, and completion report.
- Treat metals, organics, and radiological constituents in groundwater (FUSRAP COCs and other organic and inorganic constituents present within extraction system capture zone); and VOCs in air stripper off-gas. The maximum flow rate from a single well would be limited to 5 GPM, and operation schedule for 365 days per year, 24 hours per day, 60 minutes per hour. For costing and analysis purposes, it was assumed that the treatment process would not produce a residual low-level radioactive waste.
- Implement appropriate LUCs, such as well restrictions in a groundwater CEA, deed restriction, or land use designation to restrict access to groundwater for use as drinking water in areas where arsenic and benzene exceed groundwater cleanup levels. However, well restrictions in a groundwater CEA are preferable over institutional controls and land use designation, since the Federal Government does not own all of the affected property. USACE would request NJDEP establish a CEA in these areas. USACE would submit the information listed in NJAC 7:26E-8.3 to assist NJDEP in establishing a CEA. In the event the State is unable to designate a CEA, USACE would work with local government authorities and affected property owners to develop and implement appropriate LUCs intended to restrict the use of groundwater in these areas until such time as the levels of arsenic and benzene no longer exceed cleanup levels in off-site and MISS wells.
- USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. These actions would be taken in Year 1 and each time a statutory review report is prepared.

- Develop natural attenuation and groundwater monitoring plan for all AOCs.
- Install three additional overburden and three additional shallow bedrock monitoring wells downgradient of MISS groundwater AOCs 1 and 2 (downgradient and off site of the arsenic plume) in Year 1.
- Monitor the COCs and radiological concentrations in groundwater at 24 overburden wells and 24 shallow bedrock wells (upgradient, downgradient, and within the MISS); quarterly for two years, then annually for 28 years.
- Initiate groundwater analytical program. Each well located on the MISS or located in areas off the MISS, but in locations where potential migration of analytes occurs, would be analyzed for benzene, arsenic, and lithium, and documented in the long term monitoring plan. Natural attenuation parameters would be monitored/analyzed, as needed, to monitor the change in aquifer redox conditions that may impact COC degradation, fate and transport. Natural attenuation parameters include pH, Eh, dissolved oxygen, organic carbon, ferric and ferrous iron, manganese, sulfide, sulfate, nitrate/ammonia, and methane. The limited number of wells to be sampled for selected natural attenuation parameters would be addressed in the long term monitoring plan. Depth to groundwater and groundwater elevations would be determined for each well monitored. Analytical data would be validated upon receipt from the laboratory.
- Prepare a Year 2 report with justification for annual monitoring. Additionally, the analytical program would be reevaluated and the list of chemical parameters reduced as COC concentrations decrease below MCLs.
- Prepare annual monitoring reports.
- Complete a statutory review report every five years in accordance with CERCLA requirements.
- Abandon all unused GWRI monitoring wells in Year 3 (after Year 2 Monitoring Report is approved).
- Repair/replace monitoring wells, as needed, at a rate of two overburden and two bedrock wells per year for 30 years; then abandon all wells.
- Groundwater extraction would continue for 30 years.
- Perform extraction system efficiency review periodically, and install or replace additional extraction wells, as needed.
- Perform extraction system upgrades/maintenance or repairs, as needed.
- Replace wells for extraction optimization or for repairs, according to a schedule of one every five years, including piping and trenching for the conveyance line.
- Replace up to two groundwater extraction pumps every five years of operation in Years 5, 10, 15, 20, and 25.
- Perform well cleaning and maintenance annually.

The time frames provided are estimates, based on the results of the groundwater flow and transport model constructed for the site and used to evaluate the alternatives. The model results are provided in **Appendix C, Volume 2**. The model predicts that by Year 30, arsenic may still be present in both the overburden and shallow bedrock aquifers if redox conditions do not change causing dissolved arsenic to be adsorbed and precipitate and no longer be present in the groundwater. Additionally, the modeling predicts that the groundwater pumping also has the potential for increasing the arsenic concentrations in shallow bedrock by pulling contamination downward from the overburden source materials. The model also predicts that by year 30, lithium contamination would still be present in both the overburden and bedrock aquifers. Therefore, 30 years of monitoring was assumed for this alternative. This is the maximum length of time required by CERCLA for use in evaluating alternatives for costing purposes.

The 30 year technical analysis and cost evaluations were presented in the FS for consistency between alternatives. Groundwater pumping beyond 30 years is not warranted, since the groundwater modeling results indicate that groundwater extraction (for a 30 year period) does not significantly reduce the arsenic and lithium cleanup times as compared to the no action and natural attenuation options. Using the 30 year evaluation period provides groundwater extraction costs that are over three times the cost of the natural attenuation alternative and two times the in-situ treatment alternatives. Extending the technical evaluations beyond 30 years would significantly increase the costs of the groundwater extraction alternative. The monitoring wells selected for this program have been chosen to provide groundwater quality data for the FUSRAP COCs and radiological constituents upgradient, downgradient, and on the MISS. The wells were chosen in source areas so that the impacts of ex-situ treatment can be determined, and the extent and concentration trends of the major plumes (arsenic, benzene, and lithium) can be shown based on the groundwater flow conditions as illustrated on the groundwater contour maps (**Figures 6-5** and **6-6, Appendix C, Volume 2**) and particle tracking (**Figures 7-1** and **7-2, Appendix C, Volume 2**). Individual wells, where concentrations of contaminants exceeded cleanup levels, but are not indicative of a contaminant plume, are also included. The wells selected for monitoring are shown on **Figure 4-1**. All monitoring well data would be evaluated annually, and adjustments to the sampling program, if required, would be recommended at that time. Any well that is proposed for long-term monitoring that becomes damaged, or is required to be removed due to remedial action or other activities, would be replaced or repaired, as needed. The long-term monitoring would continue until concentrations are below cleanup levels. All water quality results and the results of the review would be provided in an annual monitoring report. Due to the length of the monitoring program, well repairs and replacement have been included in this program for costing purposes. Since the arsenic plume may still be present for over 30 years, it is likely that monitoring would continue beyond this time frame.

The Groundwater BRA indicated a non-cancer health risk for construction and utility workers due to exposure by dermal contact to groundwater contaminants and inhalation of vapors. The risk would be addressed using LUCs, including posted warning signs at the MISS and by project-specific health and safety plans that would identify the risks to construction workers from dermal exposure to site-related groundwater contaminants.

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5.0 DETAILED EVALUATION OF ALTERNATIVES

5.1 CRITERIA FOR EVALUATION OF ALTERNATIVES

A summary of the nine criteria used to evaluate the selected remedial alternatives is presented in this section. The criteria are addressed in this report as directed in *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988a). These criteria are divided into the following three groups:

- Threshold Criteria:
  - Overall protection of human health and the environment
  - Compliance with ARARs
- Primary Balancing Criteria:
  - Short-term effectiveness
  - Long-term effectiveness and permanence
  - Reduction in toxicity, mobility, or volume
  - Implementability
  - Cost
- Modifying Considerations:
  - State acceptance
  - Community acceptance

The above criteria are discussed in more detail in the following sections.

5.1.1 Overall Protection of Human Health and the Environment

This criterion focuses on a final assessment of each alternative with respect to the adequate protection of human health and the environment. Evaluation of protectiveness will focus on all affected media. The evaluation includes descriptions of how each pathway addressed by this GWFS is eliminated, reduced, or controlled through treatment, engineering, or administrative action.

5.1.2 Compliance with ARARs

This criterion evaluates each alternative for compliance with the chemical-, location-, and action-specific ARARs.

5.1.3 Short-Term Effectiveness

The short-term effectiveness criterion is used to evaluate the short-term effects of the remedial action on the environment, remediation workers, and the community during the construction and implementation phase of the project, and is pertinent until the project levels are met. This criterion also includes an assessment of the relative time frame required for the remedial action to achieve protection.

5.1.4 Long-Term Effectiveness and Performance

This criterion addresses the results of a remedial action in terms of the risks remaining at the site after conclusion of the remediation. The extent, effectiveness, adequacy, and reliability of the controls, as well as the magnitude of the residual risk, are some of the components of this criterion against which the alternatives are evaluated. The purpose is to determine if the alternative offers adequate management of the risk posed by the treatment of residual and/or untreated waste.

The adequacy and reliability of controls is determined by assessing whether technologies meet the process efficiencies or performance specifications; what type and degree of long-term management and monitoring are required; and what uncertainties are associated with land disposal of residuals and untreated wastes.

5.1.5 Reduction in Toxicity, Mobility, or Volume

This criterion addresses the preference for selecting remedial alternatives that employ treatment technologies that permanently and significantly reduce the toxicity, mobility, or volume of the impacted media on site. The major factors to be considered during evaluation of a particular remedial alternative are as follows:

- Principal threats addressed by employing the treatment process
- Special requirements for the treatment process
- Percent of contaminated material affected by the treatment process (volume or mass)
- Extent of contaminant reduction
- Extent of reduction in contaminant mobility
- Extent of volume reduction
- Extent of irreversible treatment effects
- Quantities, characteristics, and types of residuals
- Risks associated with treatment residuals
- Degree to which the alternative satisfies the statutory preference for treatment on site as a principal element.

5.1.6 Implementability

This criterion addresses three factors that affect the proper implementation of the alternatives. These factors are the technical and administrative feasibility of implementing the alternatives and the availability of various services and materials, equipment, and prospective technologies for carrying out the remedial alternatives.

- Technical feasibility includes the following aspects:
  - Technical difficulties or unknowns associated with construction and remedial action.
  - Reliability of the technology and the likelihood of the implementation schedule being delayed due to technical problems.
  - The ability to monitor the effectiveness of the remedial action and the risks of exposure in case the periodic monitoring of groundwater, surface water, and sediment is insufficient to detect a system failure.

- Administrative feasibility addresses the need for coordination of activities with other offices and agencies and property owners that may include obtaining permits or rights-of-way for construction.
- Availability of services and materials addresses the following items:
    - Availability of adequate off-site treatment, storage capacity, and disposal facilities.
    - Availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources.
    - Availability of services and materials in addition to the potential for obtaining competitive bids, which may be particularly important for innovative technologies.
    - Availability of prospective technologies.

5.1.7 Cost

The cost criterion addresses capital costs (direct and indirect), annual O&M costs, accuracy of cost estimates, present worth, and cost sensitivity analyses as they relate to the implementation of the remedial alternative.

- Direct Capital Costs – Initial construction costs, equipment costs, cost of land acquisition, etc.
- Indirect Capital Costs – Engineering costs, start-up costs, contingencies, etc.
- Annual O&M Costs – Post-construction costs necessary to maintain the site in accordance with the NJDEP post-closure regulations. Examples include: labor, material, and utility costs to operate and maintain any treatment facility and the cost for disposition of treatment residues. Annual O&M costs also include costs of construction for ongoing projects that may take several years to fully implement (e.g., multi-year major excavation with processing operations).
- Accuracy of Cost Estimates – The remediation costs presented in this FS are for planning and comparative purposes only, and are accurate to the required level of CERCLA accuracy plus 50 percent to minus 30 percent.
- Present Worth Analysis – Present worth analysis is used to evaluate expenditures occurring over periods of time in the future and discount them to a common base year, so all alternatives are compared on the same basis. Thirty year present worth was calculated based on a four percent annual discount rate.
- Cost Sensitivity Analysis – The cost sensitivity analysis is usually performed after the present worth analysis is concluded. The purpose of this analysis is to evaluate the uncertainties concerning specific assumptions made during the detailed analysis of the alternative.

5.1.8 State Acceptance

This criterion evaluates the technical and administrative issues and concerns the State regulators may have regarding each of the alternatives. This criterion will be addressed in the ROD after comments on this GWFS and the Proposed Plan have been received and evaluated.

5.1.9 Community Acceptance

This evaluation criterion addresses issues and concerns the public may have concerning the recommended alternatives. This assessment will be addressed in the ROD once the public comments on the GWFS and Proposed Plan are received and evaluated.

5.2 DETAILED EVALUATION OF ALTERNATIVES

The following sections present detailed analysis of the four proposed alternatives. The evaluation is summarized in **Table 5-1**. Cost summaries are provided in this section. Detailed costs are included in **Appendix D**.

As a part of this GWFS, a groundwater fate and transport model was constructed. There are uncertainties in modeling results that should be considered best estimates. The model has been used as a tool to evaluate the effectiveness of each of the alternatives. Geochemical evaluations of the FUSRAP COCs, and other organic and inorganic constituents present in the aquifer were performed for model input parameters and in-situ treatment. These evaluations are presented in **Appendix B**. The model assumptions and results are provided in detail in **Appendix C, Volume 2**. For the transport model used in this detailed evaluation:

- Solute transport models were created to evaluate the following feasibility study scenarios.
    1. No action
    2. Natural attenuation
    3. Groundwater extraction
    4. In-situ treatment using enhanced bioremediation and redox alteration (if applicable).
- Arsenic, benzene, and lithium were evaluated by transport modeling. Other volatile organic, metals, and radiological constituents present in MISS groundwater (**Table 1-1**) were not modeled, but were considered during the evaluation of the alternatives. The radionuclides gross alpha and gross beta were not modeled, since they closely follow the movement of total uranium and potassium isotope K-40. Potassium was not identified as a COPC for the FMSS during the GWRI, and therefore, was not modeled.
- Initial concentrations (year zero) for solute transport modeling and/or analytical analysis are based on data presented in the GWRI collected between 2000 and 2002. It was assumed that AOC soil sources were removed prior to implementation of the feasibility study scenarios.

The results of the model alternative analysis are summarized, where applicable, in this detailed evaluation.

5.2.1 Alternative No. 1 – No Action

In this alternative, no groundwater remedial systems would be installed or operated, and no LUCs would be used. Groundwater non-radiological contamination source soils (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) would not be remediated. Exposure to COCs at unacceptable levels identified in the BRA would not be eliminated in the foreseeable future through natural attenuation since the contaminated soils, which contribute to groundwater contamination, would not be remediated. Additionally, no contamination would be mitigated or controlled in this alternative. Any long term improvement of the groundwater quality would be through natural attenuation of the contaminants by biodegradation, adsorption to aquifer material, outgassing, dispersion, and dilution. Groundwater monitoring would not be conducted.

<u>Overall Protection of Human Health and the Environment</u>

This alternative would not be effective in protecting human health and the environment. It would be ineffective in abating migration of contamination in MISS groundwater. It would provide no administrative system to control the use of impacted groundwater or monitor impacts to determine where they have occurred. Non-radiological contaminated soils would remain in place.

TABLE 5-1

SUMMARY OF DETAILED EVALUATION OF ALTERNATIVES

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity, Mobility, and Volume	Implementability	Cost	State Acceptance	Community Acceptance
1. No Action.	Current impacts to groundwater would remain unmitigated. Any improvements would be through natural processes. There are no administrative or institutional measures to control the use or exposure to groundwater or monitor contaminant concentrations.	Would not comply with chemical-specific applicable or relevant and appropriate requirements (ARARs); contamination in groundwater.	No increased risks to workers or public, since no activities are conducted. However, a reduction of contamination and achievement of site protection would not occur.	No long-term effectiveness. Contaminated groundwater would continue uncontrolled and unmonitored. Non-radiological contaminated soils would remain in place.	No reduction in toxicity, mobility, or volume of contaminants in groundwater. Only radiological contaminated source soils are removed under the Soils and Buildings ROD. Impacts of the soil removal are not monitored.	Does not require any implementation.	No costs associated with this alternative	State acceptance would be addressed in the ROD once all comments have been received.	Community acceptance would be addressed in the ROD once all comments have been received.
2. Use Restrictions, Groundwater Monitoring, MNA of Lithium Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation.	Potential human exposure controlled by MISS non-radiological contaminated soil remediation and enforcement of well restrictions in a groundwater CEA. Construction workers would be notified of the groundwater dermal/inhalation exposure risk. Groundwater quality monitored to determine if contaminant plume is changing in concentration and location. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.	Lithium concentration would not meet cleanup goals within 30 years and groundwater contaminated with lithium would continue to migrate downgradient of the MISS. The groundwater model predicts lithium concentrations would increase off site and contamination could reach the Saddle River in more than 100 years. However, due to mixing with surface water, there should be no impact above cleanup goals. Groundwater modeling results indicate that the arsenic will persist in the aquifers for more than 3,000 years under current geochemical conditions. However, it is expected that arsenic concentrations in groundwater would decrease after the benzene attenuates (estimated at less than 10 years) and aquifer redox conditions change. Arsenic is not projected to reach the Saddle River, even under the extended attenuation time frame.	Moderate risk to remedial workers during installation of monitoring wells and non-radiological contaminated soil remediation. Low risk during monitoring. No risk to community. Implementation of LUCs and removal of non-radiological soil would achieve site protection and reduce contamination within three years of the GW OU ROD.	Based on modeling estimates, concentrations of benzene in groundwater would decrease in less than 10 years to less than proposed cleanup levels. Arsenic may be mobile in benzene impacted aquifer areas due to groundwater reducing conditions. Once benzene would no longer be present, attenuation rates for arsenic would be expected to increase. The groundwater model predicts that lithium could take 280 years to reach ARARs. The implementation of well restrictions in a groundwater CEA would control the use of groundwater.	No reduction in toxicity, mobility, or volume of contaminants through treatment of soils or groundwater. Reduction occurs naturally through biodegradation, dispersion, and sorption. Groundwater concentrations would be monitored to confirm natural attenuation processes.	Straightforward to implement. Soil remediation, well installation, monitoring, and LUCs are well documented technologies. Well restrictions in a groundwater CEA would be straightforward due to the small number of off-site, adjacent properties. Groundwater portion of the alternative could be constructed within 2 to 4 months. Non-radiological contaminated soil remediation would take approximately one year.	Capital Costs: $10,332,000 O&M: $20,122,000 Total: $30,454,000 (Present Worth)	State acceptance would be addressed in the ROD once all comments have been received.	Community acceptance would be addressed in the ROD once all comments have been received.
3. Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Bedrock Groundwater, In-situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation.	Potential human exposure controlled by MISS non-radiological contaminated soil remediation and enforcement of well restrictions in a groundwater CEA. Construction workers would be notified of the groundwater dermal/inhalation exposure risk. The arsenic in overburden groundwater would be attenuated in less than one year Hazardous chemicals would be used on-site to treat arsenic in overburden groundwater. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer, if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.	Lithium concentrations would not meet cleanup goals within 30 years and groundwater contaminated with lithium would continue to migrate downgradient of the MISS. The groundwater model predicts concentrations would increase off site and contamination could reach the Saddle River in more than 100 years. However, due to mixing with surface water, there should be no impact above cleanup goals. Treatment of arsenic in overburden groundwater would meet ARARs for these constituents by providing contaminant mass removal in the site areas of highest concentrations. It is expected that benzene would naturally attenuated in less than 10 years and arsenic in shallow bedrock in approximately 180 years or less (after the benzene degrades and aquifer redox conditions change).	Moderate risk to remedial workers during implementation due to non-radiological contaminated soil remediation, and handling and injection of chemicals and performance of tasks. Low risk to community from chemicals handled off site at injection locations. Implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.	Based on modeling estimates, concentrations of benzene in groundwater would decrease in less than 10 years to less than proposed cleanup levels. Arsenic in overburden in groundwater would decrease below proposed cleanup levels in less than one year after treatment and approximately 180 years in shallow bedrock. A concern with in-situ treatment proposed under Alternative No. 3 would be the complexities involved regarding the large number of chemical injection points, the determination of appropriate chemicals to use, and required chemical concentrations and injection volumes to treat the arsenic without mobilizing metals into groundwater from the aquifer matrix. Lithium, which cannot be treated in-situ, could take 280 years to attenuate below proposed cleanup goals. The implementation of well restrictions in a groundwater CEA would control the use of groundwater. Success of the arsenic concentration decrease is dependent on maintaining optimum aquifer geochemical conditions, which may require occasional pretreatment of groundwater.	Would reduce mobility and volume in groundwater of contaminants in arsenic plumes. Would not reduce the toxicity and volume of the benzene and lithium. Groundwater concentrations would be monitored to confirm natural attenuation processes.	Moderately complex to implement in-situ treatment; a large number of chemical injection points would be required. Variable local permeabilities would impact delivery of treatment medium. Straightforward to implement soil remediation, monitoring well installation, monitoring, and LUCs which are well documented. Well restrictions in a groundwater CEA would be straightforward due to the small number of off-site, adjacent properties. Groundwater technologies could be constructed within 6 to 12 months. Non-radiological contaminated soil remediation would take approximately one year.	Capital Costs: 14,482,000 O&M: $21,447,000 Total: $35,929,000 (Present Worth)	State acceptance would be addressed in the ROD once all comments have been received.	Community acceptance would be addressed in the ROD once all comments have been received.

TABLE 5-1 (Continued)

SUMMARY OF DETIALED EVLAUATION OF ALTERNATIVES

Alternative	Overall Protection of Human Health and the Environment	Compliance with ARARs	Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity, Mobility, and Volume	Implementability	Cost	State Acceptance	Community Acceptance
4. Use Restrictions, Groundwater Monitoring, Groundwater Recovery, Ex Situ Treatment, and Non-Radiological Contaminated Soil Remediation	Potential human exposure controlled by MISS non-radiological contaminated soil remediation and enforcement of well restrictions in a groundwater CEA. Construction workers would be notified of the groundwater dermal/inhalation exposure risk. Benzene reaches concentrations below cleanup levels in less than eight years; the arsenic plume may then attenuate as aquifer redox conditions change to allow precipitation or the dissolved contaminant. The lithium plume would continue to migrate after pumping is discontinued. Hazardous chemicals would be used on-site to treat the contaminated groundwater. USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.	Extraction of groundwater provides contaminant mass removal, as well as hydraulic control for further off-site migration, except in the case of lithium which would continue to migrate off site when pumping is discontinued at Year 30. Alternative would comply with benzene ARARs within a reasonable period of time, eight years. Extraction of groundwater provides contaminant mass removal, as well as hydraulic control for further off site migration of the benzene and plumes. Lithium cleanup time is not appreciably shortened over natural attenuation. Arsenic is calculated to remain in the aquifer under current geochemical conditions for more than 2,000 years.	Moderate risk to remedial workers during implementation due to non-radiological contaminated soil remediation, and installation of wells. No risk to community and the environment. Implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.	Based on modeling estimates, concentrations of benzene in groundwater would decrease in less than eight years to less than proposed cleanup levels. Arsenic is expected to attenuate after the benzene is removed from the aquifer. After Year 30, lithium is predicted to reach proposed cleanup goals in 275 years. A concern with the active pump and treat technology proposed under Alternative No. 4 would be the potential to draw off-site non-FUSRAP related contamination into the extraction system. Long-term pumping on the MISS over time, could impact the downgradient Dixo Company chlorinated solvent plume, potentially spreading the contamination over a larger area of the aquifer, increasing concentrations downgradient of the source area (Dixo Company property), and pulling more of the non-FUSRAP contamination onto the MISS. The implementation of well restrictions in a groundwater CEA would control the use of groundwater.	Would reduce mobility and volume in groundwater. Would also reduce toxicity, volume, and mobility from source areas. Stabilizes the lithium plume during pumping, but once extraction is discontinued, the lithium plume is still predicted to reach the Saddle River.	Straightforward. Consists of soil remediation, installation of recovery wells, monitoring, construction of treatment plant, and LUCs that are well documented technologies. However, the selection of the locations for recovery wells may be complicated by the need for the well to intercept continuous fracture zones in bedrock. Well restrictions in a groundwater CEA would be straightforward due to the small number of off-site, adjacent properties. Groundwater portion of the Alternative could be constructed within 9 to 12 months. Non-radiological contaminated soil remediation would take approximately one year.	Capital Costs: $12,936,000 O&M: $109,266,000 Total: $122,202,000 (Present Worth)	State acceptance would be addressed in the ROD once all comments have been received.	Community acceptance would be addressed in the ROD once all comments have been received.

Compliance with ARARs

The alternative would not meet ARARs. There would be no protection of potential receptors or mitigation of contamination. It would not meet the RAOs.

Short-Term Effectiveness

Since there is no remediation or treatment being implemented, there would be no associated short-term increase in potential risk to site workers. However, a reduction of contamination and achievement of site protection would not occur under this alternative.

Long-Term Effectiveness and Permanence

This remedy would not achieve long-term effectiveness or permanence. Non-radiological contaminated soils would remain in place. Impacts to groundwater continue, and may increase. The remedy would not meet the RAOs for the MISS. There would be no protection of potential receptors through contaminant containment, removal, or treatment. Impacted groundwater would continue to migrate off site, and would not be contained or monitored. In addition, no use restrictions would be in place to prevent long-term exposure to contaminated groundwater.

Reduction in Toxicity, Mobility, or Volume

This evaluation criterion refers to a reduction in toxicity, mobility, or volume through recovery or treatment. There is no treatment, so the statutory preference for treatment is not a component of the remedy. This remedy would fail to control continued migration to the off-site groundwater. There would be no reduction in toxicity or volume. Mobility of contaminants would be unaffected. The volume of impacted media would be unaffected under this alternative.

Implementability

There would be no technology or engineering controls to implement under this alternative. There would be no services required, no permits to obtain, no administrative approvals, and no resources involved.

Cost

There would be no costs associated with this alternative.

State Acceptance

State acceptance would be addressed in the GW OU ROD once all comments have been received.

Community Acceptance

Community acceptance would be addressed in the GW OU ROD once all comments have been received.

5.2.2 Alternative No. 2 – Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation on the MISS

This alternative would consist of well restrictions in a groundwater CEA where groundwater contamination above proposed cleanup levels has been identified; construction worker warnings regarding dermal and inhalation exposure; groundwater monitoring, including natural attenuation parameters; reporting;

maintenance of the monitoring well system; and non-radiological contaminated soil remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action). This alternative was developed to limit public exposure to contaminated groundwater. A detailed description of this alternative is provided in **Section 4.4.2**. Monitoring locations are provided on **Figure 4-1**. For costing purposes, the estimated period of operation for this alternative is more than 30 years (model estimated 280 years to achieve RAOs for lithium plume). The duration is expected to be less as aquifer geochemical conditions return to normal after the benzene degrades causing arsenic to become less mobile and concentrations to decrease. Metals, volatile organics, and natural attenuation parameter analyses would be conducted during the estimated 30-year period to monitor the change in aquifer conditions and chemical constituent concentrations. Additionally, because this alternative would result in contaminants remaining on the MISS above proposed cleanup levels, CERCLA requires that the site be reviewed at least once every five years.

Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure would be controlled by the MISS non-radiological contaminated soil remediation to include pond sludge on the MISS, implementation of well restrictions in a groundwater CEA, and construction worker notification. The exception area provides an institutional control through a notice that there is groundwater pollution in an area. It also gives the State the authority to restrict the installation of wells and the use of groundwater in the exception area. Aquifer redox conditions are expected to change after the benzene is removed from the aquifer allowing adsorption and mineral precipitation of arsenic and the removal from the groundwater. Monitoring of groundwater would be performed to document the extent and levels of contamination within the exception area, and to verify that the contamination does not migrate beyond the area. Natural attenuation parameters would be collected to document the conditions for natural degradation. USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. These actions would be taken in Year 1 and each time a statutory review report is prepared. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

Compliance with ARARs

Soil remediation would meet ARARs for these constituents by providing contaminant mass removal in the on-site areas of highest concentrations.

Concentrations of COCs would decrease through time. Time frames for specific contaminants to achieve ARARs are discussed in more detail under long-term effectiveness.

Short-Term Effectiveness

Since the implementation of this alternative would involve soil remediation, and the drilling and installation of monitoring wells, there would be risk to on-site workers commensurate with these types of activities. There would be additional risk to the public associated with the off-site transportation, and to disposal operation workers from the non-radiological soils to be excavated under this alternative. There may also be short term impacts to the environment from the soils excavation and handling. There would be a low risk to the workers during groundwater sampling activities. Since only sampling activities would occur off site, there would be low risk to the community, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and transported to the site for proper disposal, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

Implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.

Long-Term Effectiveness and Permanence

This alternative would include active remediation for non-radiological contaminated soils, to include pond sludge on the MISS. The removal of contamination source soils would be permanent and highly effective in the long term for reducing groundwater contamination. Additionally, the alternative would provide a passive remediation system which would monitor groundwater quality, and natural attenuation parameters to document the natural attenuation of contaminants through degradation, retardation, dispersion, adsorption and mineral precipitation; groundwater use would be controlled using a well restriction in a groundwater CEA. The effectiveness of the natural attenuation of groundwater was evaluated (estimated) using the groundwater flow and transport model provided in **Appendix C, Volume 2**. The long term effectiveness for the FUSRAP COCs and non-FUSRAP constituents is summarized below. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

Lithium: Lithium is located in both the overburden and shallow bedrock groundwater and exceeds the risk-based action level of 730 µg/L in 30 wells. Specific monitoring wells with 2000 to 2002 lithium concentrations above the proposed cleanup goal are provided in **Table 1-1**. As shown on **Figures 5-1A** and **5-2A,** lithium is present both on and downgradient of the MISS. These figures show the current conditions used for input into the groundwater model. The distribution of lithium projected into the future was modeled at 5-year intervals as presented in **Appendix C, Volume 2**. The year 30 results for the overburden and bedrock groundwater are provided on **Figures 5-1B and 5-2B**, respectively. The results show that on-site lithium concentrations would decrease in 30 years; however, they would remain an order of magnitude above proposed cleanup goals. The model predicts that the downgradient lithium concentrations would increase with time as lithium is transported from former source areas on the MISS. Based on the model, it would take more than 100 years for lithium to reach the Saddle River at concentrations in groundwater at the proposed cleanup goal. However, due to mixing with surface water, there should not be an impact to surface water. Based on the model results, it would take approximately 280 years for concentrations in groundwater to attenuate to levels below the proposed cleanup goal. Lithium does not degrade; therefore, reductions in concentration are primarily due to dispersion of the contaminant plume.

Benzene: Benzene is located in both the overburden and shallow bedrock groundwater, and exceeds the proposed cleanup level (1 µg/L) in 15 wells. Specific monitoring wells above the proposed cleanup level are provided in **Table 1-1**. The location of the benzene plume is shown on **Figures 5-3A** and **5-4A**. These figures show the current conditions used for input into the groundwater model. The distribution of benzene projected in the overburden groundwater was modeled into the future at Years 2, 4, and 6 as presented in **Appendix C, Volume 2**. The distribution of benzene projected in the shallow bedrock groundwater was modeled into the future at Years 2, 4, 6, and 9 as presented in **Appendix C, Volume 2**. An assumed biodegradation half-life of one year was used. The Year 6 results for the overburden, and Year 9 results for the bedrock groundwater, are provided on **Figures 5-3B** and **5-4B**, respectively. These results show that benzene concentrations are projected to attenuate to below the proposed cleanup level in less than 7 years in the overburden groundwater and less than 10 years in shallow bedrock groundwater. During this time, all of the mass is removed by biodegradation; there is no migration off site and no loss of mass to surface water.

Arsenic: Arsenic is located in both the overburden and shallow bedrock groundwater, and exceeds the proposed cleanup level (3 µg/L) in 10 wells. Specific monitoring wells above the proposed cleanup level are provided in **Table 1-1**. As shown on **Figures 5-5A** and **5-6A**, arsenic is present only at on-site monitoring locations in the overburden groundwater at the MISS; however, it is projected both on and off site in shallow bedrock groundwater. These figures show the current conditions used for input into the groundwater model. The distribution of arsenic concentrations projected into the future was modeled at 5-year intervals as presented in **Appendix C, Volume 2**. The Year 30 results for the overburden and shallow bedrock groundwater are provided on **Figures 5-5B** and **5-6B**, respectively. These results show that in 30 years the on-site concentrations have decreased; however, arsenic contamination is still present at approximately two orders of magnitude above the proposed cleanup levels. Very little migration of the contaminant plume has occurred. Based on the model results, it would take more than 3,000 years for concentrations in groundwater to attenuate to levels below the proposed cleanup level. The model-projected long duration is due to low groundwater velocities and high adsorption coefficients (**Table 8-1, Appendix C, Volume 2**).

The modeling assumption was that arsenic attenuation is due to equilibrium controlled adsorption/desorption reactions and dispersion, not redox reactions, and may not be appropriate for the MISS groundwater. It is believed that arsenic mobility on the MISS may be enhanced by benzene groundwater contamination and the resultant reduced aquifer conditions (**Appendix B**). Background groundwater conditions in the overburden layers at FMSS are oxidizing, and are oxidizing to mildly reducing in the bedrock units. However, within the benzene-impacted areas, redox conditions are strongly reducing, as evidenced by low to non-detectable dissolved oxygen; negative ORP measurements; conversion of nitrate to ammonia; and measurable dissolved iron, manganese, and methane. In addition, a large percentage of groundwater samples from monitoring wells located within the benzene plume had low but detectable concentrations of sulfide, indicating the presence of active sulfate-reducing anaerobes. Sulfate reduction only occurs under highly reducing conditions. Once the benzene plume is no longer present, and redox conditions become more oxidizing similar to background aquifer conditions, the natural attenuation rate of arsenic would be expected to increase. Therefore, it would be expected that arsenic would reach the proposed cleanup level quicker than the times predicted above. Groundwater use would be controlled using a well restriction in a groundwater CEA until the concentrations of arsenic decrease to the proposed cleanup level. A geochemical study prior to the implementation of this alternative would be used to further evaluate the behavior of arsenic under predicted site conditions.

Reduction in Toxicity, Mobility, or Volume

The volume of contamination would be reduced from the site by the removal of non-radiological contaminated soil. Future groundwater contamination volume and mobility would also be reduced by the soil removal. There is no active recovery or treatment for groundwater, so the statutory preference for treatment is not a component of the remedy. There is no reduction in toxicity or volume through treatment. Mobility of contaminants is unaffected by treatment. The volume of impacted media is unaffected by treatment under this alternative, except for that which occurs naturally through biodegradation, dispersion, and sorption as discussed in the *Groundwater Model Report* **Appendix C, Volume 2**.

Implementability

This alternative would be straightforward to implement. The construction activities would involve soil remediation, the installation and maintenance of additional monitoring wells, and well abandonment. All other activities are related to sampling. Soil excavation, well abandonment, installation, and sampling are well known technologies. Services and materials would be readily available to abandon and install the wells and perform regular monitoring. Maintenance and care for the monitoring wells would need to be provided. Implementation of well restrictions in a groundwater CEA would involve a small number of off-site, adjacent properties. The groundwater portion of the alternative, including preparation of the design and installation of the monitoring wells, would be implemented in two to four months. Non-radiological contaminated soils remediation would take approximately three years to complete.

Cost

Detailed costs are shown in **Appendix D, Tables 4** and **5**. Capital costs for this alternative are estimated to be $10,332,000. The present worth costs for lifetime O&M, assuming 30 years, is estimated at $20,122,000. The total present worth cost for this alternative is estimated at $30,454,000. Of this amount, $20,301,700 is estimated for non-radiological (benzene, arsenic, and lithium) soil excavation and disposal.

State Acceptance

State acceptance would be addressed in the GW OU ROD once all comments have been received.

Community Acceptance

Community acceptance would be addressed in the GW OU ROD once all comments have been received.

5.2.3 Alternative No. 3 – Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater, In-Situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS

For this alternative, non-radiological contaminated soil remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) and in-situ treatment of groundwater are combined with LUCs, groundwater monitoring, and MNA as described for Alternative No. 2. The proposed treatment technologies would use a redox altering treatment in areas where arsenic is above the proposed cleanup levels in overburden groundwater. Benzene and arsenic in shallow bedrock would not be treated and would be allowed to attenuate naturally as described in Alternative No. 2. There is no suitable or cost-effective method to treat lithium in-situ. Treatment areas for the overburden are shown on **Figure 4-3**. The estimated period of operation for this alternative is more than 30 years; however, a time frame of 30 years has been used for costing purposes.

Overall Protection of Human Health and the Environment

Under this alternative, potential human exposure would be controlled by the MISS non-radiological contaminated soil remediation, to include pond sludge on the MISS, implementation of well restrictions in a groundwater CEA, and construction worker notification. The exception area provides an institutional control by providing notice that there is groundwater pollution in an area. It also gives the State the authority to restrict the installation of wells and the use of groundwater in the exception area. Through the use of in-situ treatment, the arsenic plume in the overburden would be reduced to less than the proposed cleanup levels in a few years. Arsenic in shallow bedrock would naturally attenuate in approximately 180 years. Benzene would attenuate in less than 10 years. Monitoring of groundwater would be performed to document the performance of in-situ treatment, extent and levels of contamination within the exception area, and to verify the contamination does not migrate beyond the area. Natural attenuation parameters would be collected to document the conditions for natural degradation for those parameters which are not treated. USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

Hazardous chemicals would be used on site to treat the contaminated groundwater.

Compliance with ARARs

Soil remediation and treatment of arsenic in groundwater would meet ARARs for these constituents by providing contaminant mass removal in the on-site areas of highest concentrations. Based on the groundwater modeling evaluations, concentrations of COCs would decrease through time. In-situ treatment of lithium is not proposed, since there are no suitable or cost-effective treatment methods. Time frames for specific contaminants would be discussed in more detail under long-term effectiveness.

Short-Term Effectiveness

Since the implementation of this alternative would include non-radiological contaminated soil remediation, installation of injection points, and handling of chemicals for in-situ treatment, there would be risks to the construction worker consistent with these types of activities. There would be risks to the public associated with the off-site transportation, and to disposal operation workers from the non-radiological soils to be excavated under this alternative. There may also be short term impacts to the environment from the soils excavation and handling. Drilling and installation of monitoring wells would result in additional risk to the on-site workers commensurate with these types of activities. There would be a low risk to the workers during groundwater sampling activities. During handling of chemicals off site there would be a low risk to the community. Sampling activities would also take place off site with low risk to the community, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and transported to the site for proper disposal, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

Implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.

Long-Term Effectiveness and Permanence

This alternative would include active remediation for non-radiological contaminated soils, and arsenic in shallow overburden groundwater using in-situ treatment. The removal of contamination source soils would be permanent and highly effective in the long term for reducing groundwater contamination. The alternative would also monitor groundwater quality and natural attenuation parameters, to document the performance of the in-situ treatment and the natural attenuation of contaminants through degradation, retardation, or dispersion; while groundwater use is controlled using well restrictions in a groundwater CEA. The effectiveness of the in-situ treatment of arsenic in overburden groundwater was evaluated (estimated) using the groundwater flow and transport model provided in **Appendix C, Volume 2**. The long term effectiveness of the treatment of arsenic is summarized below. In-situ treatment of lithium is not proposed, since there are no suitable or cost-effective treatment methods. Benzene and lithium would naturally attenuate. Therefore, the long term effectiveness for these constituents would be the same time frame as discussed for Alternative No. 2 in **Section 5.2.2**. The long term effectiveness of arsenic remaining in shallow bedrock was evaluated by groundwater flow and transport modeling. The time for the arsenic to naturally attenuate in shallow bedrock is approximately 180 years.

The modeling assumption (for overburden and shallow groundwater) was that arsenic attenuation is due to equilibrium controlled adsorption/desorption reactions and dispersion, not redox reactions, and may not be appropriate for the MISS groundwater. It is believed that arsenic mobility on the MISS may be enhanced by benzene groundwater contamination and the resultant reduced aquifer conditions (**Appendix B**). Background groundwater conditions in the overburden layers at FMSS are oxidizing, and are oxidizing to mildly reducing in the bedrock units. However, within the benzene-impacted areas, redox conditions are strongly reducing, as evidenced by low to non-detectable dissolved oxygen; negative ORP measurements; conversion of nitrate to ammonia; and measurable dissolved iron, manganese, and methane. In addition, a large percentage of groundwater samples from monitoring wells located within the benzene plume had low but detectable concentrations of sulfide, indicating the presence of active sulfate-reducing anaerobes. Sulfate reduction only occurs under highly reducing conditions. Once the benzene plume is no longer present, and redox conditions become more oxidizing similar to background aquifer conditions, the natural attenuation rate of arsenic would be expected to increase. Therefore, it would be expected that arsenic would reach the proposed cleanup level quicker than the times predicted above. Groundwater use would be controlled using a well restriction in a groundwater CEA until the concentrations of arsenic decrease to the proposed cleanup level. A geochemical study prior to the implementation of this alternative would be used to further evaluate the behavior of arsenic under predicted site conditions.

Arsenic Treatment: The in-situ treatment scenario was modeled for arsenic assuming a treatment half-life of 10 days. Based on this evaluation, it is anticipated that the arsenic concentrations in overburden groundwater will be below the cleanup criteria in approximately three months. The modeling results are presented in **Appendix C, Volume 2** of the GWFS. The arsenic treatment area is shown on **Figure 4-3**. As discussed in **Appendix B**, the treatment of arsenic-impacted water may be performed using the injection of a redox altering compound, which would rapidly precipitate arsenic. The time required for arsenic to decrease to non-detect concentrations in response to the injection of a redox altering agent would be in the range of days to weeks. A treatment half-life of 10 days in response to the redox altering compound injection would be a reasonable assumption.

The treatment area for the application of in-situ treatment technology for arsenic remediation is shown on **Figure 4-3**. Arsenic treatment is assumed to be a redox altering compound injected into the overburden. The area to be treated is approximately 4.5 acres in the overburden aquifer. Due to the short treatment half-life, it is expected that arsenic concentrations would be less than the proposed cleanup level in less than a year (**Table 8-2, Appendix C, Volume 2**). During the treatment period, all arsenic mass should precipitate in the aquifer matrix. No mass would be lost to the Saddle River and no mass would remain dissolved in the aquifers. Groundwater conditions would need to be kept strongly reducing or oxidizing to prevent arsenic mobilization. Moderately reducing conditions would re-dissolve the arsenic (**Appendix B, Table 5**). This need for optimum redox conditions in the aquifer may require additional chemical injections over much longer time periods because the MISS groundwater is not isolated, and upgradient water continually flows into the site area.

Prior to performing any treatment, a detailed geochemical evaluation should be performed. Optimum aquifer redox conditions would have to be maintained for in-situ treatment, or the arsenic would re-dissolve with subsequent downgradient migration (**Appendix B**). This may require additional chemical injections beyond those assumed in this GWFS.

Reduction in Toxicity, Mobility, or Volume

The volume of contamination would be reduced from the site by the removal of non-radiological contaminated soil. Future groundwater contamination volume and mobility would also be reduced by the soil removal. Under this alternative, in-situ treatment of groundwater would meet the preference in CERCLA for treatment on site, because this remedy would result in a reduction in toxicity, mobility, and volume of contaminant in the area of the arsenic and benzene plumes, and reduce the potential for migration of the COCs from the site. The time frame for arsenic concentrations in overburden to reach proposed cleanup levels would be reduced to less than a year after treatment, provided optimum groundwater conditions could be maintained. Hazardous chemicals may be used on site to treat the contaminated groundwater. There is no reduction in the toxicity, mobility, or volume through treatment for lithium.

Implementability

This alternative would be complex to implement. Specifically, in-situ treatment would require a large number of chemical injection points. The variable permeabilities of the overburden and shallow bedrock would impact the delivery rates for the treatment medium. Construction activities for soil excavation, the installation and maintenance of additional monitoring wells, and well abandonment would be straightforward. All other activities would be related to sampling. Well abandonment, installation, and sampling are well known technologies. Services and materials would be readily available to abandon and install the wells and perform regular monitoring. Maintenance and care for the monitoring wells would need to be provided. Implementation of well restrictions in a groundwater CEA would involve a small number of off-site, adjacent properties. The groundwater portion of the alternative, including preparation of the design and installation of the monitoring wells, would be implemented in 6 to 12 months. Non-radiological contaminated soil remediation would take approximately three years to complete, provided that optimum aquifer redox conditions could be maintained.

Cost

Detailed costs are shown in **Appendix D**, **Tables 6** and **7**. Capital costs for this alternative are estimated to be $14,482,000. The present worth costs for lifetime O&M, assuming 30 years, is estimated at $21,447,000. The total present worth cost for this alternative is estimated at $35,929,000. Of this amount, $20,301,700 is estimated for non-radiological (benzene, arsenic and lithium) soil excavation and disposal. These costs may increase substantially if additional chemical injections are required to maintain optimum aquifer redox conditions.

State Acceptance

State acceptance would be addressed in the GW OU ROD once all comments have been received.

Community Acceptance

Community acceptance would be addressed in the GW OU ROD once all comments have been received.

5.2.4 Alternative No. 4 – Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soil Remediation on the MISS

Alternative No. 4 combines non-radiological contaminated soil remediation (soils located beyond the soils to be removed during the Soils and Buildings OU remedial action) with groundwater extraction, ex-situ treatment of groundwater, groundwater monitoring (as described for Alternative Nos. 2 and 3), and groundwater discharge. Six recovery wells are assumed in this system. The groundwater extraction wells would be placed to address the arsenic, benzene, and lithium plumes on the MISS. The capture zone of these extraction wells was designed to minimize the capture/influence of non-FUSRAP chlorinated solvent or other plumes downgradient of the MISS. The conceptual locations of the extraction wells, conveyance piping, and treatment plant are shown on **Figure 4-4**. The resulting groundwater modeled capture zone is shown on **Figure 4-5**. The treatment system selected includes an air stripper for VOCs, metals precipitation (present within the extraction system capture zone), reverse osmosis or ion exchange for lithium, and carbon to treat any off-gases from the air stripper. The exact number of wells and locations, and the specific components for the treatment system, would be determined during the system design. For costing purposes, the estimated period of operation for this alternative was assumed to be more than 30 years (model estimated 275 years to achieve RAOs for lithium). In accordance with CERCLA guidance procedures, a time frame of 30 years was assumed for costing. The duration is expected to be less, as aquifer geochemical conditions return to normal after benzene is removed causing arsenic to become less mobile.

Overall Protection of Human Health and the Environment

Under this alternative, potential human health exposure would be controlled by MISS non-radiological contaminated soil remediation, implementation of well restrictions in a groundwater CEA, and construction worker notification. The exception area would provide an institutional control by providing notice that there is groundwater pollution in the area. It also would give the State the authority to restrict the installation of wells and the use of groundwater in the exception area. The use of pumping on site would remove contaminant mass and stabilize the benzene, arsenic, and lithium plumes from migrating off site. Aquifer redox conditions are expected to change after the benzene is removed from the aquifer, allowing adsorption and mineral precipitation of arsenic and removal from the groundwater. Monitoring of groundwater would be performed to document the performance of groundwater extraction, extent and levels of contamination within the exception area, and to verify the contamination does not migrate beyond the area. Natural attenuation parameters would be collected to document the conditions for natural degradation for those parameters which are not within the capture zone, or are present after pumping is discontinued. USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans.

Compliance with ARARs

Soil remediation, and recovery and treatment of arsenic and benzene, would meet ARARs for these constituents by providing contaminant mass removal in the on-site areas of highest concentrations. Concentrations of COCs would decrease through time. Time frames for specific contaminants to achieve ARARs are discussed in more detail under long-term effectiveness. Lithium mass would also be removed during the 30 years of groundwater extraction.

Short-Term Effectiveness

Soil remediation, drilling and installation of extraction and monitoring wells, and construction of the treatment plant would result in a moderate to high risk to the on-site workers. There would be hazards to the public associated with the off-site transportation, and to disposal operation workers from the non-radiological soils to be excavated under this alternative. There may also be short term impacts to the environment from the soils excavation and handling. There would be a low risk to the workers during groundwater sampling activities. Sampling activities would also take place off site with low risk to the community, since the monitoring wells would be capped and locked, all sampling and purge water would be contained and transported to the site for proper disposal, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

Implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.

Long-Term Effectiveness and Permanence

This alternative includes active non-radiological contaminated soil remediation for non-radiological contaminated soils. The removal of contamination source soils would be permanent and highly effective in the long term for reducing groundwater contamination. Additionally, the arsenic and benzene plumes would be remediated using groundwater extraction and ex-situ treatment. The conceptual capture zone for the pumping system is shown on **Figure 4-5**. This capture zone is based on a composite of the optimized capture zones for the three FUSRAP COCs, benzene, arsenic and lithium, as presented in the Modeling Report (**Appendix C, Volume 2)**. The alternative also would monitor groundwater quality and natural attenuation parameters to document the performance of the extraction system treatment, and the natural attenuation of contaminants through degradation, retardation, or dispersion outside of the capture zone. Groundwater use would be controlled by well restrictions in a groundwater CEA. The effectiveness of the recovery of arsenic, benzene, and lithium as individual plumes was evaluated (estimated) using the groundwater flow and transport model provided in **Appendix C, Volume 2**. The long term effectiveness based on the solute transport models for these parameters are summarized below. Impacts on other contaminants are also discussed.

Lithium: As presented in **Appendix C, Volume 2**, the groundwater extraction scenario model was run for a period of 30 years of pumping, followed by 245 years of no action. It included four extraction wells located on MISS property, pumping a total of 10 GPM. The distribution of the well locations, and the allocated extraction rates, were designed to provide the desired capture zone while minimizing the possibility of any of the wells going dry during the course of the extraction system operation. The wells were simulated to be installed in the shallow bedrock, since the overburden saturated thickness is small (5-10 feet) in the area-of-interest. The capture zone in the overburden and shallow bedrock groundwater encompassed the MISS and upgradient lithium concentrations, while minimizing off-site (Dixo Company) plume capture.

The distribution of lithium concentrations in the overburden and shallow bedrock aquifers for the groundwater extraction scenario were determined in the model at 5-year intervals for a total of 30 years. Although the extraction well locations were selected to maximize on-site lithium plume capture, on-site groundwater extraction would also result in the stabilization of the off-site lithium plume downgradient of the MISS. The off-site overburden and shallow bedrock plumes appear to stay in-place over the 30-year pumping duration and do not migrate further downgradient. Groundwater extraction also removes some of the lithium dissolved in overburden and shallow bedrock groundwater to the south of the MISS.

Lithium concentrations at year 30 are shown on **Figure 5-7** for the overburden, and **Figure 5-8** for the shallow bedrock groundwater. Based on model results, it is estimated that after 30 years of pumping, groundwater concentrations in the overburden and the shallow groundwater would still exceed the proposed cleanup goal. Assuming that after 30 years the groundwater extraction system is terminated, it would take another 245 years of no action for the lithium concentrations to be reduced to levels below the cleanup goal, i.e., a total of 275 years. The data indicates that groundwater extraction does not significantly reduce the lithium cleanup time as compared to the no action and natural attenuation options, and lithium cannot be treated in-situ by chemical means. Groundwater extraction is not considered an effective alternative for lithium in groundwater on the MISS. Discharge to Westerly Brook is controlled by the repair of the culverts under the Soils and Buildings OU ROD. Discharge to the Saddle River is delayed by 30 years compared to Alternative Nos. 2 and 3; however, future concentrations in the River are not predicted to exceed cleanup goals.

Benzene: As presented in **Appendix C, Volume 2**, the groundwater extraction scenario model was run for a period of eight years, the time period to remove the benzene to the cleanup level. It included three extraction wells located on MISS property, pumping a total of 10 GPM. The distribution of the well locations, and the allocated extraction rates, were designed to provide the desired capture zone while minimizing the possibility of any of the wells going dry during the course of the extraction system operation. The simulated wells were placed in shallow bedrock, since the overburden saturated thickness is small (5-10 feet) in the area-of-interest. The capture zone encompassed the benzene plume in the overburden and shallow bedrock groundwater, while minimizing off-site contaminant capture.

The distributions of the benzene concentrations in the overburden and shallow bedrock aquifers for the groundwater extraction scenario were projected using the model at Years 2, 4, and 7 into the future. Based on model results, it is estimated that in less than eight years of groundwater extraction, groundwater concentrations in the overburden and the shallow groundwater would be less than the proposed cleanup levels.

Arsenic: As presented in **Appendix C, Volume 2**, the groundwater extraction scenario model was run for a period of 30 years of pumping. It included six extraction wells located on MISS property, pumping a total of 10 GPM. The distribution of the well locations, and the allocated extraction rates, were designed to provide the desired capture zone, while minimizing the possibility of any of the wells going dry during the course of the groundwater extraction system operation. The wells were modeled as if installed in the shallow bedrock, since the overburden saturated thickness is small (5-10 feet) in the area-of-interest. The capture zone encompassed the arsenic plume in the overburden and shallow bedrock groundwater, while minimizing off-site contaminant capture.

Arsenic concentrations at Year 30 are shown on **Figure 5-9** for the overburden and **Figure 5-10** for the shallow bedrock groundwater. The distributions of the arsenic concentrations in the overburden and shallow bedrock aquifers for the groundwater extraction scenario were projected at 5-year intervals for 30 years. Based on model results, it is estimated that after 30 years of pumping, groundwater concentrations in the overburden and the shallow groundwater would still exceed the proposed cleanup levels. Model predictions indicate that the arsenic would persist for more than 2,000 years under current aquifer geochemical conditions. Additionally, the pumping of groundwater is expected to pull arsenic present in overburden groundwater downward into the shallow bedrock, spreading the contamination and increasing the time for remediating the deeper groundwater.

The modeling assumption was that arsenic attenuation is due to equilibrium controlled adsorption/desorption reactions and dispersion, not redox reactions, and may not be appropriate for the MISS groundwater. It is believed that arsenic mobility on the MISS may be enhanced by benzene groundwater contamination and the resultant reduced aquifer conditions (**Appendix B**). Background groundwater conditions in the overburden layers at FMSS are oxidizing, and are oxidizing to mildly reducing in the bedrock units. However, within the benzene-impacted areas, redox conditions are strongly reducing, as evidenced by low to non-detectable dissolved oxygen; negative ORP measurements; conversion of nitrate to ammonia; and measurable dissolved iron, manganese, and methane. In addition, a large percentage of groundwater samples from monitoring wells located within the benzene plume had low but detectable concentrations of sulfide, indicating the presence of active sulfate-reducing anaerobes. Sulfate reduction only occurs under highly reducing conditions. Once the benzene plume is no longer present, and redox conditions become more oxidizing similar to background aquifer conditions, the natural attenuation rate of arsenic would be expected to increase. Therefore, it would be expected that arsenic would reach the proposed cleanup level quicker than the times predicted above. Groundwater use would be controlled using well restrictions in a groundwater CEA until the concentrations of arsenic decrease to the proposed cleanup level. A geochemical study prior to the implementation of this alternative would be used to further evaluate the behavior of arsenic under predicted site conditions.

Other Chemical Constituents

The proposed groundwater extraction system would also capture most isolated monitoring well exceedances of FUSRAP and other organic and inorganic chemical constituents located within the capture zone, including total radium, total uranium, barium, beryllium, lead, thallium, methylene chloride, PCE, TCE, VC, 2-chlorotoluene, iron, manganese, toluene, and xylene. Wells and individual compound exceedances are listed in **Table 1-1**, and well locations are shown on **Figure 4-1**.

Reduction in Toxicity, Mobility, or Volume

The volume of contamination would be reduced from the site by the removal of non-radiological contaminated soil. Future groundwater contamination volume and mobility would also be reduced by the soil removal. Under this alternative, groundwater containing the COCs benzene, arsenic, and lithium would be extracted from the aquifer and treated. Groundwater extraction and treatment would meet the preference in CERCLA for treatment on site, because this remedy would result in a reduction in toxicity, mobility, and volume of the arsenic and benzene plumes, and some lithium, and reduce the potential for migration of the COCs from the site. Other contaminants within the capture zone may also be removed and treated. Once pumping is discontinued, the remaining lithium plum would continue to migrate.

Hazardous chemicals may be used on site to treat the contaminated groundwater.

Implementability

Construction activities for this alternative include non-radiological contaminated soil remediation, installation of recovery and monitoring wells, construction of a treatment plant and associated piping from the wells to the plant, and groundwater sampling. Installation of recovery wells would be moderately complex, primarily due to the need to locate and screen the wells in a continuous fracture zone. There is variability in the number and orientation of the fractures in bedrock which might influence extraction well placement and performance. This hydrogeologic complexity would have to be accounted for during well placement, and might necessitate adding or relocating wells after initial placement and testing to achieve the desired groundwater and plume capture. Remaining activities would be straightforward. This alternative would be easy to implement. Services and materials would be readily available to abandon and install the wells and perform regular monitoring. Maintenance and care for the monitoring wells would need to be provided. Implementation of the well restrictions in a groundwater CEA would involve a small number of off-site, adjacent properties. The groundwater portion of the alternative, including preparation of the design and installation of the monitoring wells, may be implemented in 9 to 12 months. Non-radiological contaminated soil remediation would take approximately three years to complete.

Cost

Detailed costs are shown in **Appendix D, Tables 8** and **9**. Capital costs for this alternative are estimated to be $12,936,000. The present worth costs for lifetime O&M, assuming 30 years, is estimated at $109,266,000. The total present worth cost for this alternative is estimated at $122,202,000. Of this amount, $20,301,700 is estimated for non-radiological (benzene, arsenic and lithium) soil excavation and disposal.

State Acceptance

State acceptance would be addressed in the GW OU ROD once all comments have been received.

Community Acceptance

Community acceptance would be addressed in the GW OU ROD once all comments have been received.

6.0 COMPARISON OF ALTERNATIVES

The four remedial action alternatives presented in **Section 4.0** and evaluated in **Section 5.0** are compared in this section using a qualitative evaluation. The purpose of the comparative analysis is to weigh the relative performance of each alternative against a particular criterion and to determine which alternative performs consistently well or consistently better in relation to the criterion of interest. The alternatives are evaluated according to the criterion discussed in **Section 5.0** and include:

- Threshold criteria
    - Overall protection of human health and the environment
    - Compliance with ARARs
- Primary balancing criteria
    - Short-term effectiveness
    - Long-term effectiveness and permanence
    - Reduction in toxicity, mobility, or volume
    - Implementability
    - Cost

In accordance with the *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP 40 CFR, Part 300), modifying considerations (State acceptance and community acceptance) are not included in the evaluation, since comments from the agencies and the public have not yet been received.

The four remedial alternatives retained for detailed analysis are:

- Alternative No. 1 – No Action
- Alternative No. 2 – Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Groundwater, and Non-Radiological Contaminated Soil Remediation on the MISS
- Alternative No. 3 – Use Restrictions, Groundwater Monitoring, MNA of Lithium, Benzene and Arsenic in Shallow Bedrock Groundwater In-Situ Treatment of Arsenic in Overburden Groundwater with Redox Alteration, and Non-Radiological Contaminated Soil Remediation on the MISS
- Alternative No. 4 – Use Restrictions, Groundwater Monitoring, Groundwater Extraction, Ex-Situ Treatment, Groundwater Discharge, and Non-Radiological Contaminated Soil Remediation on the MISS

The "No Action" alternative was retained, as required, under CERCLA and the NCP. This alternative serves as a baseline for comparison with other alternatives and involves taking no action towards a remedy, implying no active management or expectation that the RAOs would be achieved over time.

6.1 THRESHOLD CRITERIA

Overall Protection of Human Health and the Environment

Alternative No. 1, No Action, would not protect human health or the environment.

Alternative Nos. 2, 3, and 4 are each protective of human health and the environment. In each of these alternatives, groundwater would not be used and future use of impacted groundwater would be controlled by instituting well restrictions in a groundwater CEA. For all three alternatives, non-radiological contaminated soil source areas would be remediated. Impacted groundwater is not predicted to reach the Saddle River based on the groundwater fate and transport model data results. The potential for future exposure to COCs above ARARs would be controlled with well restrictions in a groundwater CEA during implementation of the remedy and would eventually be eliminated.

Compliance with ARARs

Alternative No. 1 would not comply with ARARs, since no remedial actions would be performed.

Alternative Nos. 2, 3, and 4 would comply with ARARs for lithium, benzene and arsenic. Non-radiological soils which contribute to groundwater contamination would be remediated and chemical-specific ARARs for lithium, benzene and arsenic would be met through different approaches. The primary difference would be the time frame the ARAR is achieved. For each of the three alternatives, LUCs (e.g., well restrictions in a groundwater CEA) would restrict access to impacted groundwater until ARARs or cleanup goals are achieved. In addition, radiological contaminated soils would be remediated under the Soils and Buildings OU ROD for each of these alternatives. For Alternative No. 2, MNA would be the primary technology. In Alternative No. 3, after in-situ treatment of arsenic in the overburden, MNA would be the primary technology for arsenic, lithium and benzene in shallow bedrock. Groundwater monitoring would be used to track aquifer redox conditions, which could impact COC degradation, fate, and transport of benzene and arsenic after treatment. Alternative No. 3 does not treat arsenic, lithium and benzene in shallow bedrock. Alternative No. 4 would remove the benzene and arsenic and some of the lithium plumes. In Alternative No. 4, pumping would be discontinued after 30 years, and the remaining lithium plume would be allowed to naturally attenuate. Recall that the USACE will address lithium materials remaining on the Federal Government-owned MISS in consideration of constructability and stability issues, future redevelopment of the site, property transfer if determined to be excess to Federal needs, and to prevent potential future use of impacted groundwater on and off the property since consumption of the lithium-contaminated groundwater would represent an unacceptable risk.

6.2 PRIMARY BALANCING FACTORS

Short-Term Effectiveness

Alternative No. 1 would not involve construction activities; therefore, there would be no risk to workers or the community. However, a reduction of contamination and achievement of site protection would not occur under this alternative.

Alternative Nos. 2, 3, and 4 would include non-radiological contaminated soil remediation, drilling, and installation and sampling of monitoring wells. There would be hazards to the public associated with the off-site transportation, and to disposal operation workers from the non-radiological soils to be excavated under Alternative Nos. 2, 3, and 4. There may also be short term impacts to the environment from the soils excavation and handling. Alternative No. 4 also would include construction of a treatment plant. All of these activities would pose a moderate risk to the remedial worker and low risk to the community, since the work would be performed on the Federal Government-owned MISS. Remedial Alternative No. 2 would pose a slightly lower risk, since construction of the treatment plant would not be involved. All groundwater sampling activities would pose a moderate risk to the remedial worker and a low risk to the community. Since the monitoring wells would be capped and locked, all sampling and purge water would be contained and transported to the site for proper disposal, and traffic controls would be maintained during sampling for any wells installed in or near roadways.

For Alternative Nos. 2, 3, and 4, implementation of LUCs and removal of non-radiological soil would achieve short-term site protection and a reduction of contamination within three years of the GW OU ROD.

Long-Term Effectiveness

Under Alternative No. 1, source areas would not be addressed; therefore, there would not be management of residual risk.

Under Alternative Nos. 2, 3, and 4, the source areas would be addressed by the remediation of non-radiological contaminated soil, to include pond sludge on the MISS. Under each alternative, groundwater use would be controlled using a LUC, such as well restrictions in a groundwater CEA. Likewise under each alternative, USACE would notify local utilities and governments of the dermal/inhalation risks from site-related groundwater contaminants. These entities, in turn, would be asked to notify their workers. Additional notification would be provided through posting of warning signs at the MISS, and by project-specific health and safety plans. Alternative No. 3 would be the most effective, because it actively treats the overburden arsenic contaminant plume, the source of most of the groundwater exceeding the cleanup standard for this material. The benzene plume is not treated, since it was determined that the difference in time between Alternative No. 2 and Alternative No. 3 to reach cleanup levels would be negligible. For Alternative Nos. 2 and 4, model predictions indicate that the arsenic would persist for more than 3000 and 2000 years respectively, under current aquifer geochemical conditions. However, arsenic would be expected to be removed from groundwater at a faster rate when natural (slightly reducing to oxidizing) conditions are restored in the aquifer, after the benzene biodegrades (**Appendix B** for more details). A concern with the in-situ treatment of the arsenic plume, proposed under Alternative No. 3, would be the mobilization of metals present in the aquifer matrix. However, the treatment assumption is that this would not occur.

Optimum aquifer redox conditions would have to be maintained for in-situ treatment Alternative No. 3, or the arsenic would re-dissolve with subsequent downgradient migration (**Appendix B**). This may require additional chemical injections beyond those assumed for the detailed evaluation of Alternative No. 3. Prior to performing any treatment, a detailed geochemical evaluation should be performed.

Alternative No. 3 does not treat the lithium plume because there are no suitable or cost-effective in-situ treatment methods. Alternative No. 4 reduces the time frame for the cleanup of the lithium plume by a few years; however, this plume would be present for a time period similar to Alternative No. 2. This is appropriate, especially considering the current and expected future land use, since any residual soils left remaining would be diminimis as compared to current on-site conditions.

A concern with the active pump and treat technology proposed under Alternative No. 4 would be the potential to draw off-site non-FUSRAP related contamination into the extraction system. Long-term pumping on the MISS over time could impact the downgradient Dixo Company chlorinated solvent plume, potentially spreading the contamination over a larger area of the aquifer, increasing concentrations downgradient of the source area (Dixo Company property), and pulling more of the non-FUSRAP contamination onto the MISS. Groundwater pumping also has the potential to spread the arsenic plume vertically downward into shallow bedrock.

Reduction of Toxicity, Mobility and Volume

Alternative No. 1 would not reduce contaminant toxicity, mobility, or volume.

Both Alternative No. 3 and Alternative No. 4 would include active treatment as part of the alternative. Alternative No. 2 and part of Alternative No. 3 would address the contaminant plume through passive treatment (Monitored Natural Attenuation) of groundwater. Under Alternative No. 2, and part of

Alternative No. 3 toxicity, mobility, and volume of groundwater contamination would be addressed through naturally occurring biodegradation, dispersion, adsorption, and mineral precipitation. The primary attenuation mechanism for lithium would be dispersion, and for arsenic the mechanism would be dispersion, adsorption, and mineral precipitation. The primary attenuation mechanism for benzene would be biodegradation. Alternative No. 3 would reduce the toxicity, mobility, and the volume of the groundwater contaminants in the arsenic overburden plume through in-situ treatment. Alternative No. 4 would reduce the toxicity, mobility, and volume of the benzene, arsenic, and lithium plumes in groundwater through extraction and ex-situ treatment. However, the time frame to reach the proposed cleanup goal is not significantly reduced from Alternative No. 2.

Implementability

Alternative No. 1 would require no implementation. Alternative No. 2 would be easy to implement and uses proven technologies. Alternative No. 3 would be complex to implement, since a large number of chemical injection points are required. In addition, the local variable permeabilities of the substrata would impact delivery of the treatment medium. Alternative No. 3 would also require optimum aquifer redox conditions, which may be problematic and substantially increase costs. Most activities for Alternative No. 4 would be straightforward; however, selection of the recovery well locations may increase the complexity, since the wells need to intercept continuous fracture zones. Under all alternatives, implementation of well restrictions in a groundwater CEA would involve a small number of off-site, adjacent properties.

Cost

The total present-worth costs are estimated as follows:

- Alternative No. 1 is $0.00,
- Alternative No. 2 is $30,454,000,
- Alternative No. 3 is $35,929,000,
- Alternative No. 4 is $122,202,000.

Costing assumptions and details are described in **Appendix D**.

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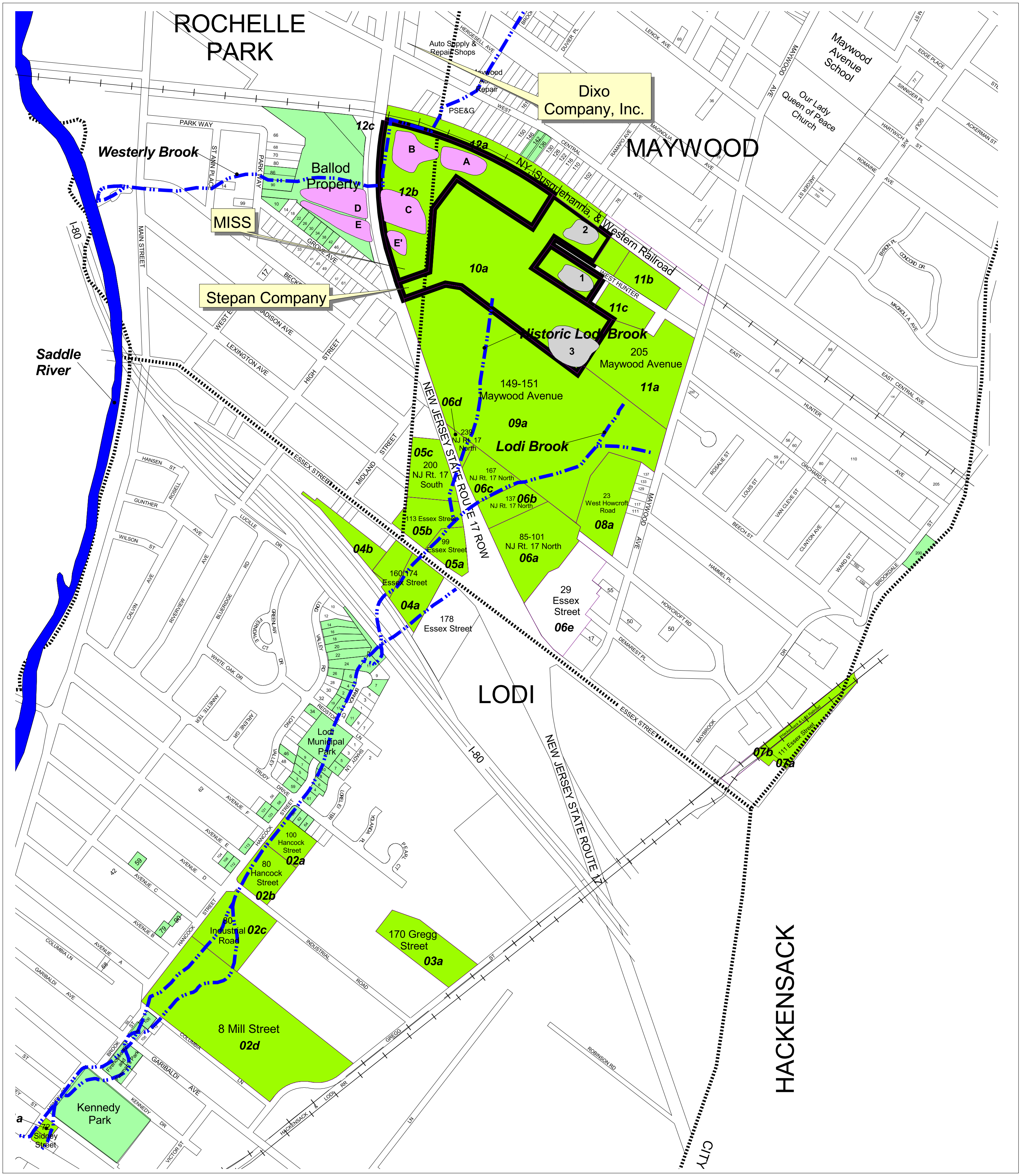
FIGURES



Phase 1 Properties

🟩 ***Remediated***

Phase II Properties

🟩 ***Scheduled for remediation***

▨ ***Burial Pits***

🟪 ***Retention Ponds***

Figure 1-1
FMSS and Surrounding Properties

N
W E
S

Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

US Army Corps of Engineers® FUSRAP Maywood Superfund Site Shaw® Shaw Environmental, Inc

0 600 1200 Feet

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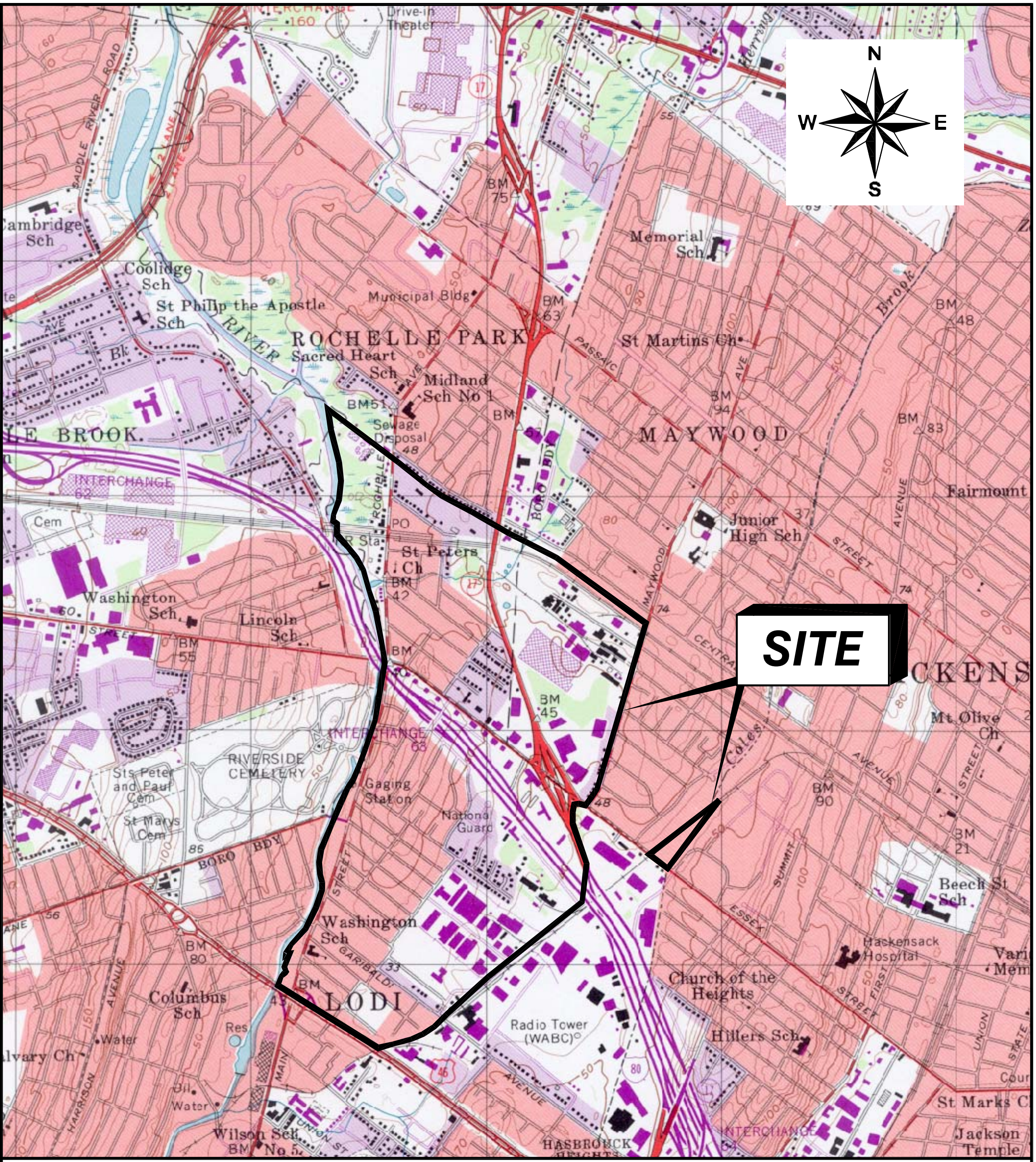

SCALE

0 2000 4000 FEET

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Pittsburgh, PA	2/15/05	--	A. Smith	G. Gaillot	--	108783-A7

Xref: .
Image: 108783IM-1 FMSS

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Plot Date/Time: 03/29/05 02:13pm
Plotted by: william.snyder

FIGURE 1-2

SITE LOCATION MAP

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.

REFERENCE:

7.5 MIN USGS TOPOGRAPHIC MAP OF
HACKENSACK, NJ QUADRANGLE. DATED: 1997

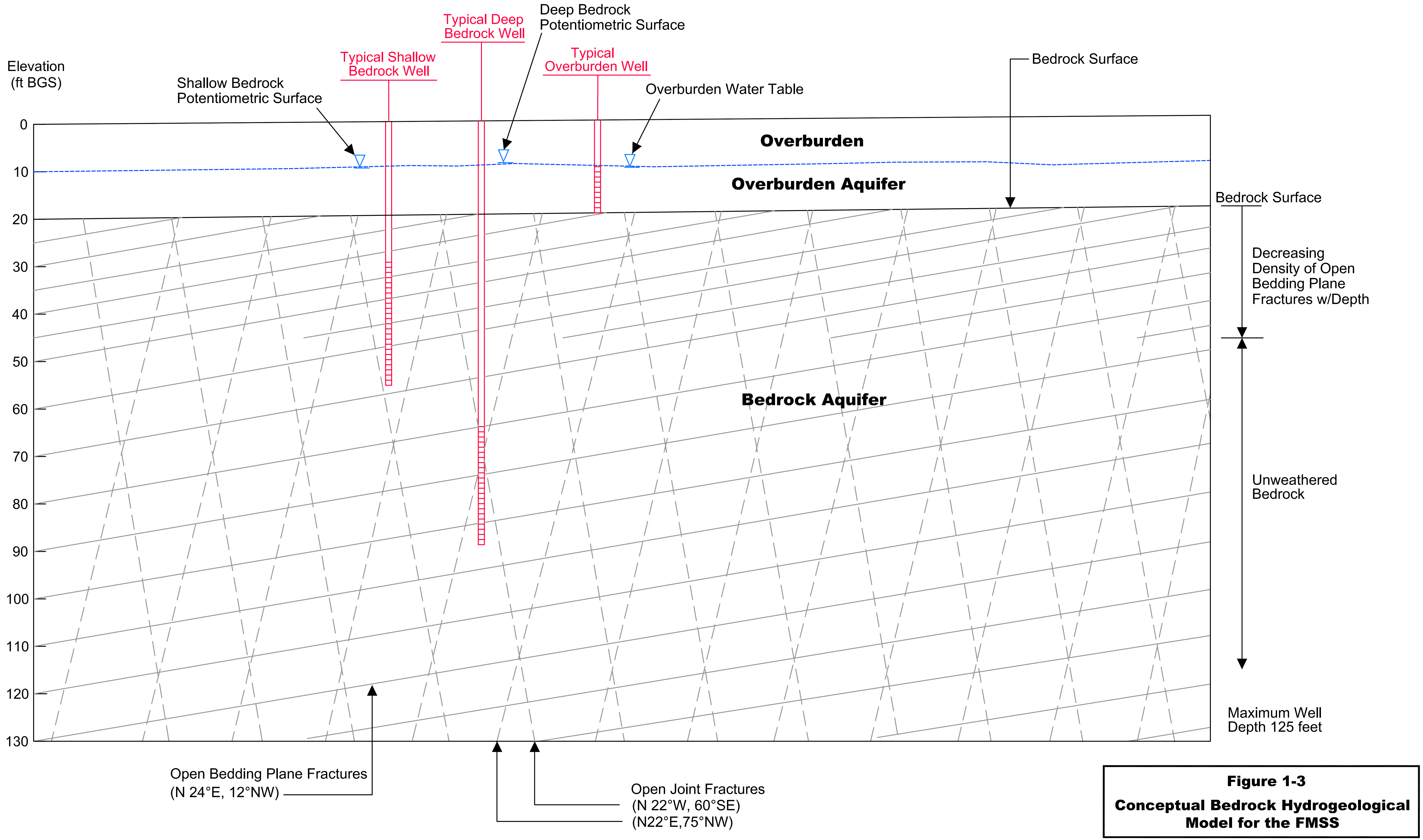
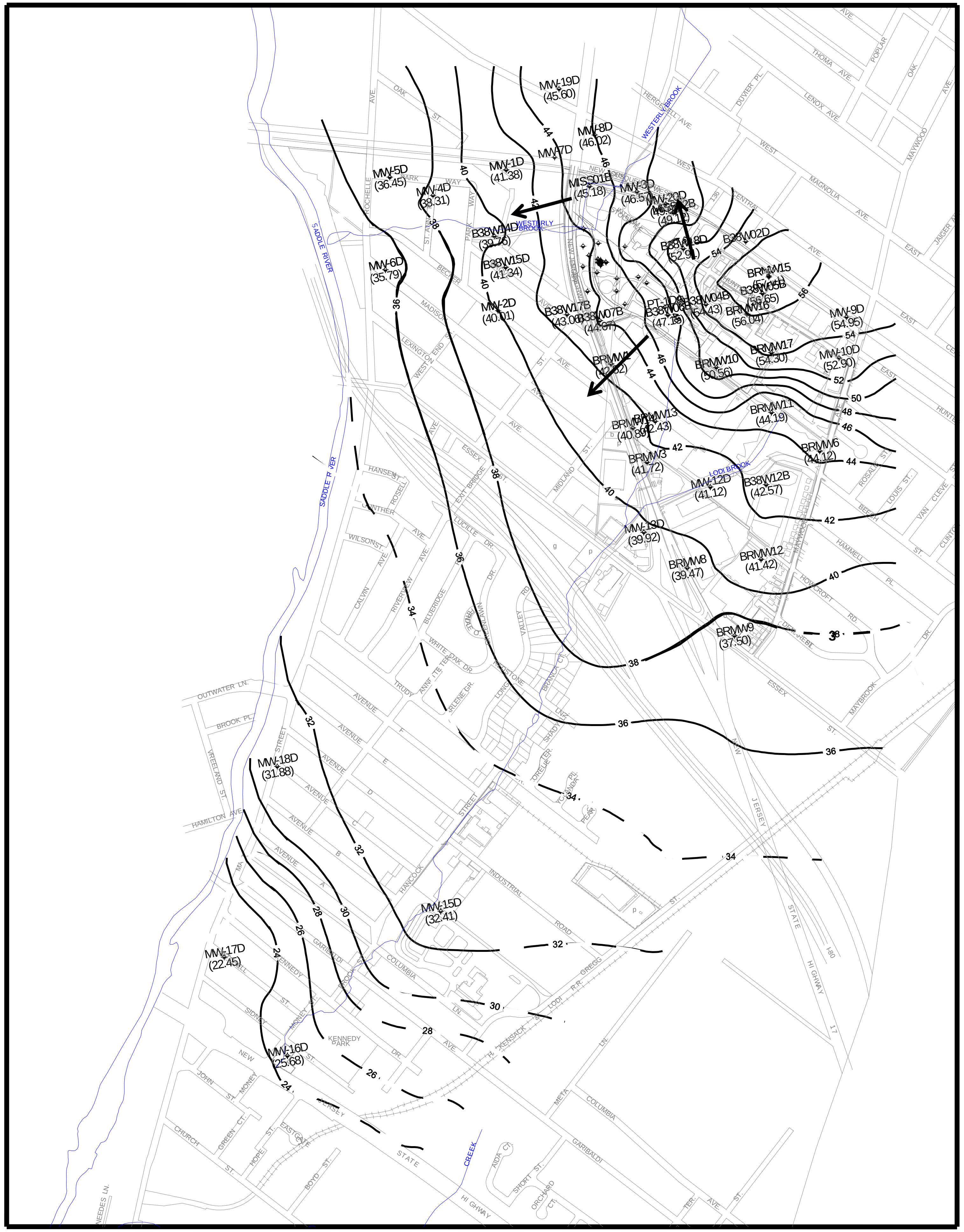


Figure 1-3
Conceptual Bedrock Hydrogeological Model for the FMSS

NOTE: ORIGINALLY FIGURE 3-14b FROM GWRI REPORT DATED NOVEMBER 2004

US Army Corps of Engineers®
FUSRAP
Maywood Superfund Site
Shaw® Shaw Environmental, Inc.

V:\maywood\Task10878305\drawings\108783B4_rev1.dwg Dated February 15, 2005



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Legend:

MW-15D (32.41) **Shallow Bedrock Monitoring Well (July, 2001 Head Measurement Displayed in Parentheses.)**

32 **Equipotential Contour in feet above Mean Sea Level (MSL).**
Contour Interval = 2 feet.

← **Groundwater Flow Direction**

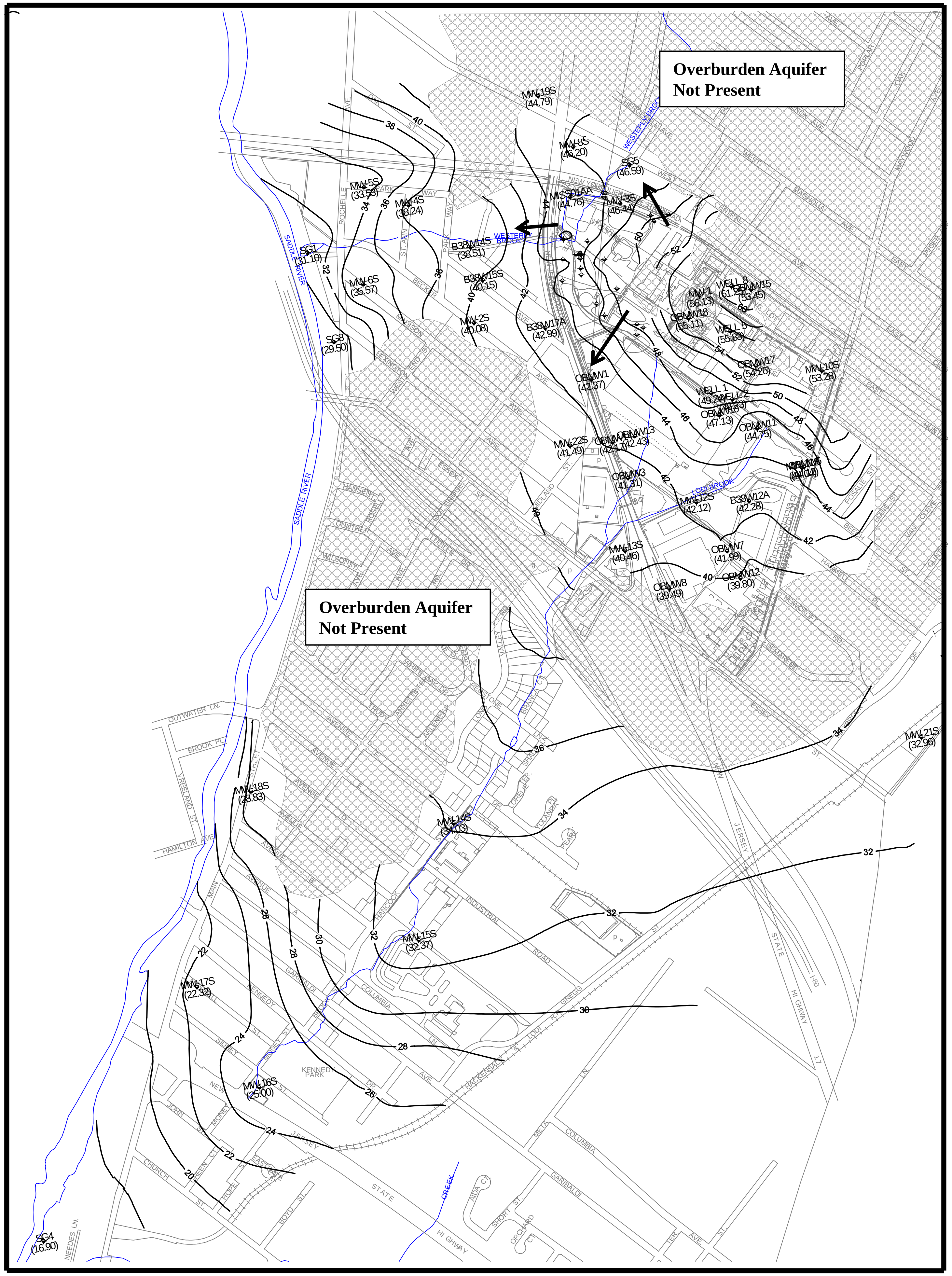
Note: Figure 1-4 initially appeared as Figure 3-15a of the GWRI – November 2004

Horizontal Scale in feet
0 500 1000 1500

Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

Figure 1-4
Shallow Bedrock, Groundwater Potentiometric Surface Map of FMSS (July 2001 Synoptic Event)

US Army Corps of Engineers
FUSRAP Maywood Superfund Site
Shaw Shaw Environmental, Inc.



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Legend:

MW-15S ✦ (32.37) **Overburden Monitoring Well**

▨ **Zone of 0 ft. Saturated Thickness (i.e., overburden aquifer not present).**

32 **Equipotential Contour in feet above Mean Sea Level (MSL). Contour Interval = 2 feet.**

← **Groundwater Flow Direction**

Note: Figure 1-5 initially appeared as Figure 3-19a
of the GWRI – November 2004

Horizontal Scale in feet

0 500 1000 1500

Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

Figure 1-5
Overburden, Groundwater Surface Elevation
Map of FMSS
(July 2001 Synoptic Event)

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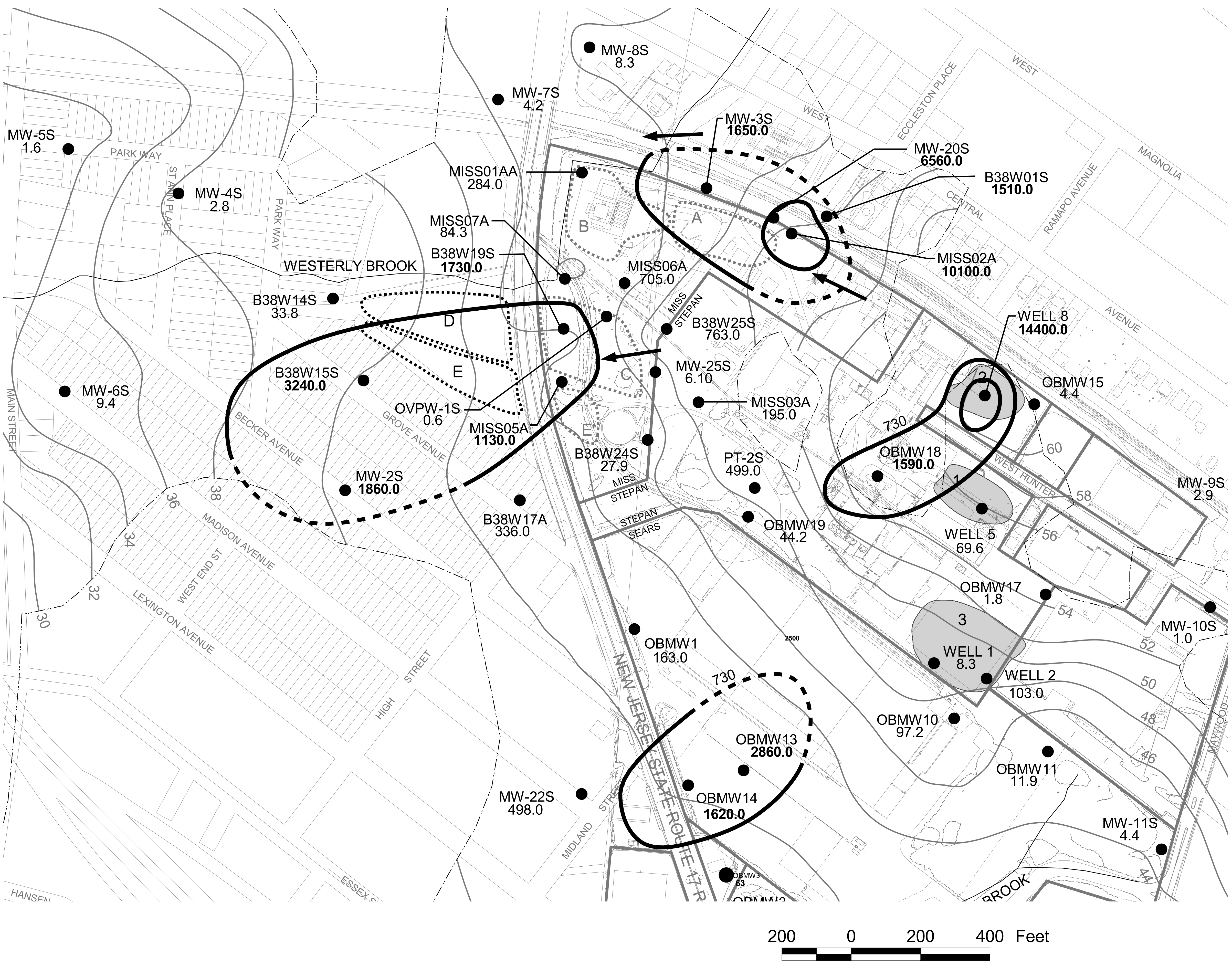
Shaw® Shaw Environmental, Inc.



LEGEND:

● MISS02A 10100	WELL IDENTIFICATION WITH LITHIUM CONCENTRATION
1000	LINE OF EQUAL LITHIUM CONCENTRATION
1000	DASHED WHERE INFERRED
42	EQUIPOTENTIAL CONTOUR
	LIMIT OF ZERO SATURATED THICKNESS (JULY 2001) TRANSITIONAL
←	GROUNDWATER FLOW DIRECTION
A	FORMER RETENTION POND
D	FORMER RETENTION POND - REMEDIATED
▨	NRC BURIAL PIT
ND	NON-DETECT
NA	NOT ANALYZED

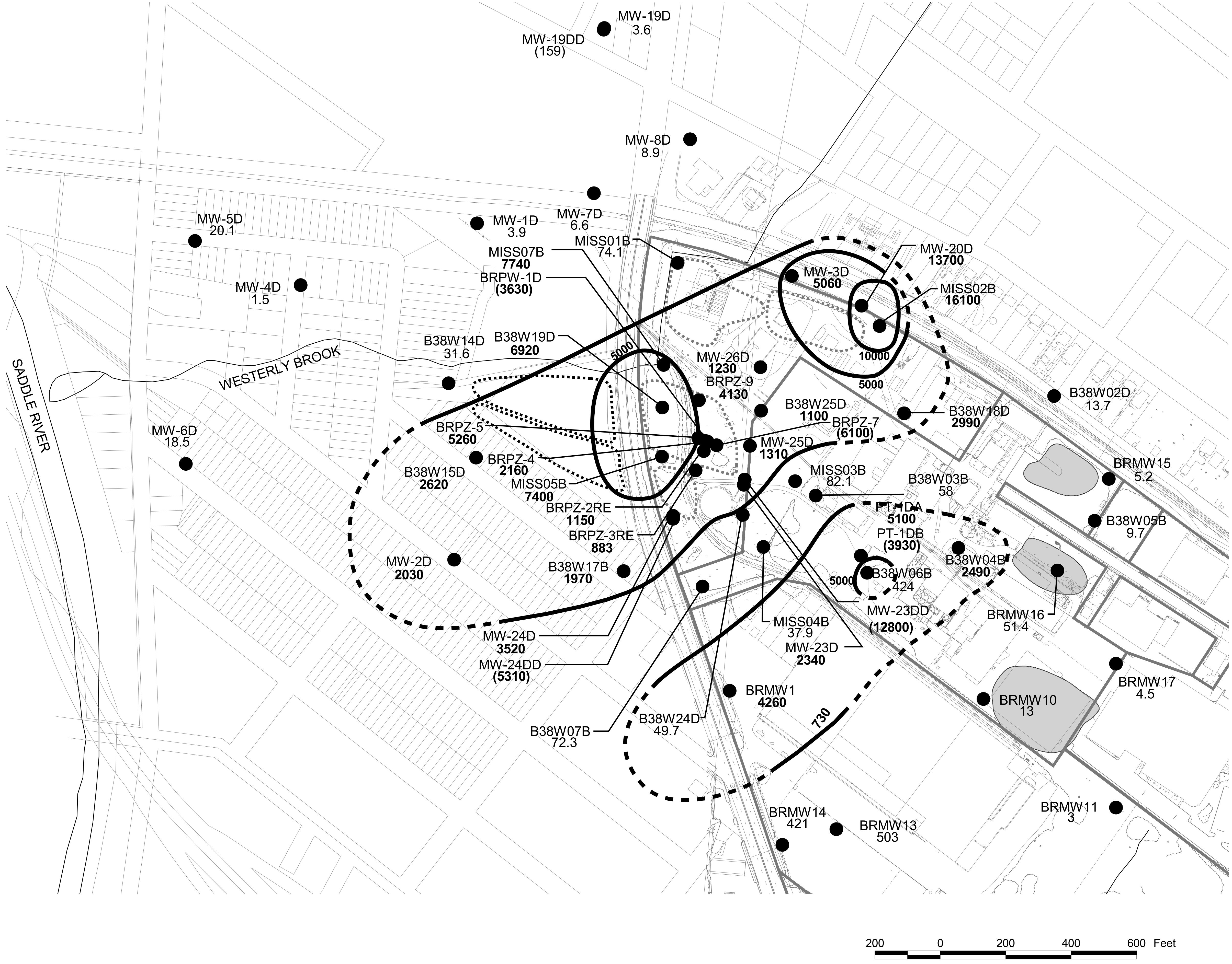
BOLD CONCENTRATION DENOTES EXCEEDANCE OF USEPA REGION IX PRG OF 730 ug/L

RESULTS IN MICROGRAMS PER LITER (ug/L)

ORIGINALLY FIGURE 5-5 FROM GWRI REPORT DATED NOVEMBER 2004

FIGURE 1-6
LITHIUM RESULTS FOR
OVERBURDEN GROUNDWATER SAMPLES
(2000 - 2002)

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.



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LEGEND:

● MW-20D 13700	WELL IDENTIFICATION WITH LITHIUM CONCENTRATION
● PT-1DB (3930)	WELL IDENTIFICATION DATA FROM DEEP BEDROCK WELL PRESENTED BUT NOT USED IN CONTOURING OF DATA
730	LINE OF EQUAL LITHIUM CONCENTRATION
730	DASHED WHERE INFERRED
42	EQUIPOTENTIAL CONTOUR
A	FORMER RETENTION POND
D	FORMER RETENTION POND - REMEDIATED
▨	NRC BURIAL PIT
ND	NON-DETECT
NA	NOT ANALYZED

BOLD CONCENTRATION DENOTES EXCEEDANCE OF REGION IX PRG OF 730 ug/L

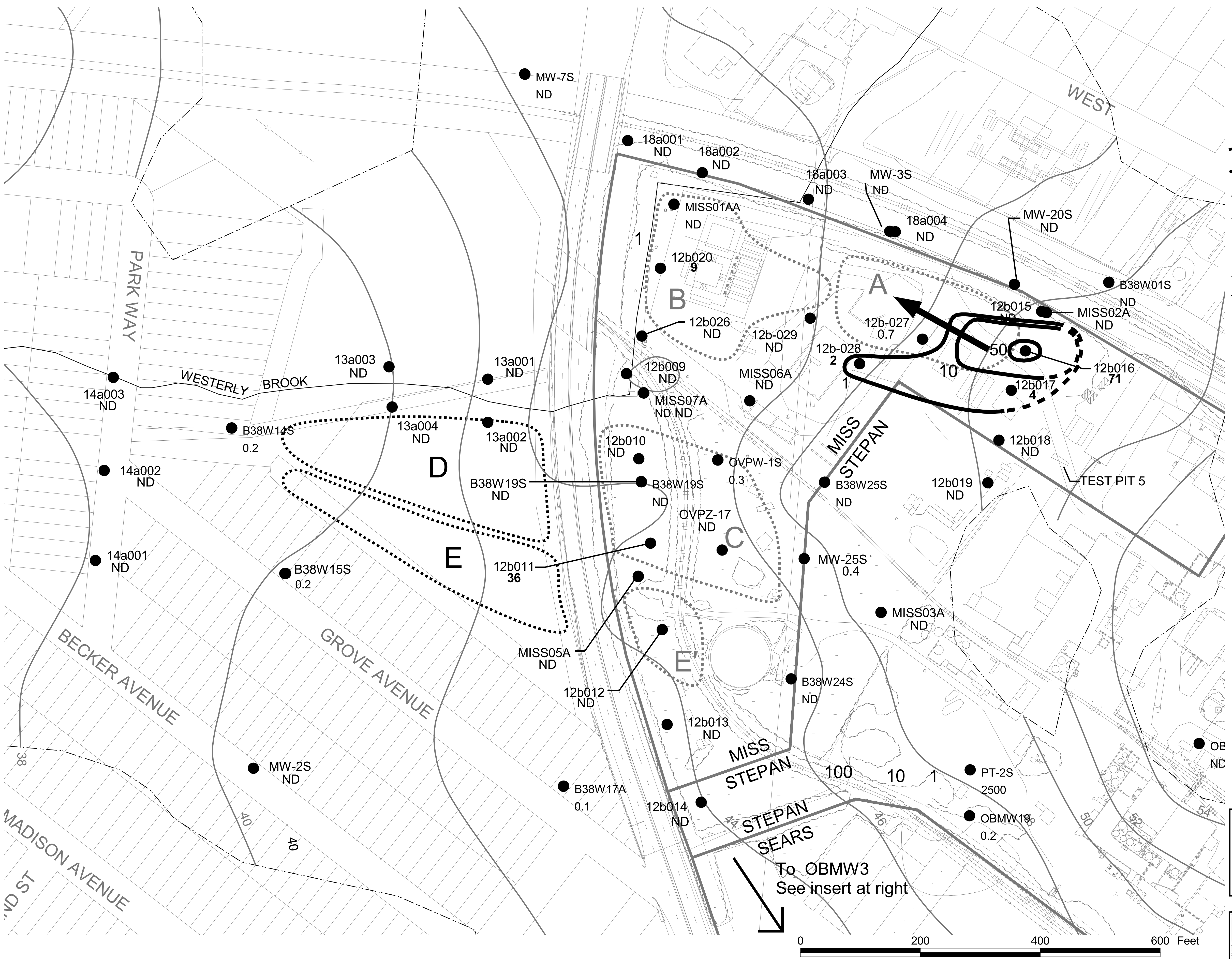
RESULTS IN MICROGRAMS PER LITER (ug/L)
USEPA REGION IX PRG = 730

ORIGINALLY FIGURE 5-16 FROM GWRI REPORT DATED NOVEMBER 2004

FIGURE 1-7
LITHIUM RESULTS FOR SHALLOW BEDROCK
GROUNDWATER SAMPLES
(2000 - 2002)

US Army Corps of Engineers.
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.

\\bosfs01\maywood\maywood\Task1087830308\Contours-Bedrock_rev3.apr LAYOUT: Lithium-Bedrock-17x11 November 24, 2008



LEGEND:

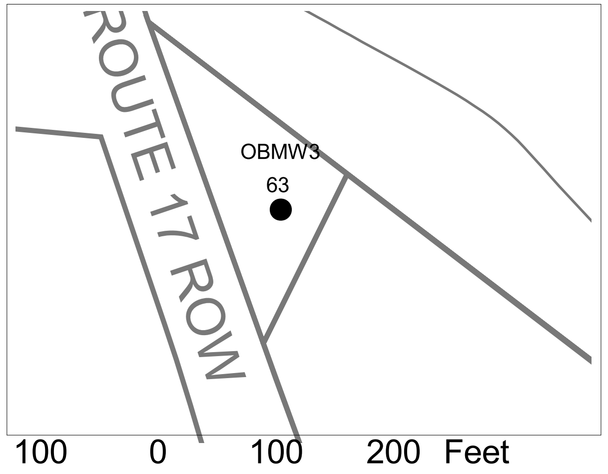
●	12b011 36	WELL/GEOPROBE IDENTIFICATION WITH DETECTED BENZENE CONCENTRATION
5		LINE OF EQUAL BENZENE CONCENTRATION
5		DASHED WHERE INFERRED
42		EQUIPOTENTIAL CONTOUR
		LIMIT OF ZERO SATURATED THICKNESS (JULY 2001) TRANSITIONAL
←		GROUNDWATER FLOW DIRECTION
A		FORMER RETENTION POND
D		FORMER RETENTION POND - REMEDIATED
ND		NON-DETECT
NA		NOT ANALYZED

BOLD CONCENTRATION DENOTES EXCEEDANCE OF NJDEP MCL OF 1 ug\L

RESULTS IN PARTS PER BILLION (ug/L)

FEDERAL MCL= 5
NJDEP MCL = 1

ORIGINALLY FIGURE 5-6 FROM GWRI REPORT DATED NOVEMBER 2004



Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

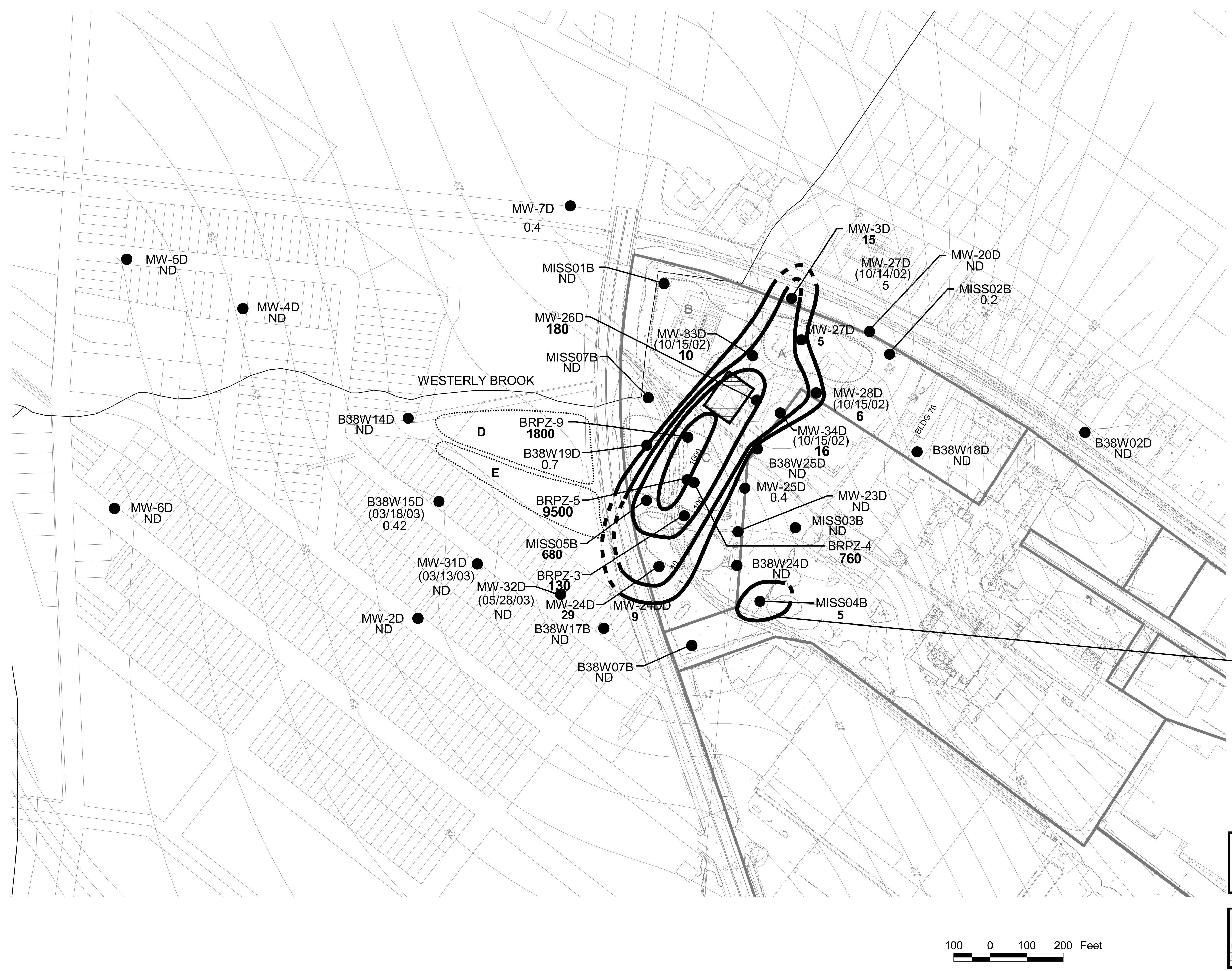
FIGURE 1-8
BENZENE RESULTS FOR
OVERBURDEN GROUNDWATER SAMPLES
(2000 - 2002)

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc

\\bosfs01\maywood\maywood\Task1087830305\Contours-Overburden_rev3.apr LAYOUT: Benzene January 30, 2006



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LEGEND:

● MW-27D 5 ug/L	BEDROCK WELL IDENTIFICATION WITH BENZENE CONCENTRATION
A	FORMER RETENTION POND
D	FORMER RETENTION POND - REMEDIATED
ND	NON-DETECT

RESULTS IN MICROGRAMS PER LITER (ug/L)

10	LINE OF EQUAL BENZENE CONCENTRATION
10	DASHED WHERE INFERRED
47	LINE OF EQUAL HYDRAULIC HEAD (JUNE 2003)
▤	POTENTIAL SOURCE AREA

BOLDED CONCENTRATIONS DENOTE EXCEEDANCE
OF BENZENE GROUNDWATER
STANDARD OF 1 ug/L (NJ GWQC)

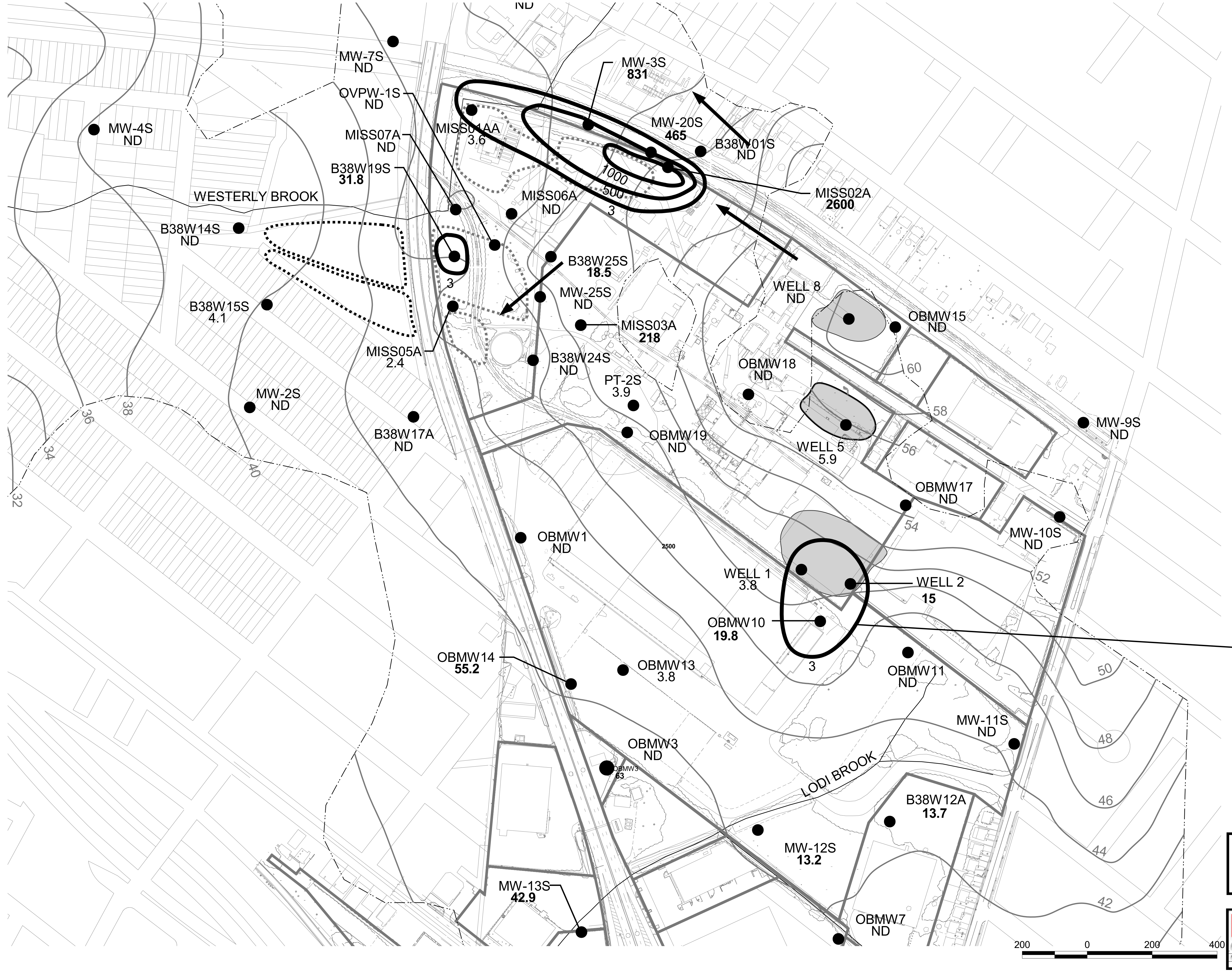
ORIGINALLY FIGURE 5-17 FROM GWRI REPORT
DATED NOVEMBER 2004

Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

FIGURE 1-9
BENZENE RESULTS FOR SHALLOW
BEDROCK GROUNDWATER SAMPLES
SUPPLEMENTAL INVESTIGATION

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.

\\Bosfs01\maywood\Maywood\tASK108783035\Chem2.apr LAYOUT: Benzene-17x11 December 14, 2005



LEGEND:

● MW-20S 465 WELL IDENTIFICATION WITH ARSENIC CONCENTRATION

100 LINE OF EQUAL ARSENIC CONCENTRATION

100 DASHED WHERE INFERRED

42 EQUIPOTENTIAL CONTOUR

LIMIT OF ZERO SATURATED THICKNESS (JULY 2001) TRANSITIONAL

GROUNDWATER FLOW DIRECTION

A FORMER RETENTION POND

D FORMER RETENTION POND - REMEDIATED

NRC BURIAL PIT

ND NON-DETECT

NA NOT ANALYZED

BOLD CONCENTRATION DENOTES EXCEEDANCE OF NJDEP PQL OF 3 ug/L

RESULTS IN MICROGRAMS PER LITER (ug/L)

ORIGINALLY FIGURE 5-4 FROM GWRI REPORT DATED NOVEMBER 2004

FIGURE 1-10
ARSENIC RESULTS FOR
OVERBURDEN GROUNDWATER SAMPLES
(2000 - 2002)

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.

\\bosfs01\Maywood\Maywood\task1087830306\Contours-Overburden_arsenic.apr LAYOUT: Arsenic-Overburden-17x11 July 05, 2007
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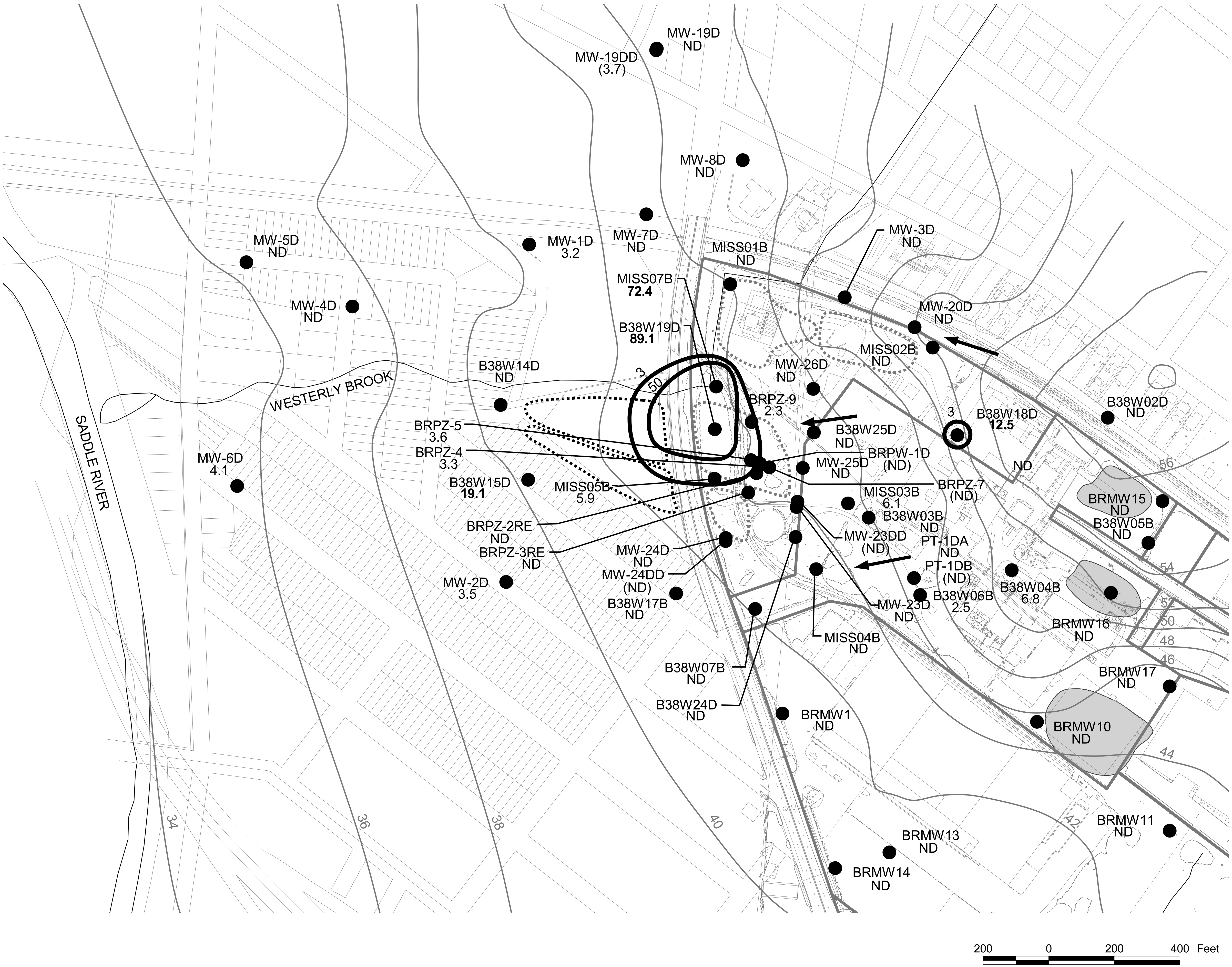


N
W E
S

LEGEND:

● MISS07B 72.4	WELL IDENTIFICATION WITH ARSENIC CONCENTRATION
● MW-19DD (3.7)	WELL IDENTIFICATION DATA FROM DEEP BEDROCK WELL PRESENTED BUT NOT USED IN CONTOURING OF DATA
8	LINE OF EQUAL ARSENIC CONCENTRATION
8	DASHED WHERE INFERRED
42	EQUIPOTENTIAL CONTOUR
←	GROUNDWATER FLOW DIRECTION
A	FORMER RETENTION POND
D	FORMER RETENTION POND - REMEDIATED
▭	NRC BURIAL PIT
ND	NON-DETECT
NA	NOT ANALYZED

RESULTS IN MICROGRAMS PER LITER (ug/L)
NJDEP GWQC PQL = 3

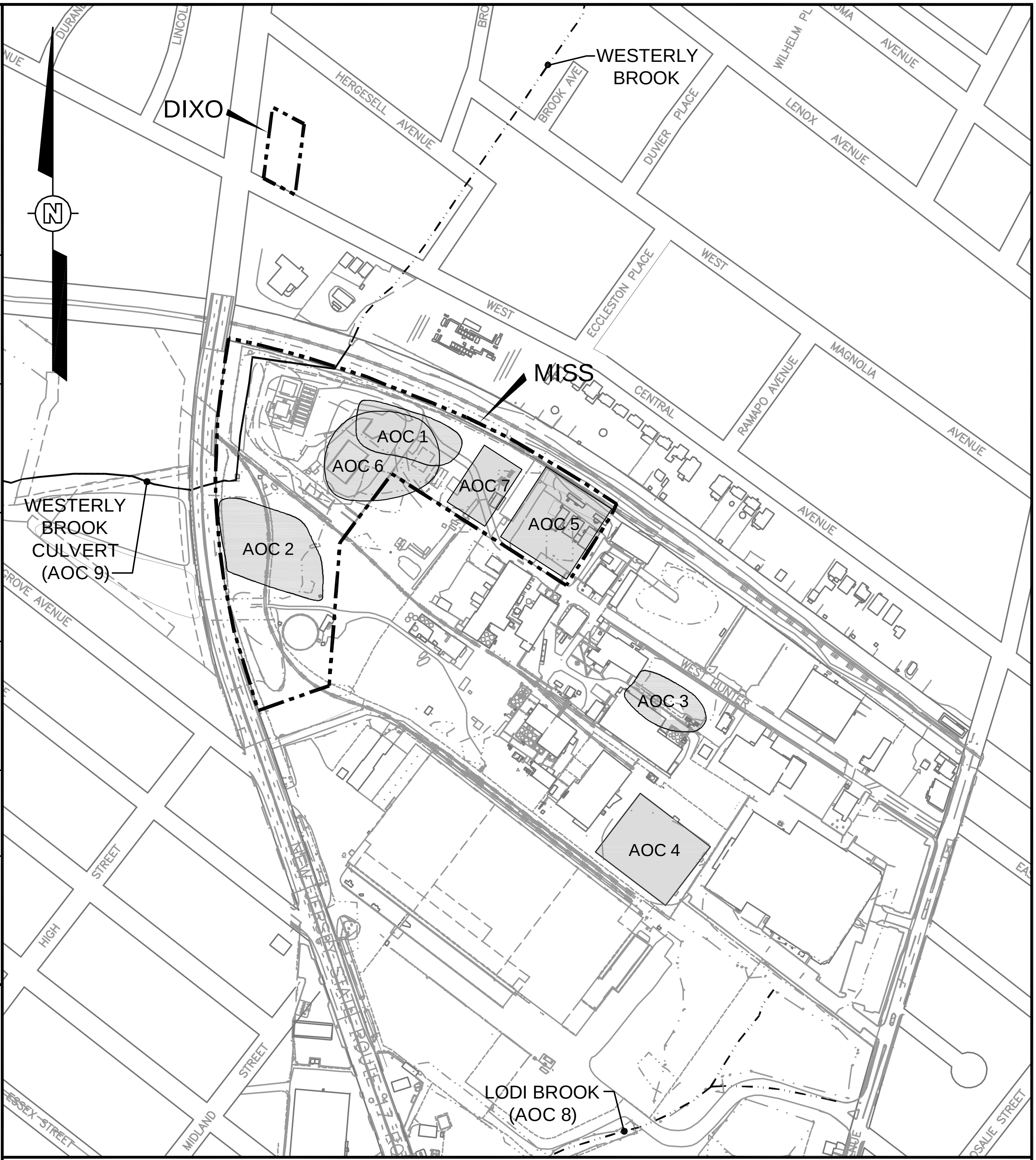
BOLD CONCENTRATION DENOTES EXCEEDANCE OF NJGWQC MCL OF 3 ug/L

ORIGINALLY FIGURE 5-14 FROM GWRI REPORT
DATED NOVEMBER 2004

FIGURE 1-11
ARSENIC RESULTS FOR SHALLOW
BEDROCK GROUNDWATER SAMPLES
(2000 - 2002)

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.

\\bosfs01\maywood\maywood\Task1087830306\Contours-Bedrock_rev2.apr LAYOUT: Arsenic-Bedrock-17x11 July 10, 2007



AREAS OF CONCERN:

AOC 1 - FORMER RETENTION POND A
AOC 2 - FORMER RETENTION POND C
AOC 3 - NRC BURIAL PIT 1
AOC 4 - NRC BURIAL PIT 3
AOC 5 - WELL B38W18D (FORMER THORIUM MANUFACTURING)
AOC 6 - PROBABLE BENZENE SOURCE AREA (BEDROCK)
AOC 7 - PROBABLE BENZENE SOURCE AREA (OVERBURDEN)
AOC 8 - LODI BROOK
AOC 9 - WESTERLY BROOK

SCALE

0 400 800 FEET

FIGURE 1-12
GROUNDWATER AREAS OF CONCERN (AOCs)
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

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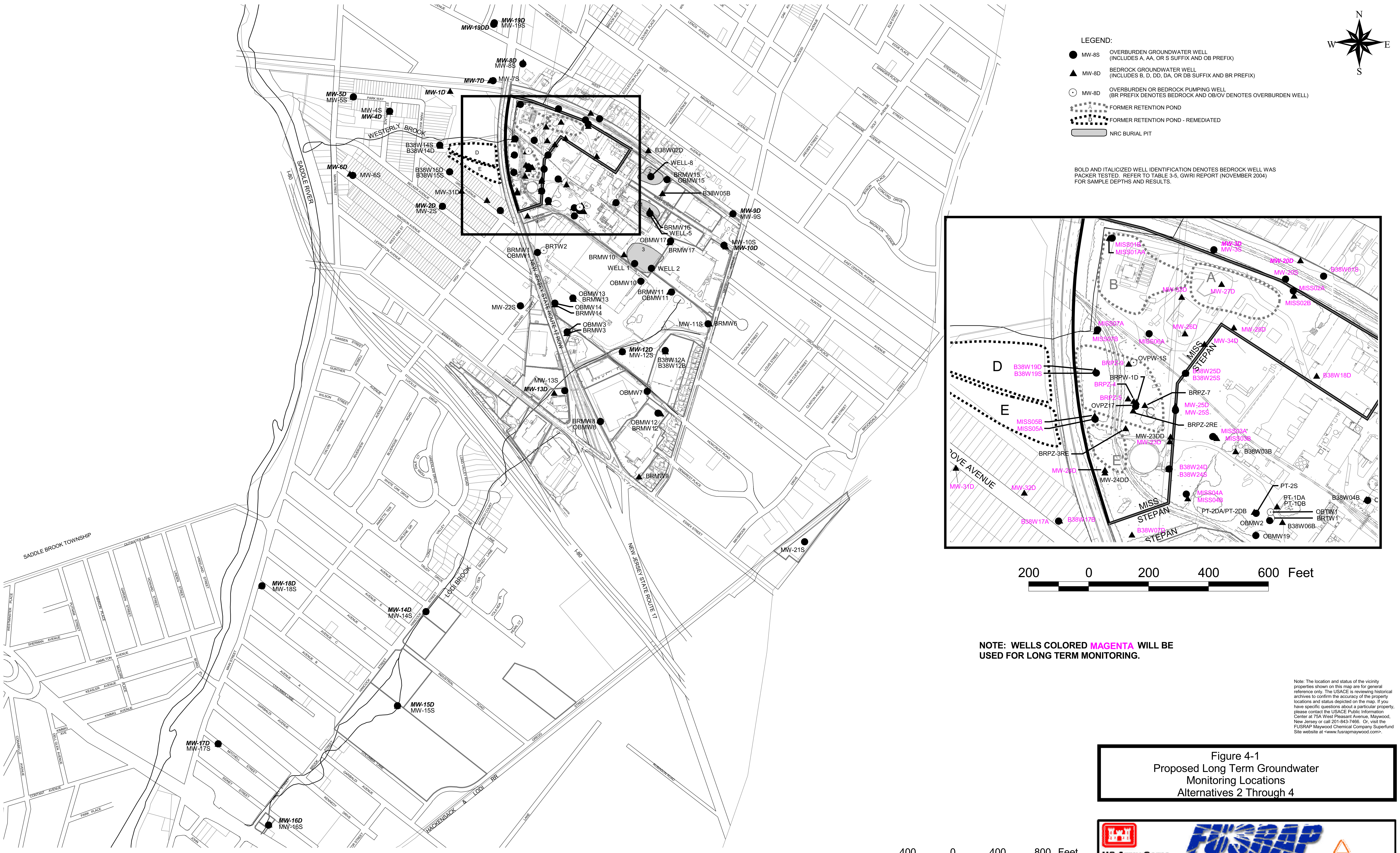
OFFICE	DATE	DESIGNED BY	DRAWN BY	CHECKED BY	APPROVED BY	DRAWING NUMBER
Pittsburgh, PA	5/5/05	--	B. Snyder	G. Gaillot	--	108783-A11

Xref: 108783X1
Image: FMSS

O:\Project\108783\108783A11.dwg
Plot Date/Time: 11/29/05 09:27am
Plotted by: greg.jones



LEGEND:

●	MW-8S	OVERBURDEN GROUNDWATER WELL (INCLUDES A, AA, OR S SUFFIX AND OB PREFIX)
▲	MW-8D	BEDROCK GROUNDWATER WELL (INCLUDES B, D, DD, DA, OR DB SUFFIX AND BR PREFIX)
⊙	MW-8D	OVERBURDEN OR BEDROCK PUMPING WELL (BR PREFIX DENOTES BEDROCK AND OB/OV DENOTES OVERBURDEN WELL)
A		FORMER RETENTION POND
D		FORMER RETENTION POND - REMEDIATED
▭		NRC BURIAL PIT

BOLD AND ITALICIZED WELL IDENTIFICATION DENOTES BEDROCK WELL WAS PACKER TESTED. REFER TO TABLE 3-5, GWRI REPORT (NOVEMBER 2004) FOR SAMPLE DEPTHS AND RESULTS.

NOTE: WELLS COLORED MAGENTA WILL BE USED FOR LONG TERM MONITORING.

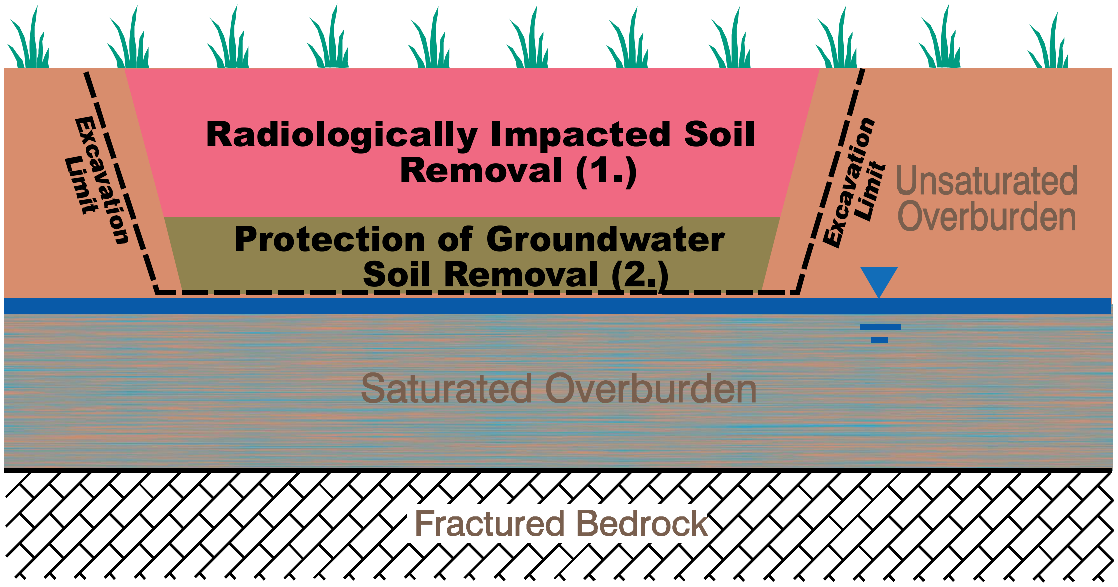
Note: The location and status of the vicinity properties shown on this map are for general reference only. The USACE is reviewing historical archives to confirm the accuracy of the property locations and status depicted on the map. If you have specific questions about a particular property, please contact the USACE Public Information Center at 75A West Pleasant Avenue, Maywood, New Jersey or call 201-843-7466. Or, visit the FUSRAP Maywood Chemical Company Superfund Site website at <www.fusrapmaywood.com>.

Figure 4-1
Proposed Long Term Groundwater
Monitoring Locations
Alternatives 2 Through 4

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.

\\swibosfs01\envir\maywood\Task1087830305\GWRI-Wells_rev7.apr LAYOUT: Figure 4-1 11x17 3 August 2007

DRAWING NUMBER	APPROVED BY	CHECKED BY	DRAWN BY	DESIGNED BY	DATE	OFFICE
108783-A13	--	G. Gaillot	G. Jones	--	8/2/05	Pittsburgh, PA



Conceptual Cross-Section of Soil Remediation

"Not to Scale"

Legend:

▼ Groundwater table

Notes:

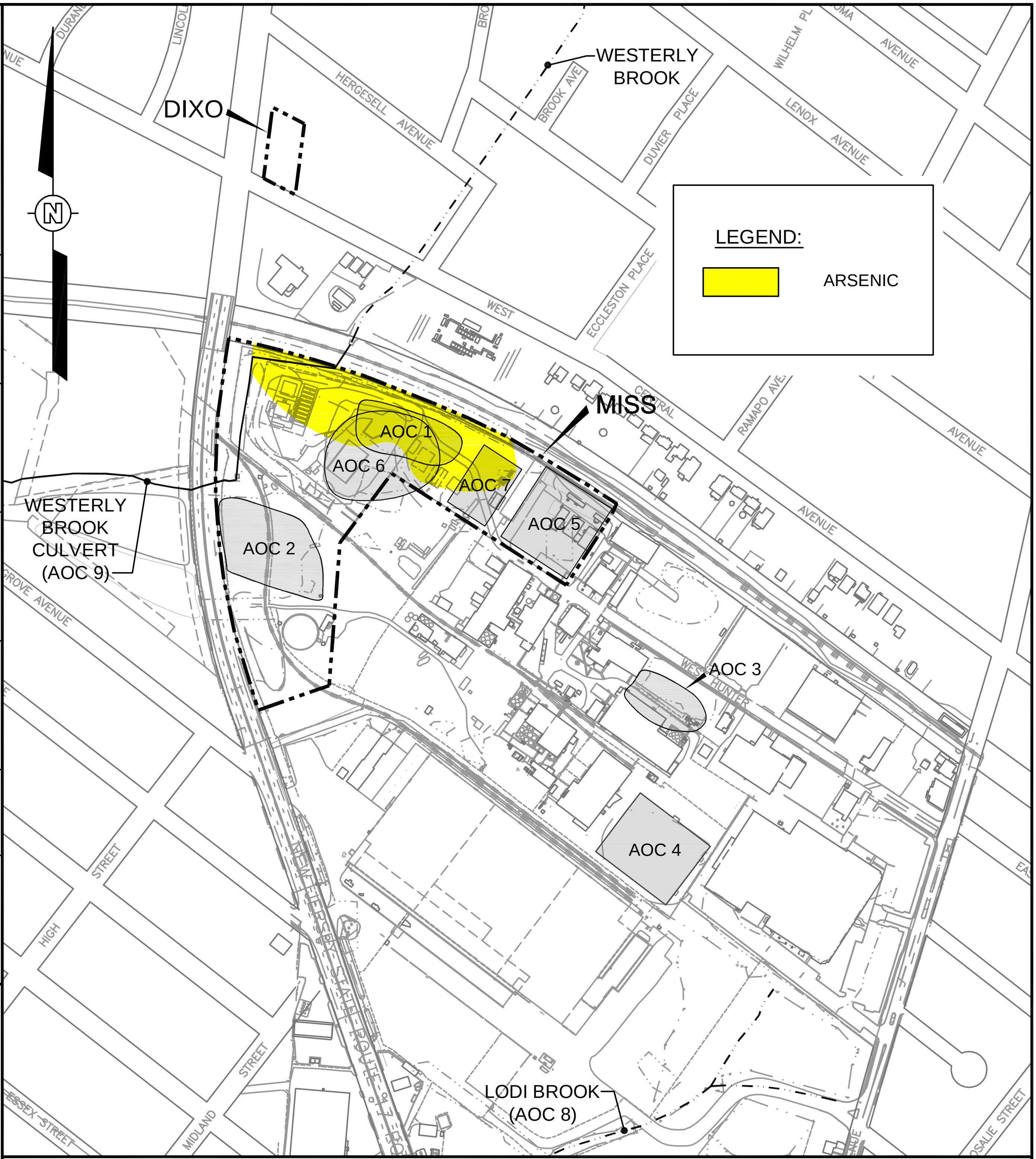
(1.) To be removed under the Soils and Buildings ROD.

(2.) To be removed under the Groundwater ROD. Some soil will be removed from below the groundwater table in localized areas.

FIGURE 4-2
CONCEPTUAL DIAGRAM OF MISS SOIL REMEDIATION
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.

OFFICE	DATE	DESIGNED BY	DRAWN BY	CHECKED BY	APPROVED BY	DRAWING NUMBER
Pittsburgh, PA	*1/24/05*	--	*A. Smith*	*G. Gaillot*	--	108783-A3



AREAS OF CONCERN:

- AOC 1 - FORMER RETENTION POND A
- AOC 2 - FORMER RETENTION POND C
- AOC 3 - NRC BURIAL PIT 1
- AOC 4 - NRC BURIAL PIT 3
- AOC 5 - WELL B38W18D (FORMER THORIUM MANUFACTURING)
- AOC 6 - PROBABLE BENZENE SOURCE AREA (BEDROCK)
- AOC 7 - PROBABLE BENZENE SOURCE AREA (OVERBURDEN)
- AOC 8 - LODI BROOK
- AOC 9 - WESTERLY BROOK

SCALE

0 400 800 FEET

FIGURE 4-3
ALTERNATIVE 3 - ARSENIC
IN-SITU TREATMENT AREA, OVERBURDEN
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

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Xref: 108783X1
Image: FMSS

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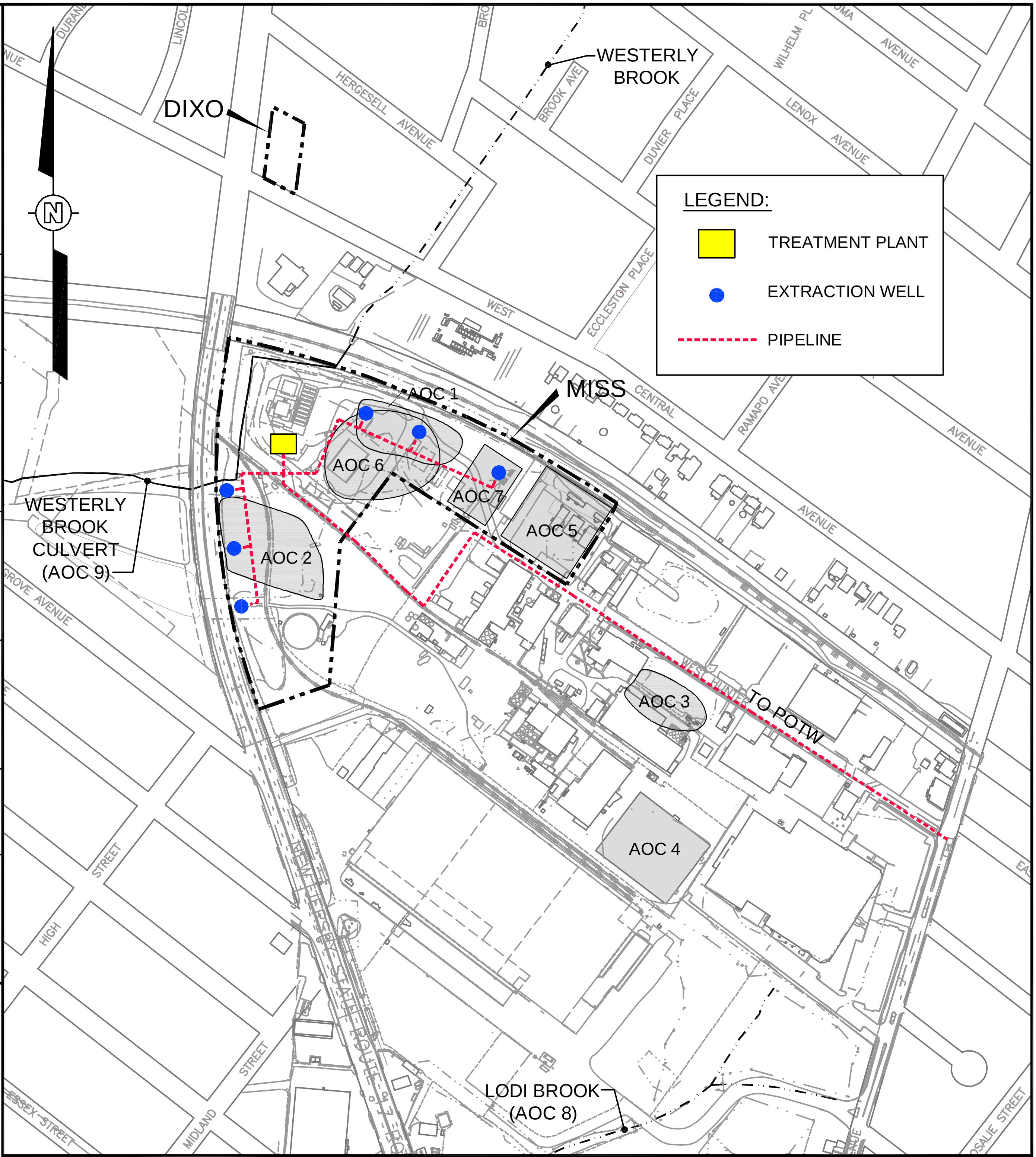
Plot Date/Time: 09/12/07 09:23am
Plotted by: bernadette.oconnor



AREAS OF CONCERN:

AOC 1 - FORMER RETENTION POND A
AOC 2 - FORMER RETENTION POND C
AOC 3 - NRC BURIAL PIT 1
AOC 4 - NRC BURIAL PIT 3
AOC 5 - WELL B38W18D (FORMER THORIUM MANUFACTURING)
AOC 6 - PROBABLE BENZENE SOURCE AREA (BEDROCK)
AOC 7 - PROBABLE BENZENE SOURCE AREA (OVERBURDEN)
AOC 8 - LODI BROOK
AOC 9 - WESTERLY BROOK

SCALE
0 400 800 FEET

FIGURE 4-4
ALTERNATIVE 4 - CONCEPTUAL GROUNDWATER TREATMENT PLANT & EXTRACTION WELL LOCATIONS
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers
FUSRAP Maywood Superfund Site
Shaw Shaw Environmental, Inc.

OFFICE	DATE	DESIGNED BY	DRAWN BY	CHECKED BY	APPROVED BY	DRAWING NUMBER
Pittsburgh, PA	1/24/05	--	A. Smith	G. Gaillot	--	108783-A6

Xref: 108783X1
Image: FMSS

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Plot Date/Time: 11/29/05 09:59am
Plotted by: greg.jones

OFFICE	DATE	DESIGNED BY	DRAWN BY	CHECKED BY	APPROVED BY	DRAWING NUMBER
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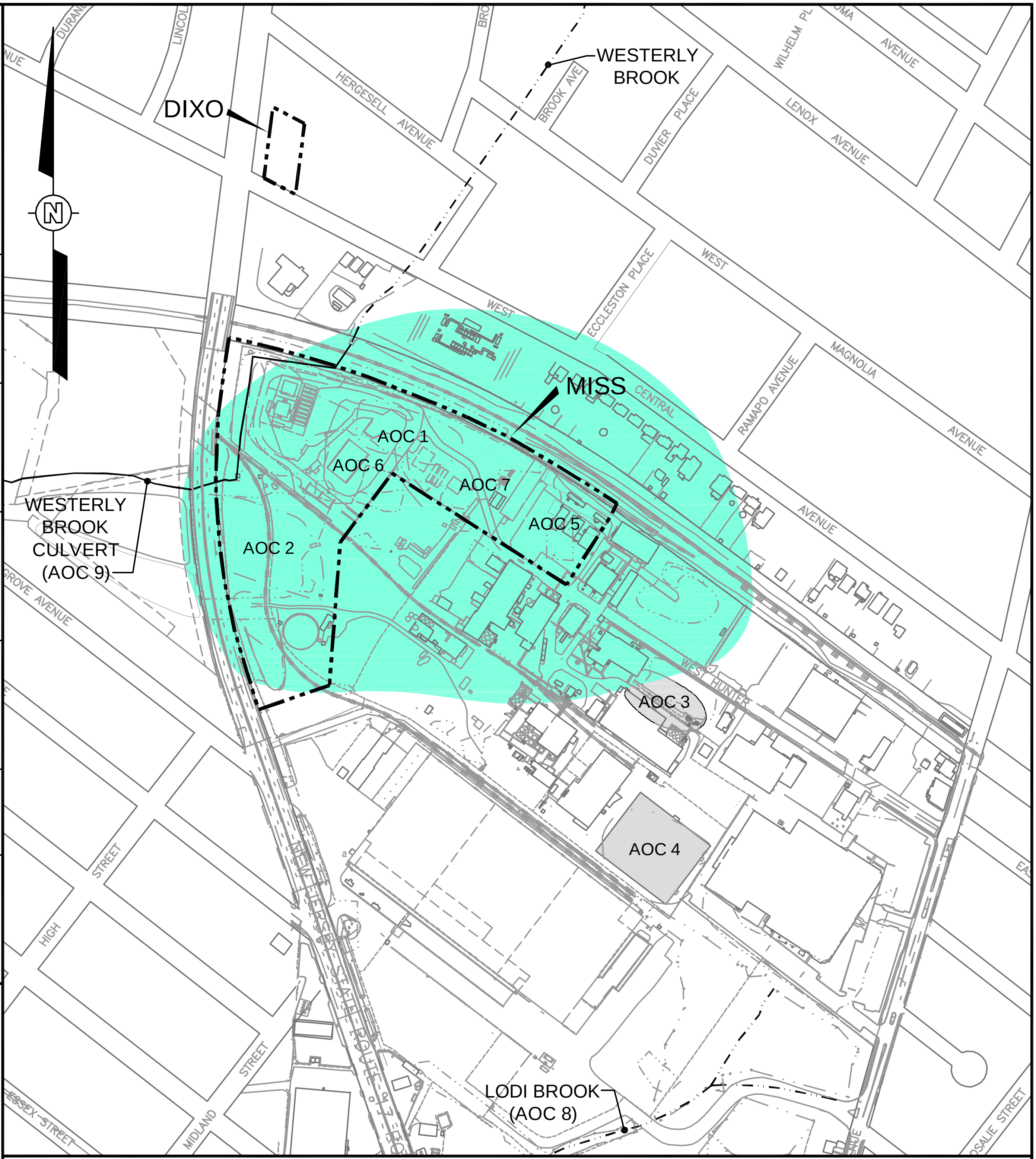

AREAS OF CONCERN:

- AOC 1 - FORMER RETENTION POND A
- AOC 2 - FORMER RETENTION POND C
- AOC 3 - NRC BURIAL PIT 1
- AOC 4 - NRC BURIAL PIT 3
- AOC 5 - WELL B38W18D (FORMER THORIUM MANUFACTURING)
- AOC 6 - PROBABLE BENZENE SOURCE AREA (BEDROCK)
- AOC 7 - PROBABLE BENZENE SOURCE AREA (OVERBURDEN)
- AOC 8 - LODI BROOK
- AOC 9 - WESTERLY BROOK

SCALE

0 400 800 FEET

FIGURE 4-5
ALTERNATIVE 4 - GROUNDWATER EXTRACTION CAPTURE ZONE
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

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Xref: 108783X1
Image: FMSS

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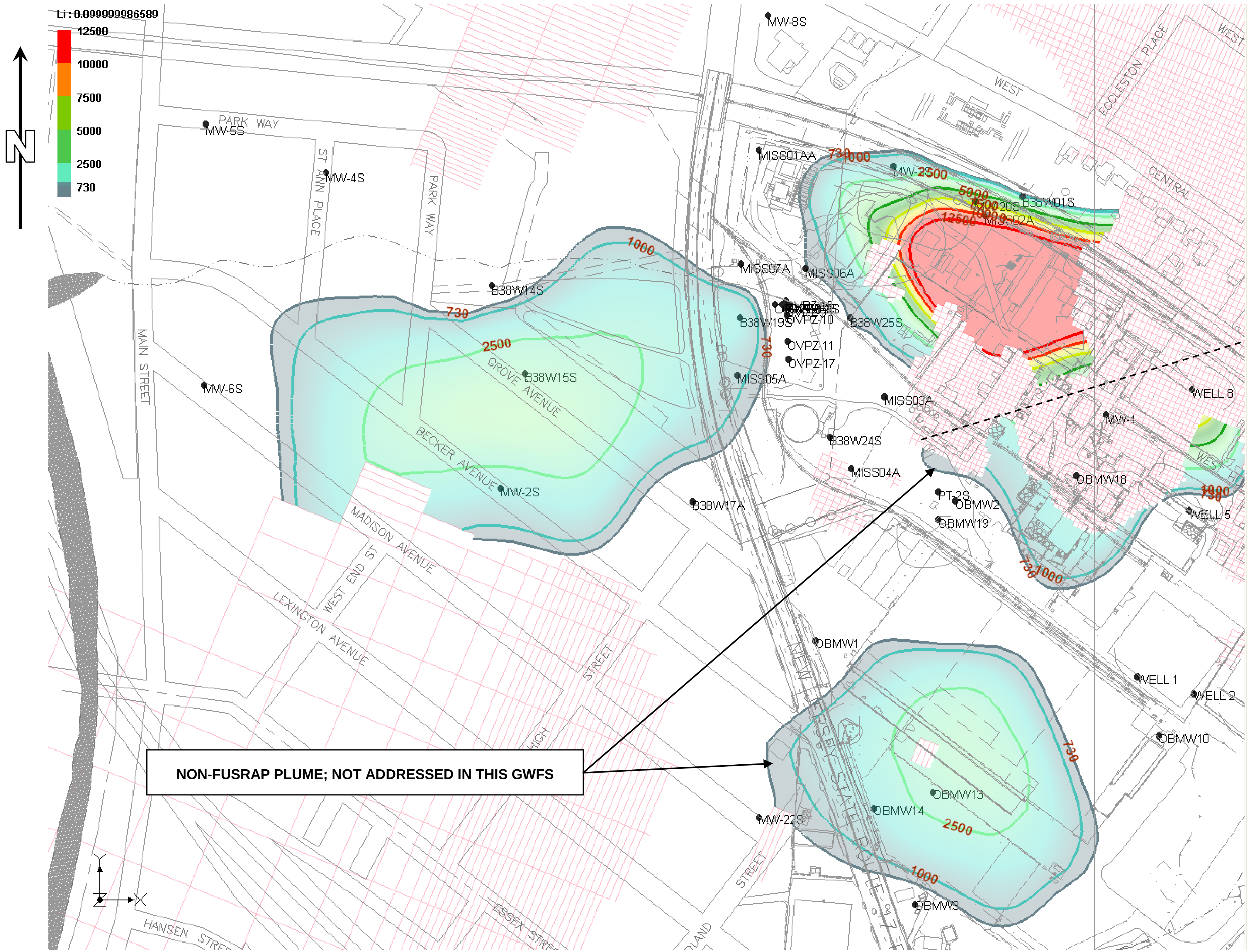
Plotted by: greg.jones



NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE RISK-BASED ACTION LEVEL FOR LITHIUM IS 730 UG/L.

4. YEAR ZERO LITHIUM CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE

1 INCH = 300 FEET

FIGURE 5-1A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
LITHIUM PLUME, OVERBURDEN
MAYWOOD SUPERFUND SITE, NEW JERSEY

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Shaw®
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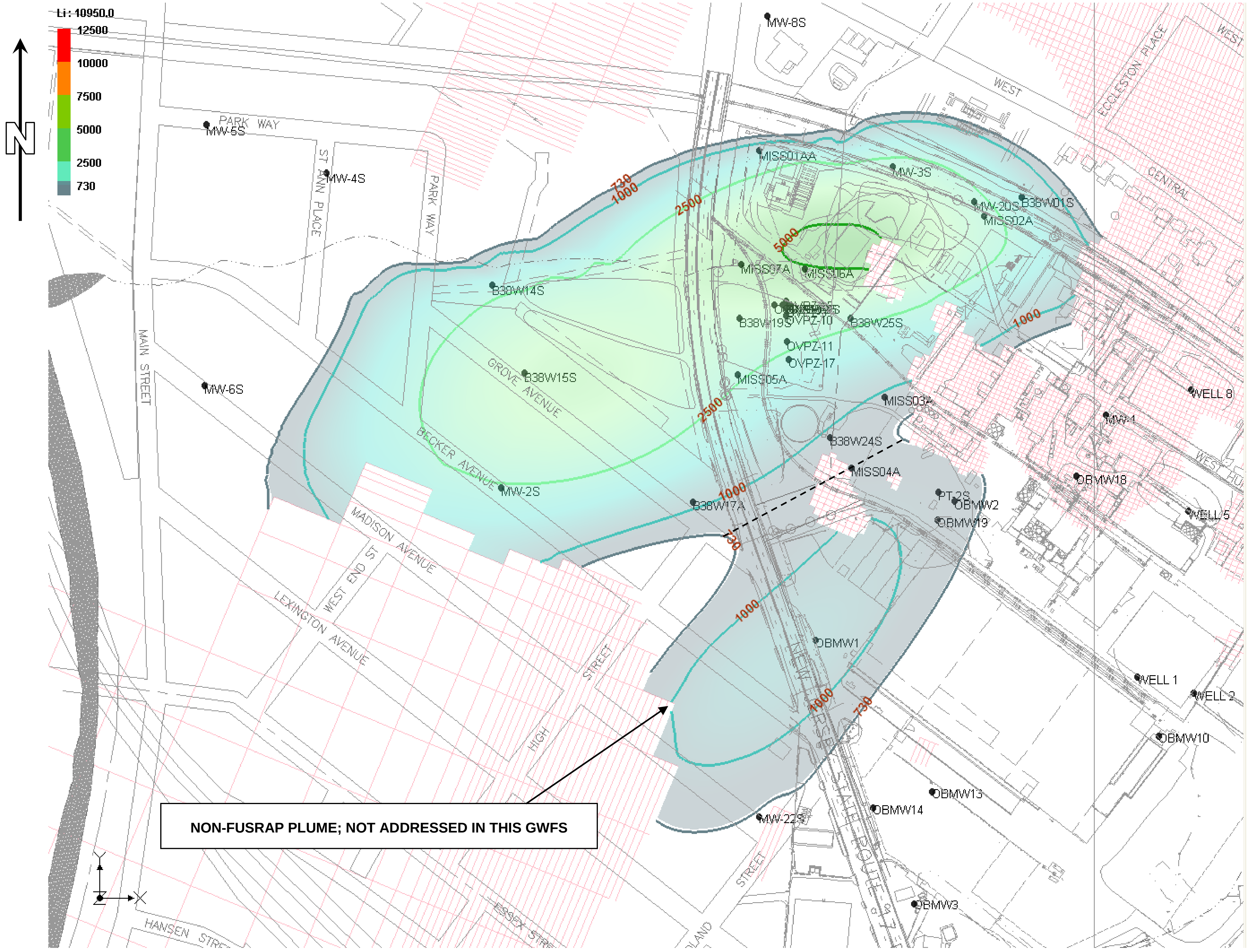

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE RISK-BASED ACTION LEVEL FOR LITHIUM IS 730 UG/L.

SCALE

1 INCH = 300 FEET

FIGURE 5-1B

ALTERNATIVES 1 AND 2 – MODEL YEAR 30 LITHIUM PLUME, OVERBURDEN

MAYWOOD SUPERFUND SITE, NEW JERSEY

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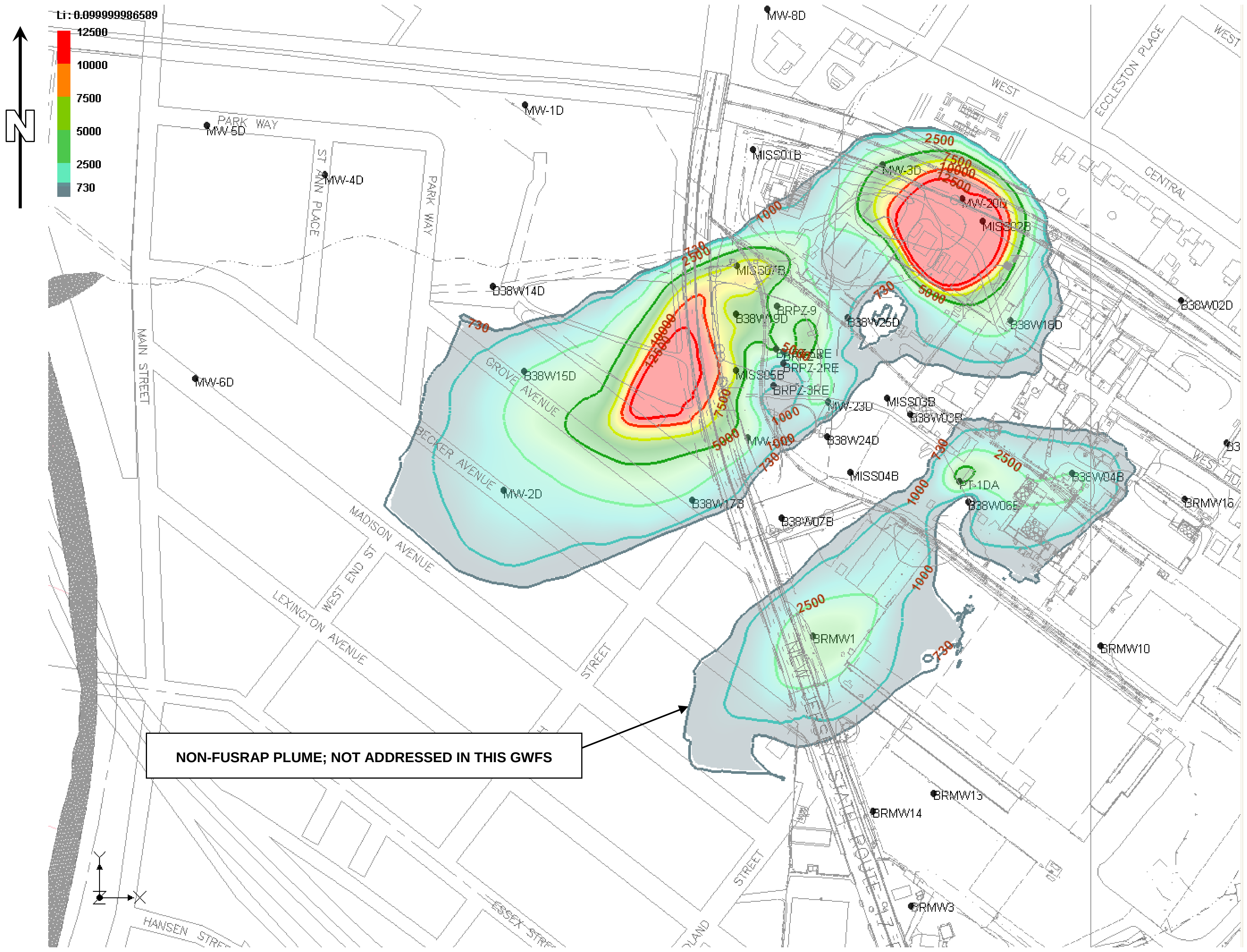

NON-FUSRAP PLUME; NOT ADDRESSED IN THIS GWFS

NOTES:

1. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE RISK-BASED ACTION LEVEL FOR LITHIUM IS 730 UG/L.

3. YEAR ZERO LITHIUM CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE

1 INCH = 300 FEET

FIGURE 5-2A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
LITHIUM PLUME, SHALLOW BEDROCK
MAYWOOD SUPERFUND SITE, NEW JERSEY

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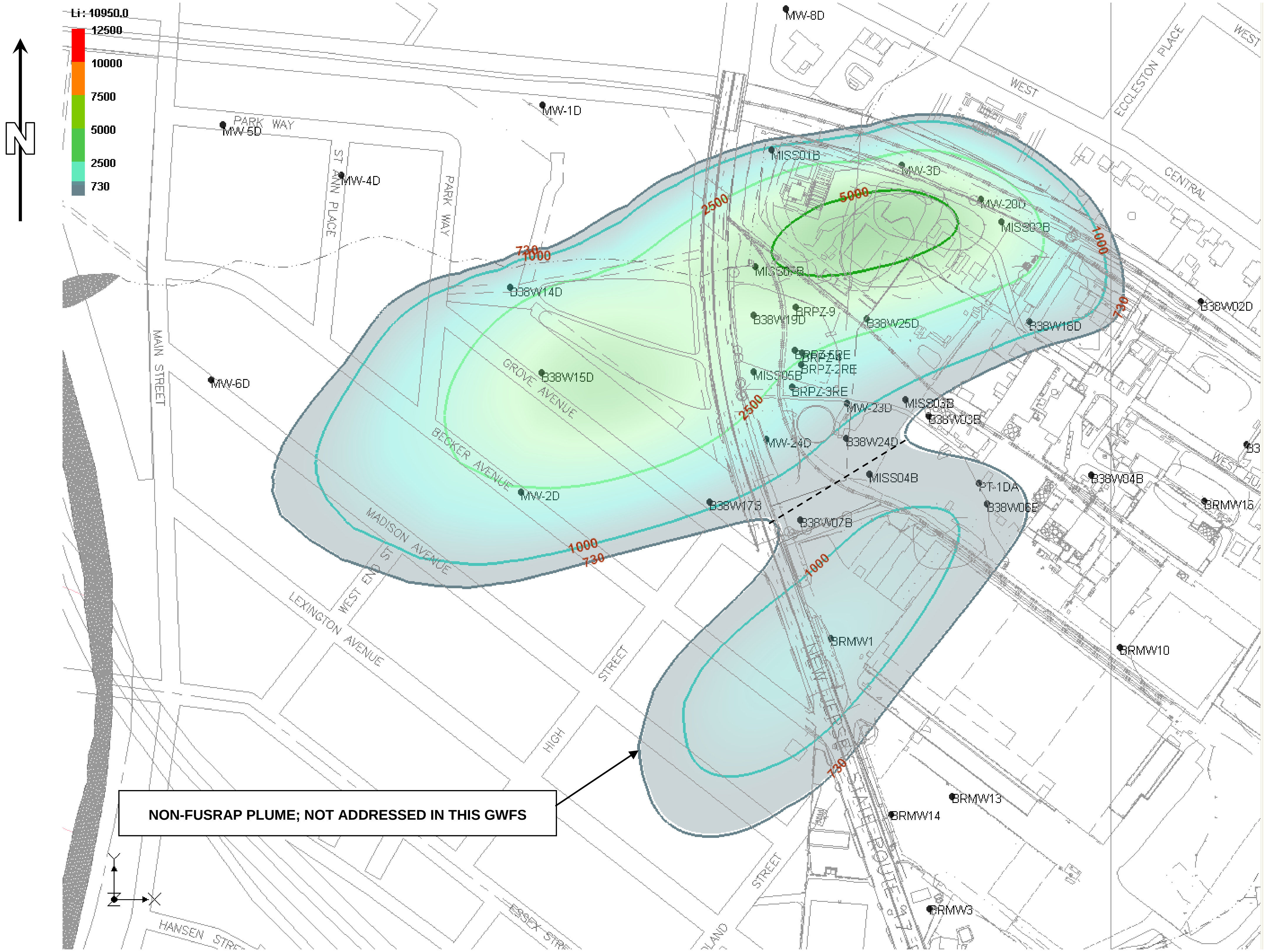

NOTES:

1. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE RISK-BASED ACTION LEVEL FOR LITHIUM IS 730 UG/L.

SCALE

1 INCH = 300 FEET

FIGURE 5-2B

ALTERNATIVES 1 AND 2 – MODEL YEAR 30 LITHIUM PLUME, SHALLOW BEDROCK

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP Maywood Superfund Site

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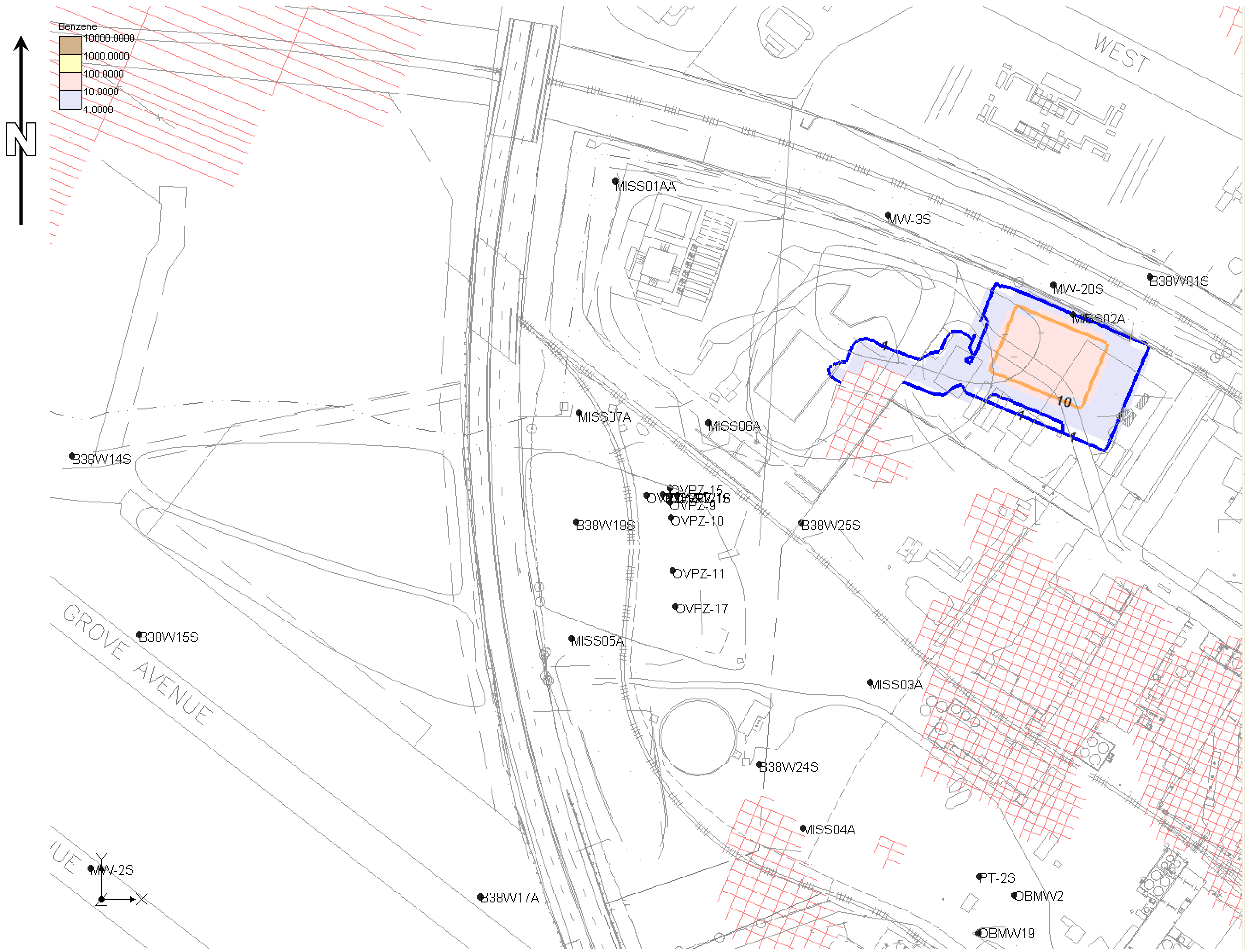

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. BENZENE CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR BENZENE IS 1 UG/L.

4. YEAR ZERO BENZENE CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE

1 INCH = 150 FEET

FIGURE 5-3A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
BENZENE PLUME, OVERBURDEN
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

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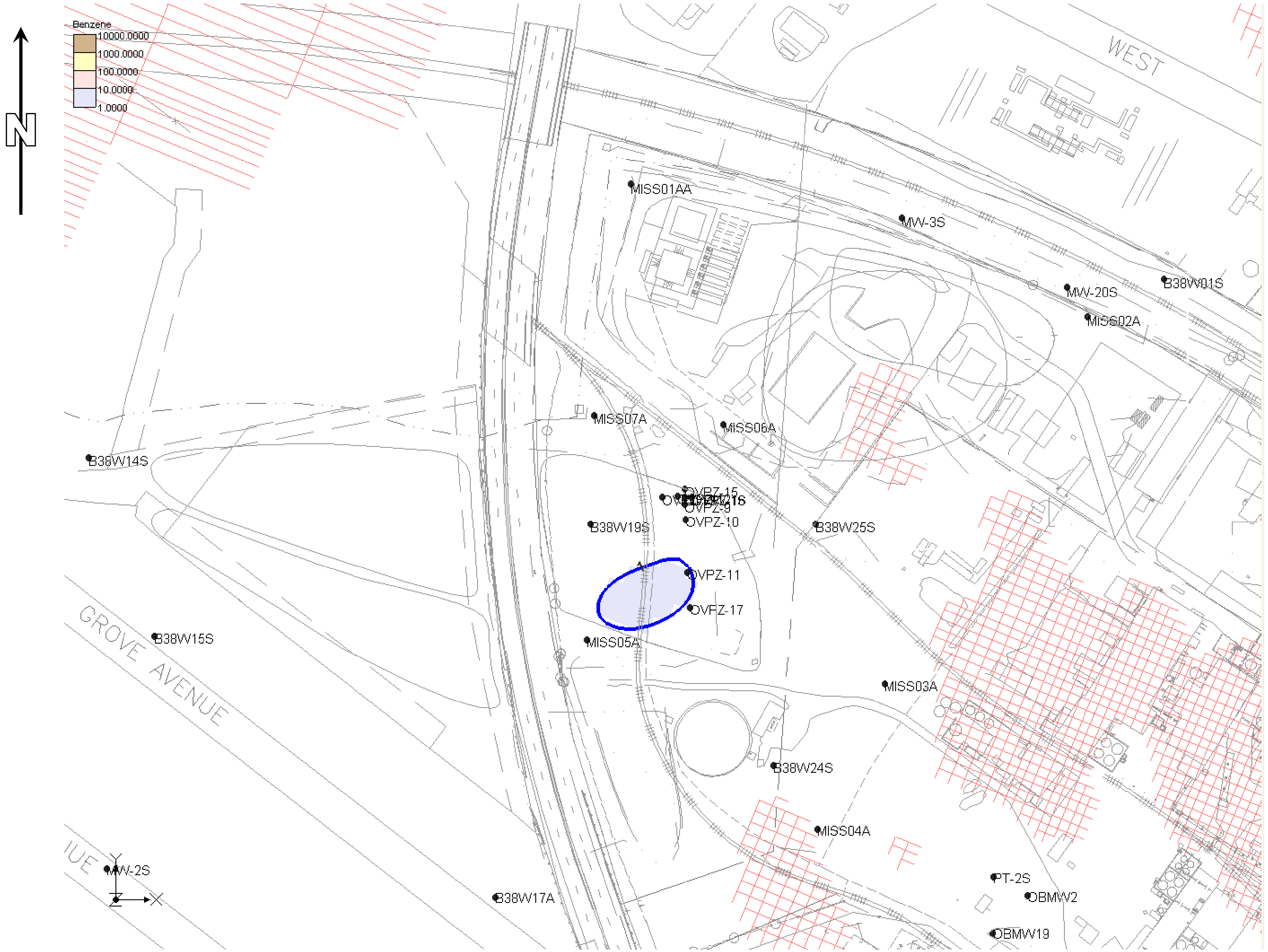

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. BENZENE CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR BENZENE IS 1 UG/L.

SCALE

1 INCH = 150 FEET

FIGURE 5-3B

ALTERNATIVES 1 AND 2 – MODEL YEAR 6 BENZENE PLUME, OVERBURDEN

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

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Maywood Superfund Site

Shaw
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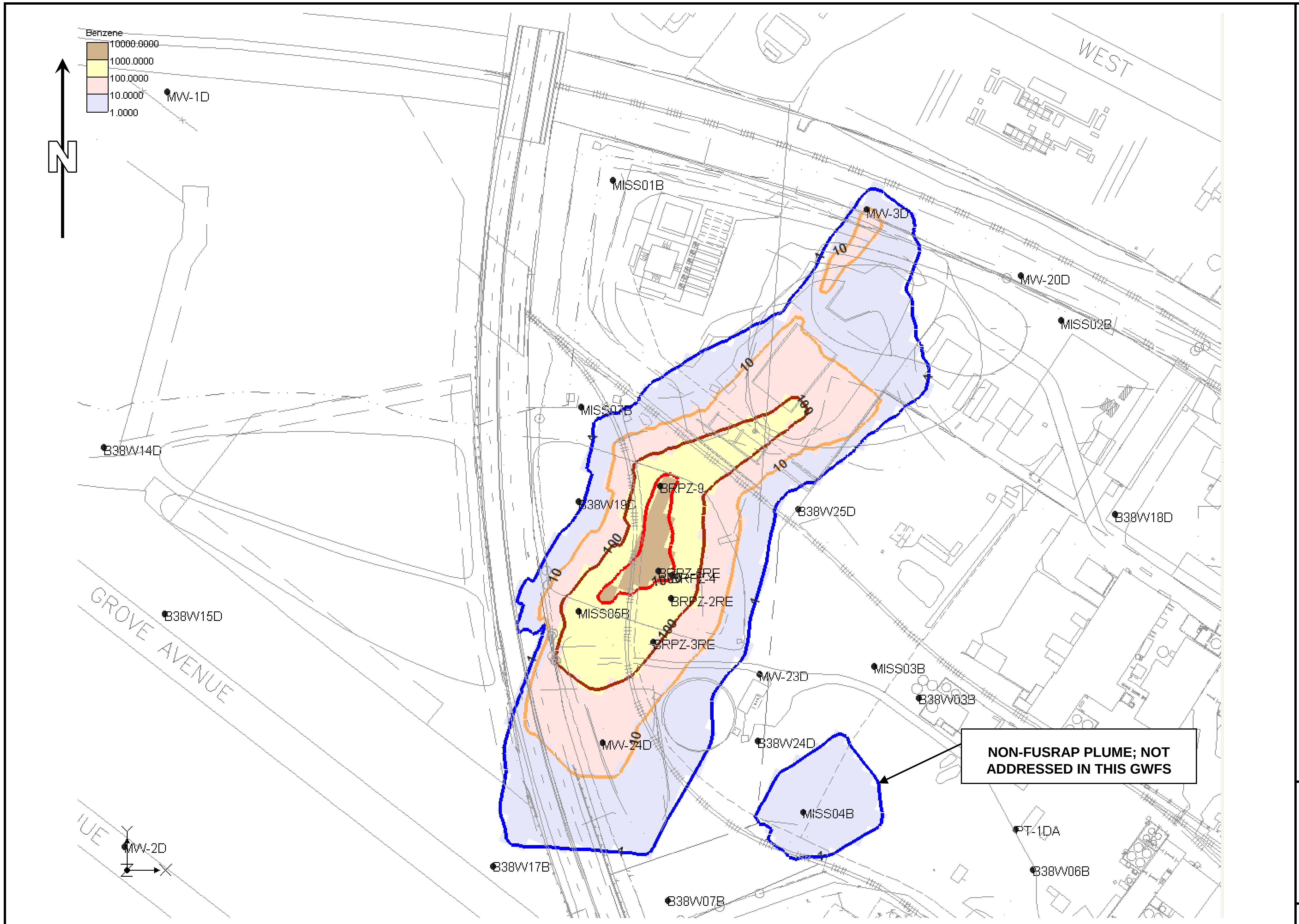


NOTES:

1. BENZENE CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE REGULATORY LIMIT FOR BENZENE IS 1 UG/L.

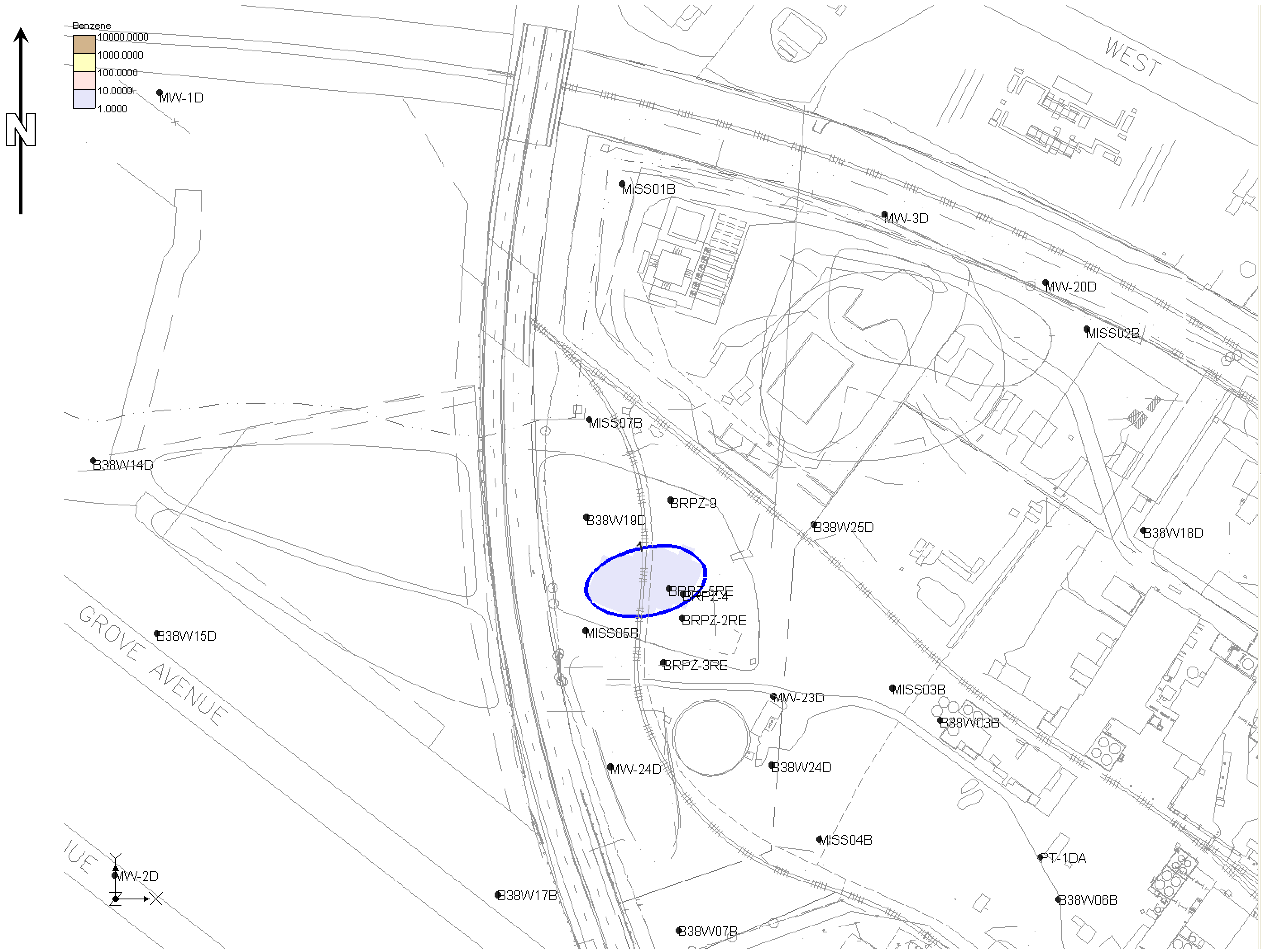
3. YEAR ZERO BENZENE CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE
1 INCH = 150 FEET

FIGURE 5-4A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
BENZENE PLUME, SHALLOW BEDROCK
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw
Shaw Environmental, Inc.



NOTES:

1. BENZENE CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE REGULATORY LIMIT FOR BENZENE IS 1 UG/L.

SCALE

1 INCH = 150 FEET

FIGURE 5-4B

ALTERNATIVES 1 AND 2 – MODEL YEAR 9
BENZENE PLUME, SHALLOW BEDROCK
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

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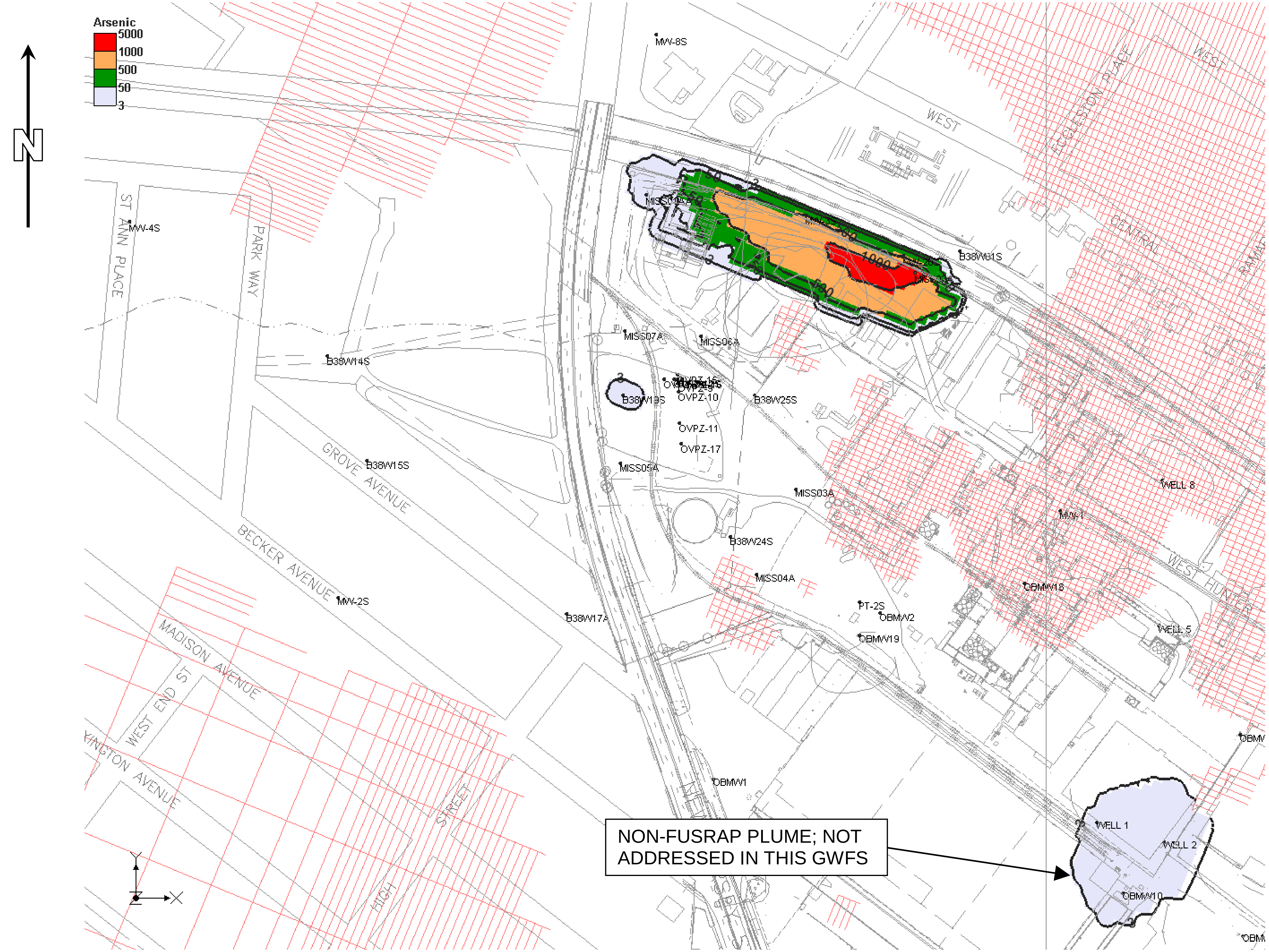

NON-FUSRAP PLUME; NOT ADDRESSED IN THIS GWFS

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

4. YEAR ZERO ARSENIC CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE

1 INCH = 250 FEET

FIGURE 5-5A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
ARSENIC PLUME, OVERBURDEN
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
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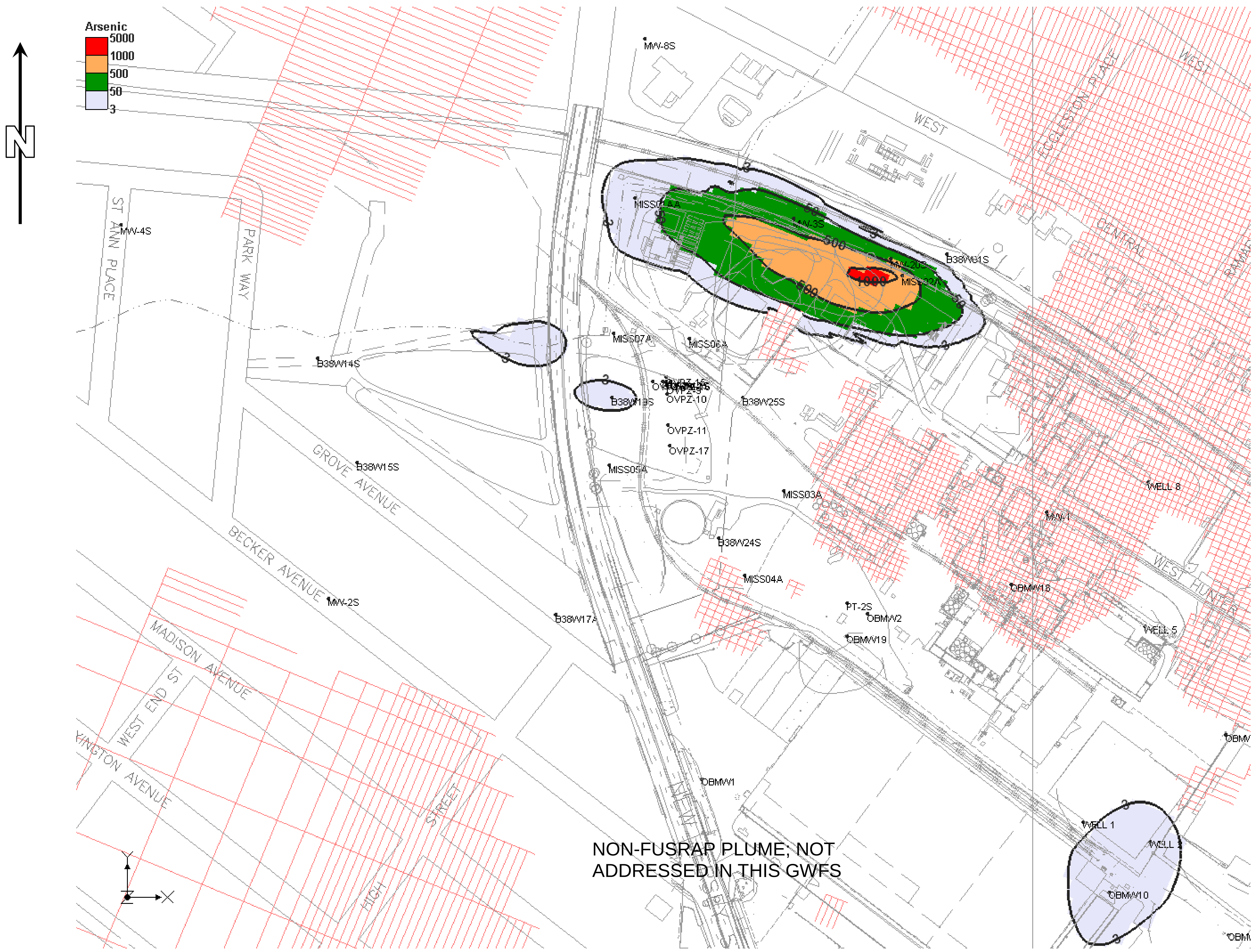


NON-FUSRAP PLUME; NOT ADDRESSED IN THIS GWFS

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

SCALE

1 INCH = 250 FEET

FIGURE 5-5B

ALTERNATIVES 1 AND 2 – MODEL YEAR 30
ARSENIC PLUME, OVERBURDEN
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.

NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

4. YEAR ZERO ARSENIC CONCENTRATIONS ARE BASED ON GROUNDWATER MONITORING RESULTS OBTAINED BETWEEN 2000 AND 2002.

SCALE

1 INCH = 250 FEET

FIGURE 5-6A

ALTERNATIVES 1 AND 2 – MODEL YEAR 0
ARSENIC PLUME, SHALLOW BEDROCK
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers
FUSRAP
Maywood Superfund Site
Shaw Environmental, Inc.

NOTES:

1. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

SCALE

1 INCH = 250 FEET

FIGURE 5-6B

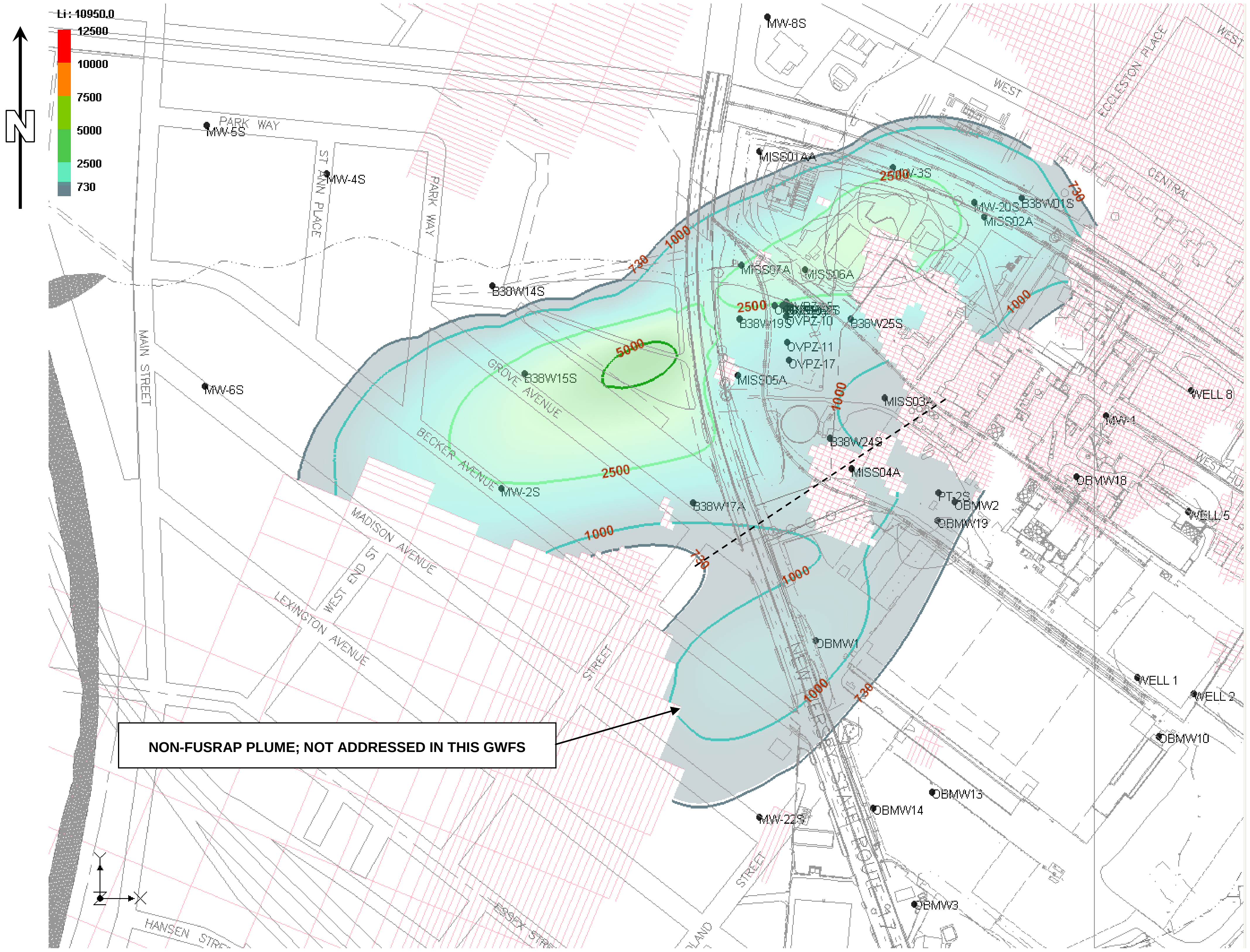
ALTERNATIVES 1 AND 2 – MODEL YEAR 30 ARSENIC PLUME, SHALLOW BEDROCK

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.



NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT IN AREAS WITH MODEL GRID.

2. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE RISK-BASED LEVEL FOR LITHIUM IS 730 UG/L.

SCALE

1 INCH = 300 FEET

FIGURE 5-7

ALTERNATIVE 4 – MODELED LITHIUM OVERBURDEN PLUME AFTER 30 YEARS OF GROUNDWATER EXTRACTION

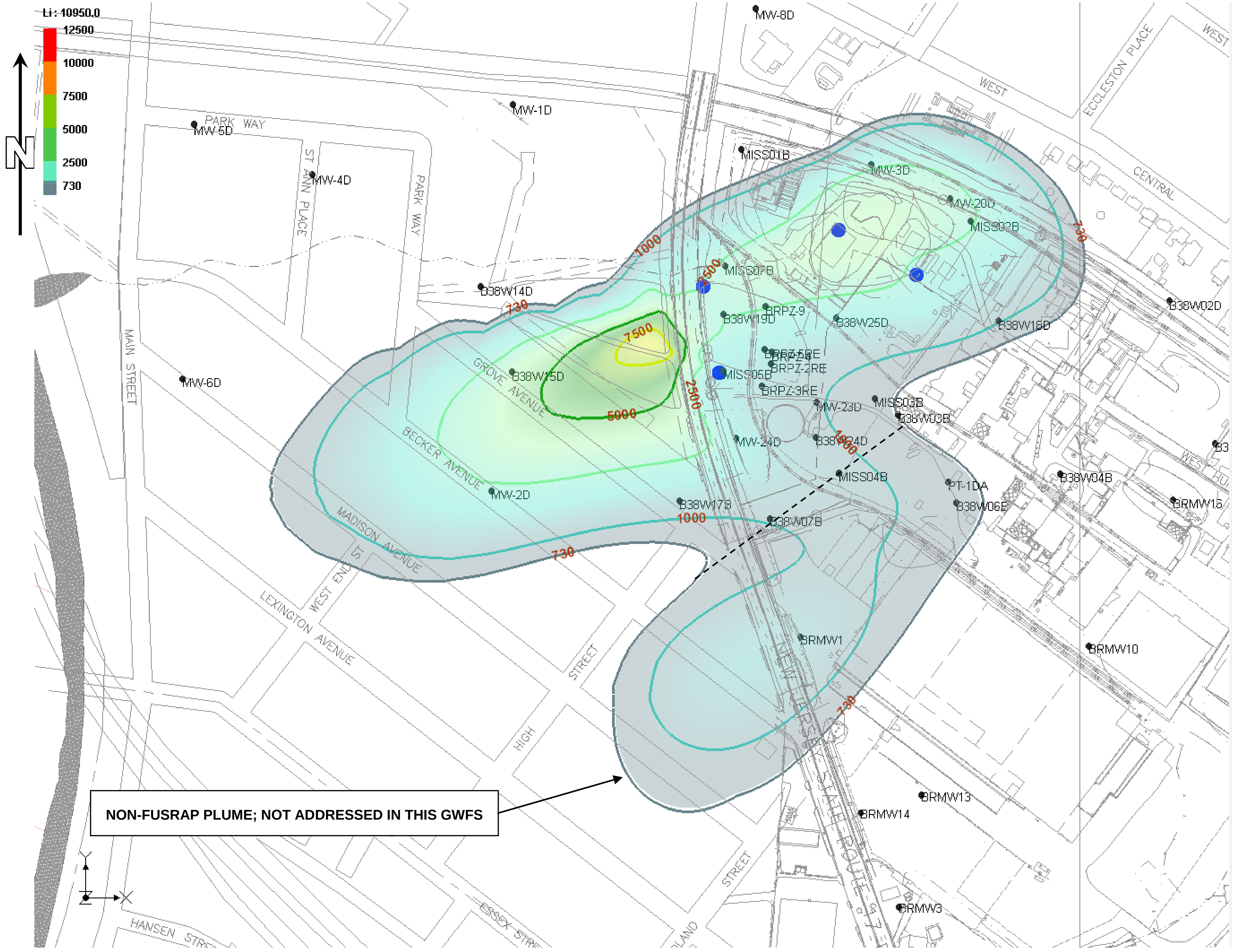
MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP

Maywood Superfund Site

Shaw Shaw Environmental, Inc.



NON-FUSRAP PLUME; NOT ADDRESSED IN THIS GWFS

NOTES:

1. LITHIUM CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE RISK-BASED ACTION LEVEL FOR LITHIUM IS 730 UG/L.

LEGEND:

● EXTRACTION WELL

SCALE

1 INCH = 300 FEET

FIGURE 5-8

ALTERNATIVE 4 – MODELED LITHIUM SHALLOW BEDROCK PLUME AFTER 30 YEARS OF GROUNDWATER EXTRACTION

MAYWOOD SUPERFUND SITE, NEW JERSEY

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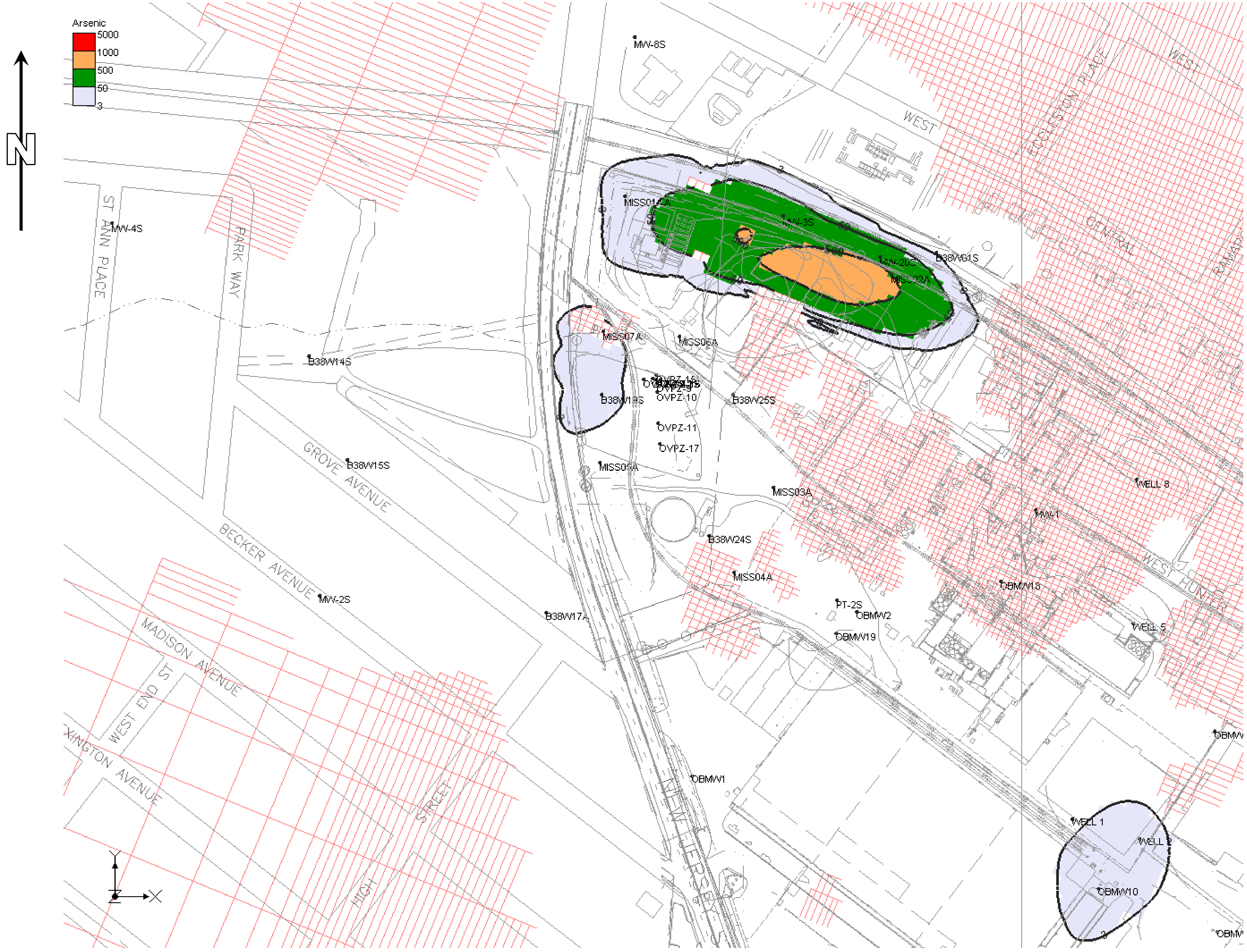


NOTES:

1. THE OVERBURDEN AQUIFER IS NOT PRESENT AREAS WITH MODEL GRID.

2. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

3. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

SCALE

1 INCH = 250 FEET

FIGURE 5-9

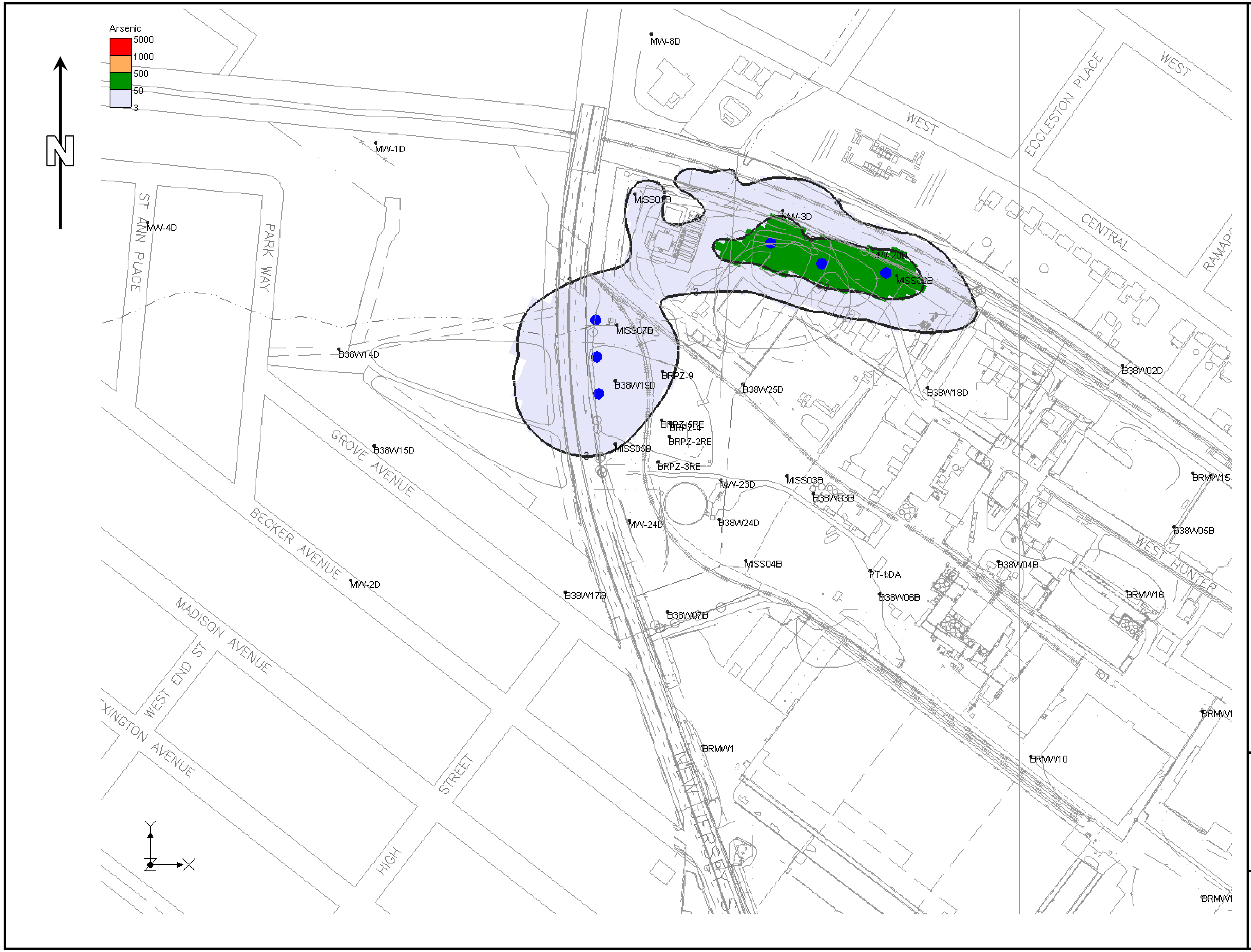
ALTERNATIVE 4 – MODELED ARSENIC OVERBURDEN PLUME AFTER 30 YEARS OF GROUNDWATER EXTRACTION

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.



NOTES:

1. ARSENIC CONCENTRATIONS ARE DISPLAYED IN UNITS OF MICROGRAMS PER LITER (UG/L).

2. THE REGULATORY LIMIT FOR ARSENIC IS 3 UG/L.

LEGEND:

● EXTRACTION WELL

SCALE

1 INCH = 250 FEET

FIGURE 5-10

ALTERNATIVE 4 – MODELED ARSENIC SHALLOW BEDROCK PLUME AFTER 30 YEARS OF GROUNDWATER EXTRACTION

MAYWOOD SUPERFUND SITE, NEW JERSEY

US Army Corps of Engineers

FUSRAP
Maywood Superfund Site

Shaw
Shaw Environmental, Inc.

APPENDIX A

SUMMARY OF HISTORICAL GROUNDWATER TRENDS (VOLUME 1)

APPENDIX A

Summary of Historical Groundwater Trends
FUSRAP Maywood Superfund Site
Maywood, New Jersey

1.0 Historical Groundwater Trends

An evaluation of historical groundwater concentration trends over time for selected chemical constituents in overburden and shallow bedrock groundwater wells was performed. The purpose of this evaluation was to determine if concentrations were increasing, decreasing, or remained stable.

Historical groundwater analytical data and RI data were reviewed for FUSRAP Maywood Superfund Site (FMSS) monitoring wells. The selection of groundwater wells and trend analysis was primarily based on the locations of the Maywood Interim Storage Site (MISS) and Areas of Concern (AOCs) 3 and 4, and exceedances of State and Federal MCLs or PRGs. Groundwater monitoring wells within the MISS and AOCs, and upgradient and downgradient of the MISS and AOCs, were selected, if warranted. Groundwater monitoring wells eliminated from the trend analysis were wells with only one sampling event or wells with a high number of non-detected (ND) concentrations. Wells selected that had some ND concentrations had their values reduced by half for trend analysis purposes. In addition, only unfiltered laboratory results were plotted.

The following sections describe the results of the plotted groundwater concentration trends over time for specific chemical constituents of selected overburden and shallow bedrock groundwater wells. The constituent data were reviewed for: lithium, benzene, thallium, arsenic, barium, beryllium, lead, adjusted gross alpha, adjusted gross beta, total radium, total uranium, methylene chloride, tetrachloroethene, toluene, trichloroethene, and vinyl chloride. Refer to Attachment 1 to review the trend plots. Well locations are shown on Groundwater Feasibility Study (GWFS) Figure 4-1.

1.1 Lithium Overburden Groundwater Trends

Eight overburden groundwater wells were selected for lithium trend analysis: MISS02A, B38W01S, MISS06A, MISS05A, B38W19S, MISS03A, B38W15S, and B38W17A.

Trends for northern MISS well MISS02A results show increasing concentrations of lithium through December 2000 (10,100 µg/L), then concentrations decrease in subsequent sampling events to 6,200 µg/L. Well B38W01S had increasing concentrations of lithium until April 1991 (3,550 µg/L), then decreased to a concentration of 1,250 µg/L in the last sampling event (June 2003). In the central portion of the MISS, well MISS06A had a decreasing trend, with concentrations ranging from 12,400 µg/L (July 1991) to less than 100 µg/L (ND for two sampling events). The most recent concentration was 1,450 µg/L. In the southwestern portion of the MISS, wells MISS05A and B38W19S had a decrease in concentration of lithium as well. Well MISS05A ranged from 1,850 µg/L (July 1991) to 560 µg/L (July 2003), and well B38W19S concentrations ranged from 1,730 µg/L (November 2000) to 960 µg/L (July 2003).

Wells downgradient and off the MISS (MISS03A, B38W15S and B38W17A) had trends that decreased in lithium concentration during the last several sampling events after what may have been a longer term increase in concentration. Well MISS03A lithium concentrations ranged from 213 µg/L in October 1990 to less than 100 µg/L (ND) in January 1991. Well B38W15S had increased lithium concentrations from less than 100 µg/L (ND) in January 1991 to 3,240 µg/L (November 2000), then decreasing to 2,240 µg/L in July 2003. Well B38W17A had an increasing and decreasing trend with the highest lithium concentration in July 1991 (551 µg/L), which then decreased to 298 µg/L in June 2001.

1.2 Lithium Shallow Bedrock Groundwater Trends

Eight shallow bedrock groundwater wells were selected for lithium trend plots: MISS02B, B38W18D, MISS01B, MISS05B, MISS07B, MISS03B, B38W15D, and B38W17B. Northern MISS well MISS02B had one of the highest concentrations of lithium (16,700 µg/L), but had a decreasing trend in the last three sampling events with the most recent lithium concentration of 9,590 µg/L. Well B38W18D (south of MISS02B) had a consistent trend of concentrations near 3,000 µg/L with the exception of two lower concentrations of 1,480 µg/L and 307 µg/L. Well MISS01B had a decreasing trend with concentrations ranging from 119 µg/L (October 1990) to ND (less than100 µg/L to less than 38.6 µg/L). Southwest of well MISS02B, well MISS05B increased to 7,400 µg/L in November 2000, then decreased to the most recent concentration of 1,290 µg/L. Well MISS07B had both increases and decreases in the trend data with the lowest concentration of 459 µg/L and the highest concentration of 9,100 µg/L. However, the trend appears to be generally upward.

Just outside the MISS, well MISS03B had an overall decreasing trend with concentrations ranging from 161 µg/L (July 1991) to less than 100 µg/L (ND for two sampling events). Further off the MISS, well B38W15D had an increasing and decreasing trend with the most recent concentration of 2,940 µg/L. Off the MISS, well B38W17B had an overall increasing trend of lithium concentrations ranging from less than 100 µg/L (ND for two sampling events) to 1,970 µg/L (November 2000) with the most recent concentration of 1,810 µg/L.

1.3 Benzene Overburden Groundwater Trends

No overburden groundwater wells were selected for trend analysis due to low detected concentrations of benzene in the MISS overburden groundwater.

1.4 Benzene Shallow Bedrock Groundwater Trends

Seven shallow bedrock wells were selected for benzene trend analysis: MISS02B, MW-3D, MW-26D, BRPZ-9, B38W19D, MISS05B, and MW-24D. Well MISS02B had a decreasing trend with concentrations ranging from 180 µg/L (several sampling events) to very low concentrations. Well MW-3D had a concentration of 5 µg/L (April 2001) and during another sampling event, a concentration of 15 µg/L (August 2002). South of well MISS02B, well MW-26D had concentrations ranging from 520 µg/L (January 2002) to 180 µg/L (August 2002). Further south of well MW-26D, well BRPZ-9 had concentrations of 1,500 µg/L (July 2001) and 1,800 µg/L (August 2002).

In the southwestern portion of the MISS, wells B38W19D and MISS05B had generally low concentrations with an increase to 39 µg/L and 3,500 µg/L, respectively, in June 2001 and November 2000, then decreasing to 0.5 µg/L and less than 5 µg/L (ND), thereafter. In the southern portion of the MISS, well MW-24D had concentrations of 78 µg/L (September 2001) and 29 µg/L (July 2002).

1.5 Thallium Overburden Groundwater Trends

No overburden groundwater wells were selected for trend analysis due to many ND thallium concentrations.

1.6 Thallium Shallow Bedrock Groundwater Trends

Two shallow bedrock groundwater wells were selected in the MISS for thallium trend analysis: B38W02D and B38W18D. Well B38W02D had concentrations ranging from ND (less than 8 µg/L to less than 1 µg/L) to 5.5 µg/L (July 2000). Well B38W18D had concentrations ranging from 7.8 µg/L (July 2000) to ND (less than 50 µg/L to less than 2 µg/L).

1.7 Arsenic Overburden Groundwater Trends

Seven overburden groundwater wells were selected for arsenic trend analysis: MISS02A, MISS06A, B38W19S, MISS03A, B38W14S, B3815S, and B38W17A. All three wells within the MISS, wells MISS02A, MISS06A, and B38W19S, had variable concentrations. Well MISS02A arsenic concentrations ranged from 4,770 µg/L (April 2000) to 2,110 µg/L (July 2002), and well MISS06A arsenic concentrations ranged from 38 µg/L (October 1990) to ND (less than 200 µg/L to less than 2.3 µg/L). Well B38W19S arsenic concentrations ranged from 32 µg/L (November 2000) to ND (less than 200 µg/L to less than 18 µg/L).

Just outside of the MISS, well MISS03A had variable concentrations with the highest concentration being 252 µg/L. Downgradient and off the MISS, wells B38W14S and B38W17A had generally lower concentrations of arsenic. The highest concentrations for wells B38W14S and B38W17A were 20 µg/L and 10.5 µg/L. Well B38W15S had concentrations ranging from 6.4 µg/L to ND (less than 7 µg/L to less than 2 µg/L).

1.8 Arsenic Shallow Bedrock Groundwater Trends

Six shallow bedrock groundwater wells were selected for arsenic trend analysis: B38W18D, MISS07B, MISS05B, B38W19D, MISS03B, and B38W15D. Within the eastern portion of the MISS, well B38W18D had concentrations of arsenic ranging from 23 µg/L (April 2000) to ND (less than 10 µg/L to less than 2 µg/L).

In the western portion of the MISS, well MISS07B showed wide ranges of concentrations; well MISS05B had a generally increasing trend; and well B38W19D had an overall decreasing trend during the later sampling period. MISS07B had the highest concentration of arsenic of the three wells with concentrations ranging from 155 µg/L (July 1991) to 4.6 µg/L (January 1991).

Just outside the MISS, well MISS03B had concentrations of arsenic with concentrations ranging from 10.3 µg/L (April 1991) to ND (less than 6.1 µg/L to less than 2 µg/L).

Downgradient and off the MISS, well B38W15D had arsenic concentrations ranging from 19.1 µg/L (November 2000) to less than 2 µg/L (ND for two sampling events).

1.9 Barium Overburden Groundwater Trends

There were no overburden wells selected for trend analysis due to low concentrations of barium within the MISS.

1.10 Barium Shallow Bedrock Groundwater Trends

Four MISS shallow bedrock groundwater wells were selected for trend analysis: B38W25D, MISS05B, B38W24D, and B38W15D. All wells, with the exception of B38W25D, had a decreasing trend with low concentrations of barium with the exception of the last sampling event. Well B38W25D had an increase in barium concentrations with the highest concentration of 312 µg/L. The last sampling event had a lower result of 237 µg/L.

1.11 Beryllium Overburden Groundwater Trends

There were no overburden wells selected for trend analysis due to low concentrations of beryllium.

1.12 Beryllium Shallow Bedrock Groundwater Trends

There were no shallow bedrock wells selected for trend analysis due to low concentrations of beryllium.

1.13 Lead Overburden Groundwater Trends

Four overburden groundwater wells were selected for lead trend analysis: MISS02A, MISS06A, B38W14S, and B38W17A. Wells MISS02A and MISS06A had overall decreasing trends. Well MISS02A concentrations ranged from 30 µg/L (January 1991) to ND (less than 3.6 µg/L to less than 50 µg/L). The highest concentration for well MISS06A was 79 µg/L (October 1990) and less than 3.6 µg/L (ND) in the last sampling event.

Downgradient and off the MISS, wells B38W14S and B38W17A also had decreasing trends with lead concentrations of 62.4 µg/L for B38W14S and 168 µg/L for well B38W17A in 1991 to ND (less than 10 µg/L to less than 1.1 µg/L) for both wells thereafter.

1.14 Lead Shallow Bedrock Groundwater Trends

There were no shallow bedrock wells selected for trend analysis due to low lead concentrations within the MISS.

1.15 Adjusted Gross Alpha Overburden Groundwater Trends

There were no overburden groundwater wells selected for trend analysis due to many NDs and laboratory-reported measurement errors.

1.16 Adjusted Gross Alpha Shallow Bedrock Groundwater Trends

There were no shallow bedrock wells selected for trend analysis due to many NDs and laboratory-reported measurement errors.

1.17 Adjusted Gross Beta Overburden Groundwater Trends

There were no overburden wells selected for trend analysis due to many NDs and laboratory-reported measurement errors.

1.18 Adjusted Gross Beta Shallow Bedrock Groundwater Trends

There were no shallow bedrock wells selected for trend analysis due to many NDs and laboratory-reported measurement errors.

1.19 Total Radium Overburden Groundwater Trends

Five overburden groundwater wells were selected for trend analysis of total radium: B38W19S, MISS06A, MISS03A, B38W14S, and B38W15S. In the south-central portion of the MISS, well B38W19S had an increasing trend with total radium concentrations of 0.59 pCi/L (May 1994) to 5.18 pCi/L (July 2003). Well MISS06A had concentrations ranging from 0.7 pCi/L (July 2002) to 6.30 pCi/L (July 2003).

Just outside the MISS, well MISS03A had a decreasing trend with concentrations ranging from 7.5 pCi/L (July 1991) to 1.0 pCi/L (July 2001). Downgradient and off the MISS, wells B38W14S and B38W15S had overall decreasing trends that were more recently near 1.0 pCi/L.

1.20 Total Radium Shallow Bedrock Groundwater Trends

Seven shallow bedrock groundwater wells were selected for trend analysis of total radium: MISS02B, B38W18D, MISS07B, MISS05B, MISS03B, B38W04B, and B38W15D. Within the MISS, wells MISS02B, B38W18D, MISS07B, and MISS05B all had decreasing trends with current concentrations near 1.0 pCi/L.

Just outside the MISS, well MISS03B had a decreasing trend with low concentrations of total radium, and well B38W04B was variable with the most current result being less than 2 pCi/L.

Downgradient of the MISS, well B38W15D had a decreasing trend with the last six sample results being less than 2 pCi/L.

1.21 Total Uranium Overburden Groundwater Trends

Six overburden groundwater wells were selected for trend analysis of total uranium: B38W19S, B38W25S, MISS05A, MISS03A, B38W15S, and B38W17A. Within the MISS, well B38W19S had increasing and decreasing concentrations with generally lower concentrations of total uranium. Well B38W25S had a decreasing trend with one total uranium concentration near 8 µg/L (July 2001), while all other concentrations were below 2 µg/L. Well MISS05A had increasing and decreasing concentrations with values ranging from 75 µg/L (June 2001) to 544 µg/L (June 1998).

Just outside of the MISS, well MISS03A had increasing and decreasing total uranium concentrations ranging from 15 µg/L (July 1991) to 0.4 µg/L (November 2000). Downgradient of the MISS, wells B38W15S and B38W17A both had overall decreasing trends with the most recent concentrations less than 2.0 µg/L.

1.22 Total Uranium Shallow Bedrock Groundwater Trends

There were no shallow bedrock wells selected for trend analysis due to low concentrations of total uranium.

1.23 Methylene Chloride Overburden Groundwater Trends

There were no overburden groundwater wells selected for trend analysis due to the low number of detected concentrations of methylene chloride.

1.24 Methylene Chloride Shallow Bedrock Groundwater Trends

There were no shallow bedrock groundwater wells selected for trend analysis due to the low number of detected concentrations of methylene chloride.

1.25 Tetrachloroethene Overburden Groundwater Trends

There were no overburden groundwater wells selected for trend analysis due to the low number of detected concentrations of tetrachloroethene.

1.26 Tetrachloroethene Shallow Bedrock Groundwater Trends

Four shallow bedrock wells were selected for groundwater trend analysis of tetrachloroethene: MISS02B, MISS05B, MISS01B, and MISS07B. Within the MISS, wells MISS02B and MISS05B had decreasing trends with higher initial tetrachloroethene concentrations (near 30 µg/L) that decreased to ND (less than 12.5 µg/L to less than 0.1 µg/L). MISS wells MISS01B and MISS07B had increasing and decreasing concentrations. Well MISS01B concentrations ranged from ND (less than 5 µg/L) to 140 µg/L (May 1994). Well MISS07B concentrations ranged from 110 µg/L (January 1985) to 2 µg/L (July 2003).

1.27 Toluene Overburden Groundwater Trends

There were no selected overburden wells for trend analysis of toluene due to low concentrations.

1.28 Toluene Shallow Bedrock Groundwater Trends

There were no selected shallow bedrock wells for trend analysis of toluene due to low concentrations.

1.29 Trichloroethene Overburden Groundwater Trends

There were no selected overburden wells for trend analysis of trichloroethene due to low concentrations of trichloroethene within the MISS.

1.30 Trichloroethene Shallow Bedrock Groundwater Trends

Two shallow bedrock groundwater wells were selected for trichloroethene trend analysis: MISS01B and MISS07B. Within the MISS, well MISS01B had variable concentrations with trichloroethene concentrations ranging from less than 5 µg/L (ND for several sampling events) to 9 µg/L (May 1994 and May 1996). Well MISS07B had a decreasing trend with concentrations ranging from 16 µg/L (January 1986) to less than 5 µg/L (ND for several sampling events).

1.31 Vinyl Chloride Overburden Groundwater Trends

There were no selected overburden wells for trend analysis of vinyl chloride due to low concentrations of vinyl chloride within the MISS.

1.32 Vinyl Chloride Shallow Bedrock Groundwater Trends

There were no selected shallow bedrock wells for trend analysis of vinyl chloride due to low concentrations of vinyl chloride within the MISS.

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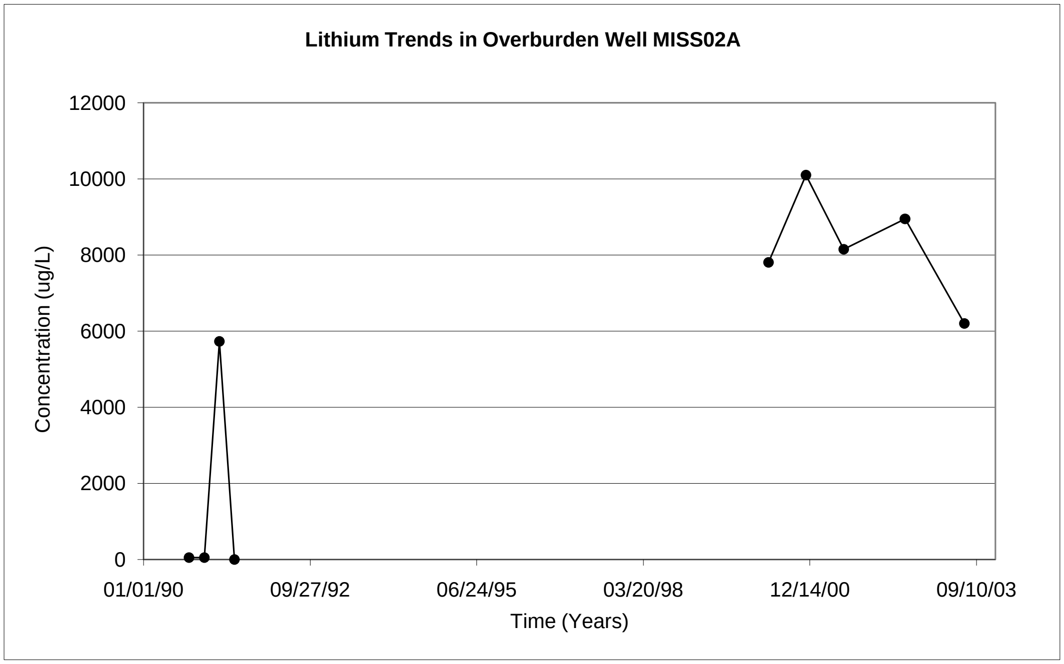
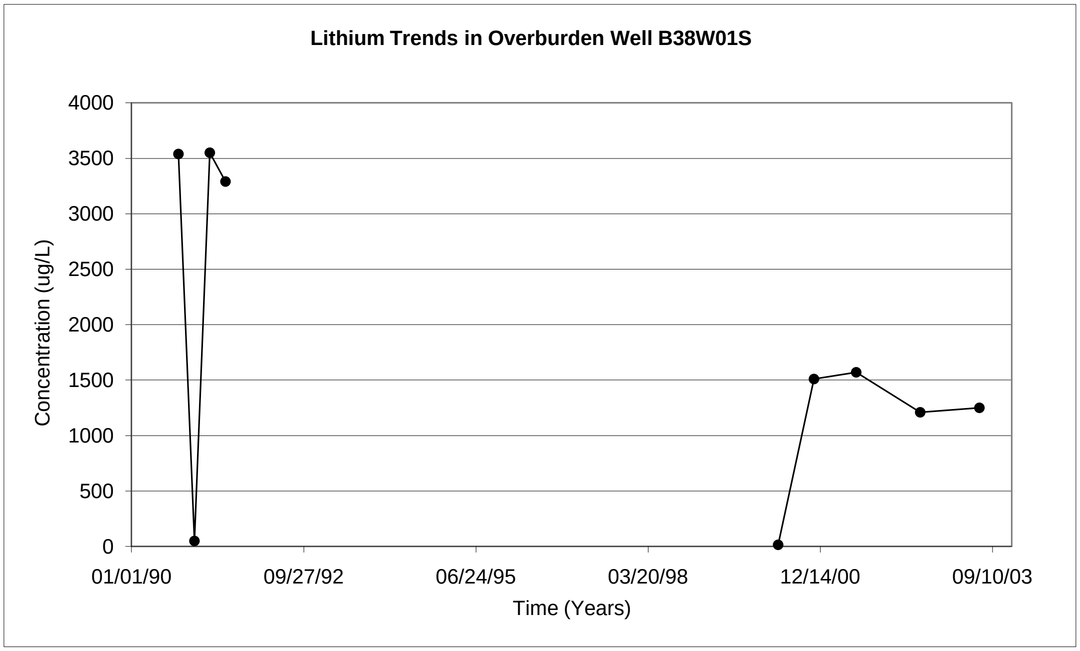
ATTACHMENT 1

GROUNDWATER TREND PLOTS

APPENDIX A

SUMMARY OF HISTORICAL GROUNDWATER TRENDS
FUSRAP MAYWOOD SUPERFUND SITE
MAYWOOD, NEW JERSEY





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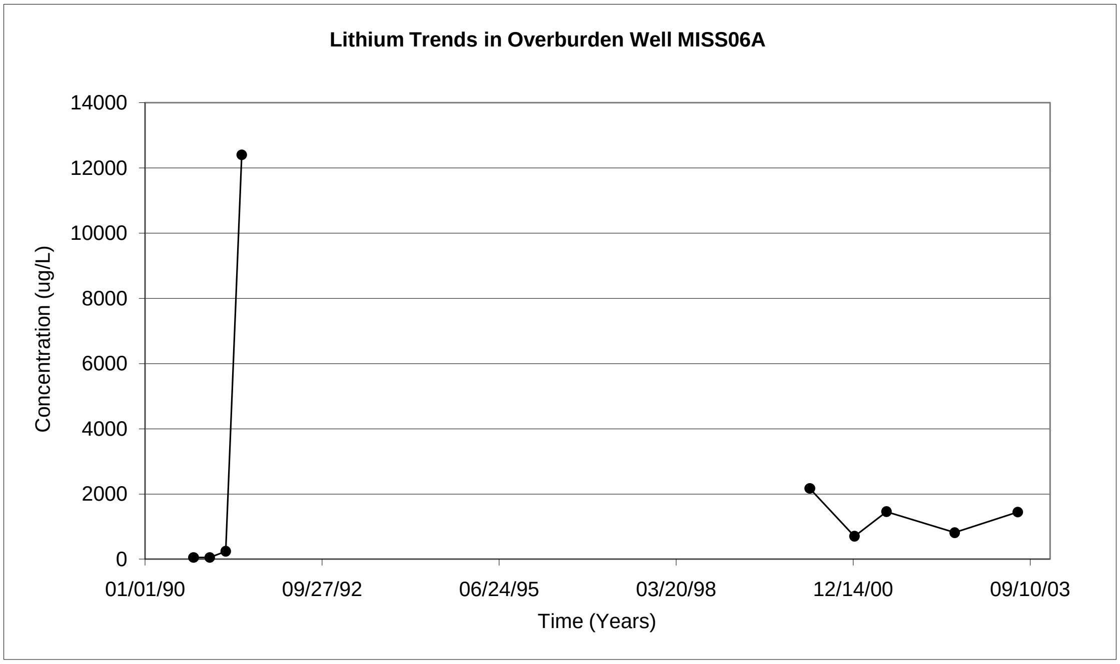

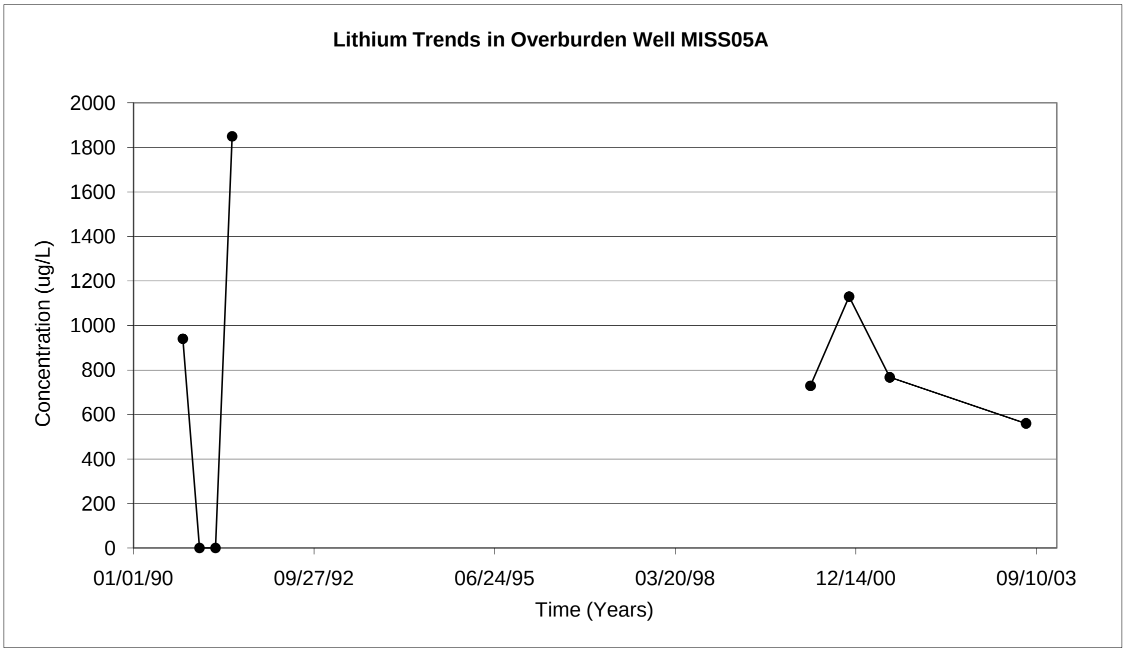

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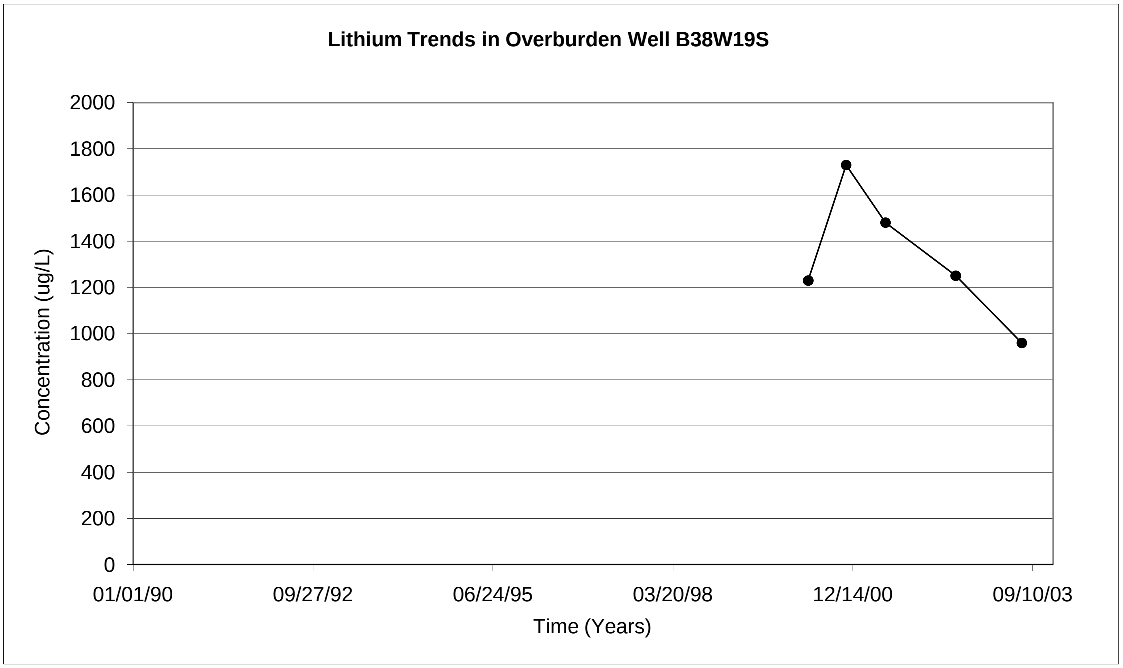

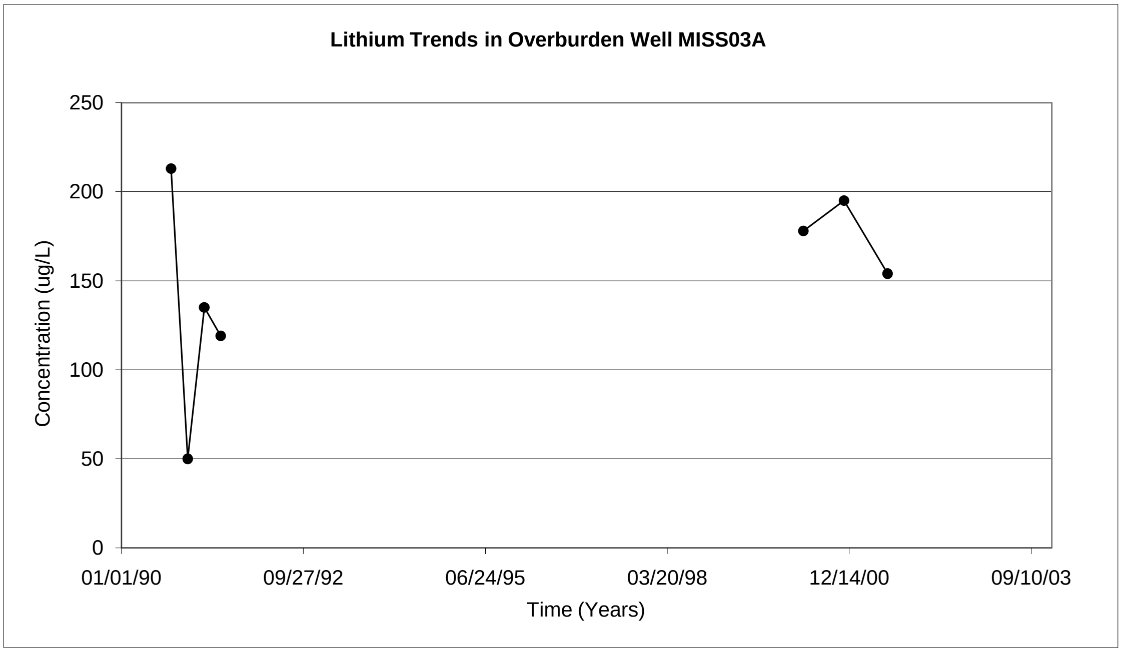

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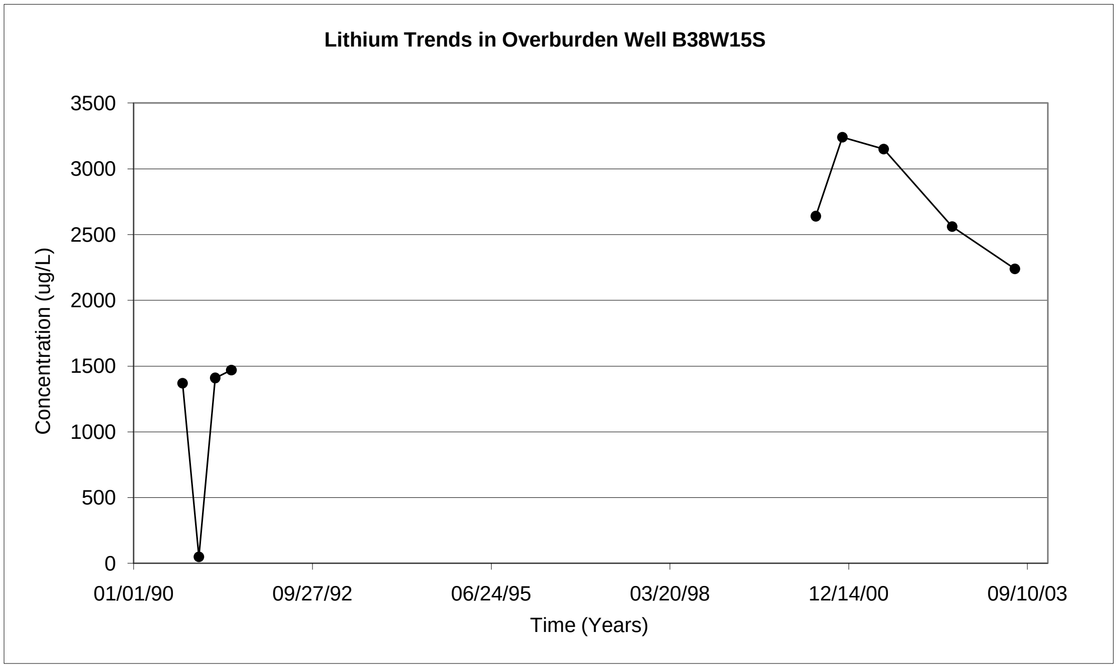

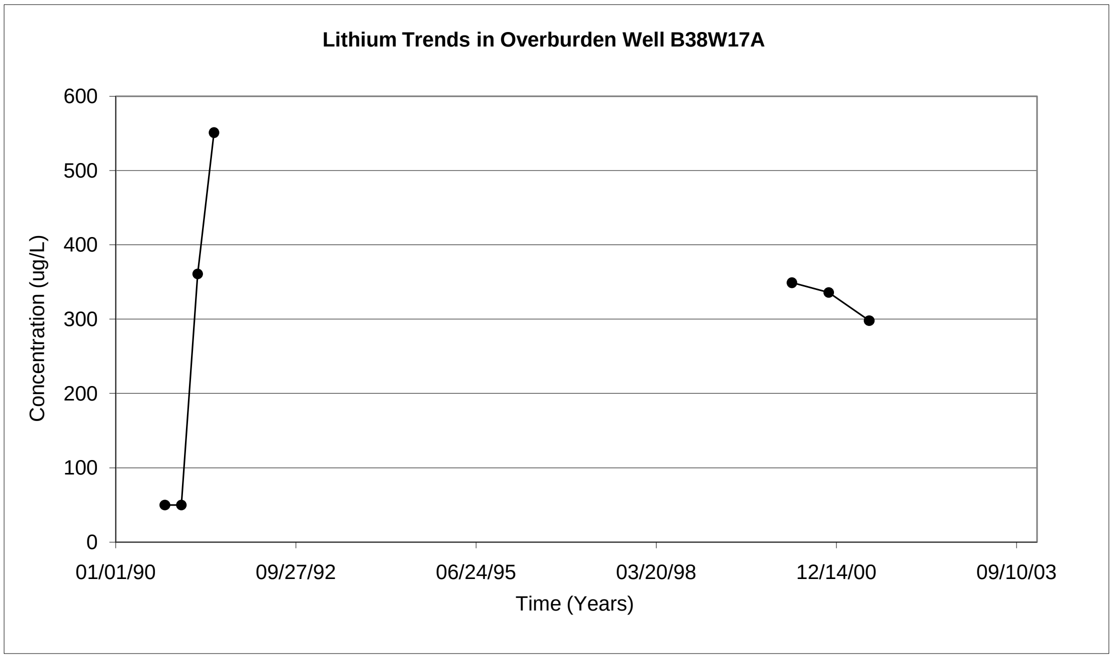

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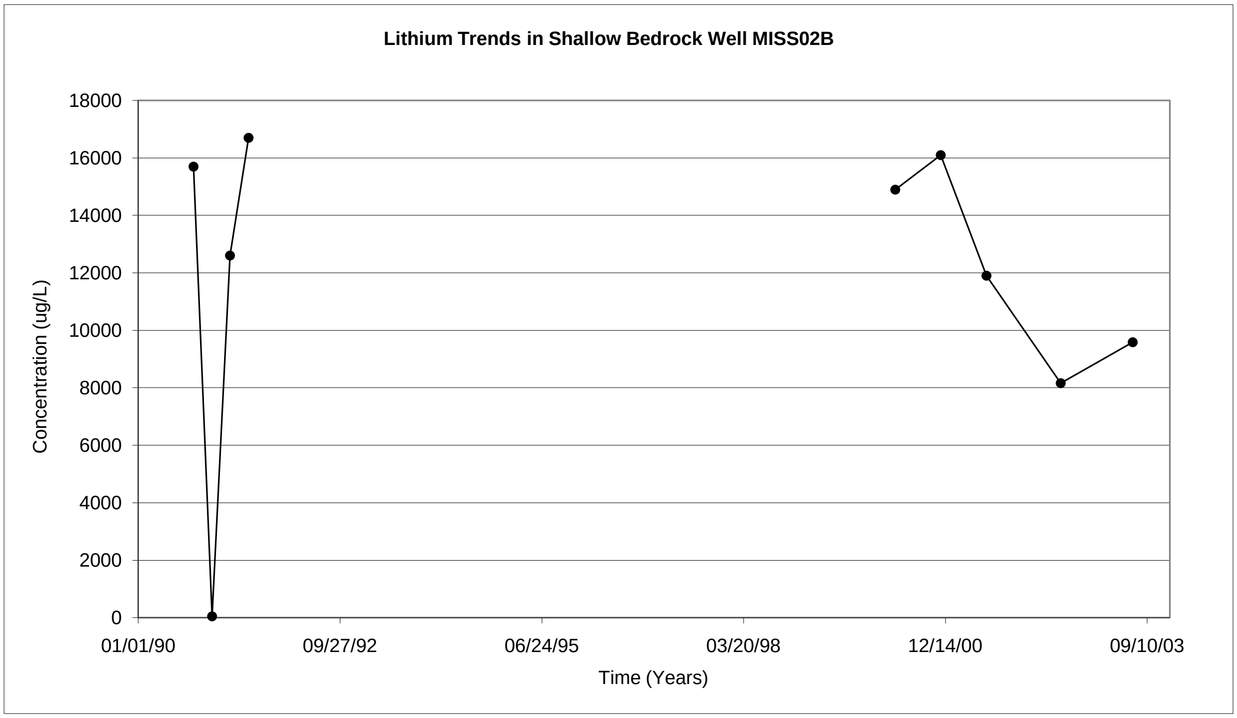

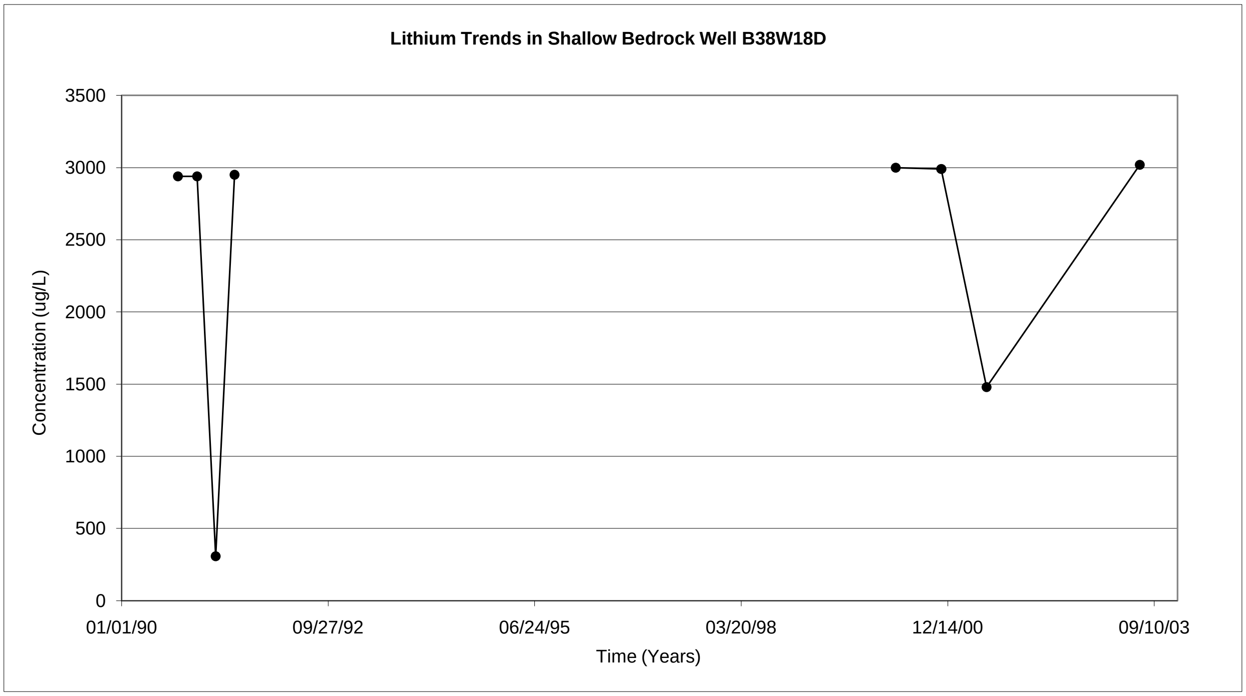

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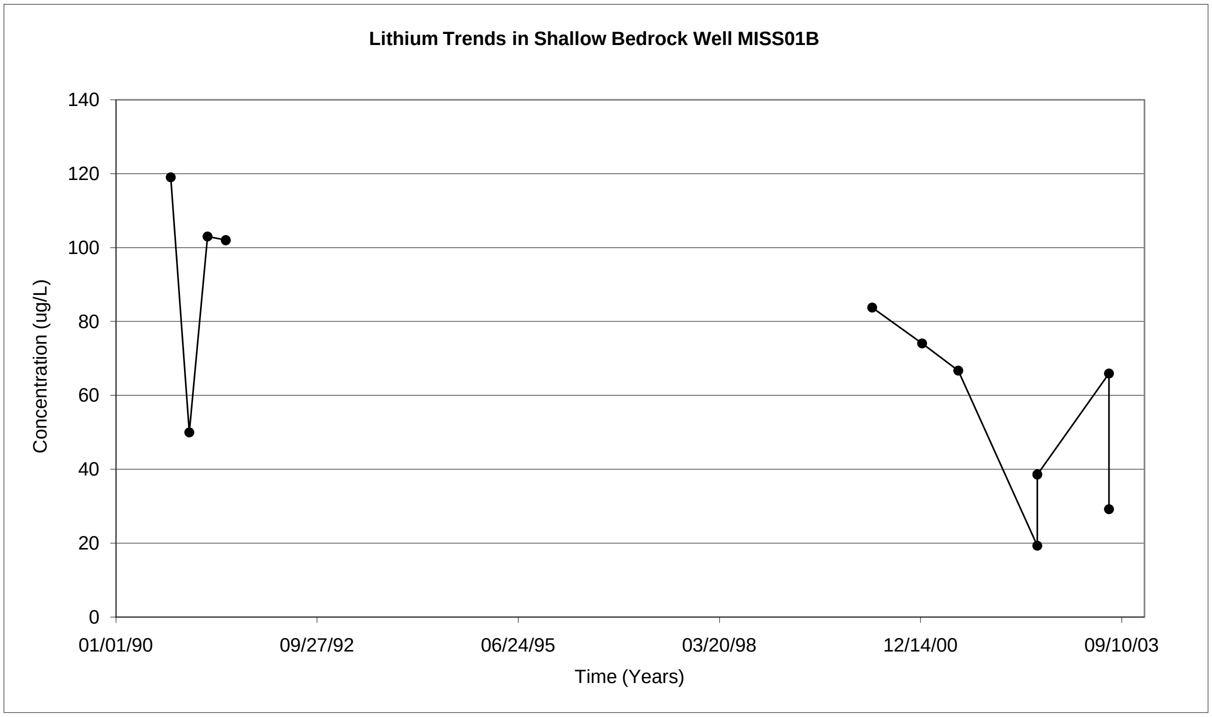

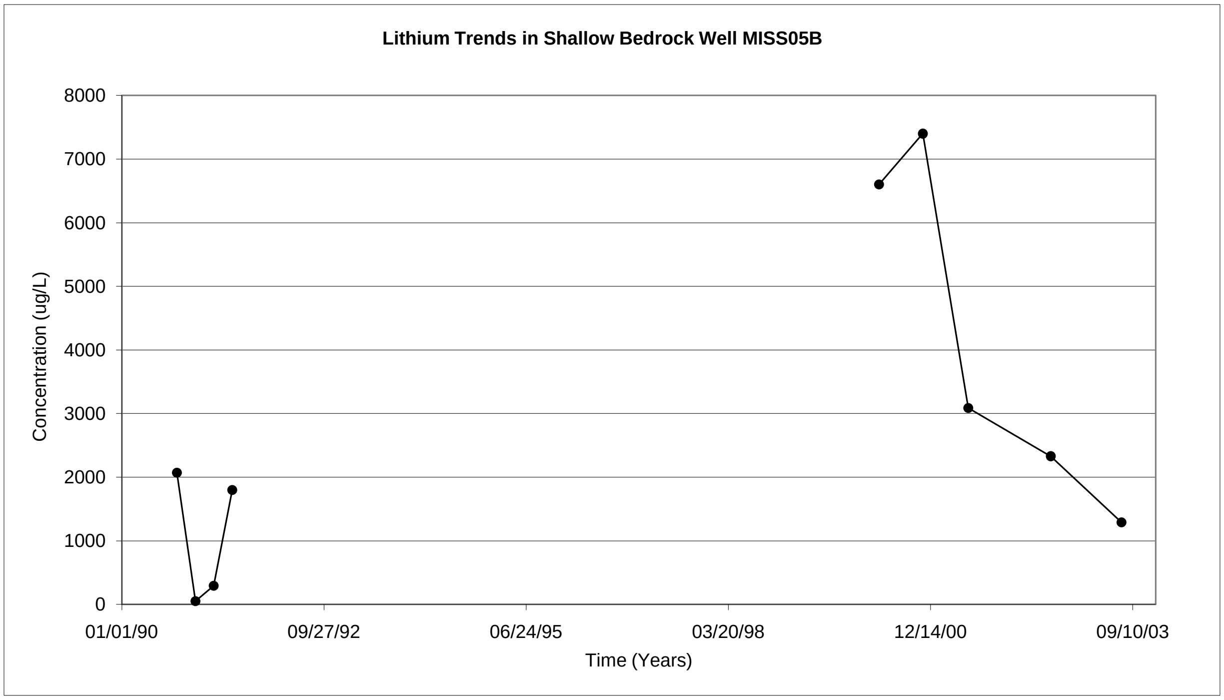

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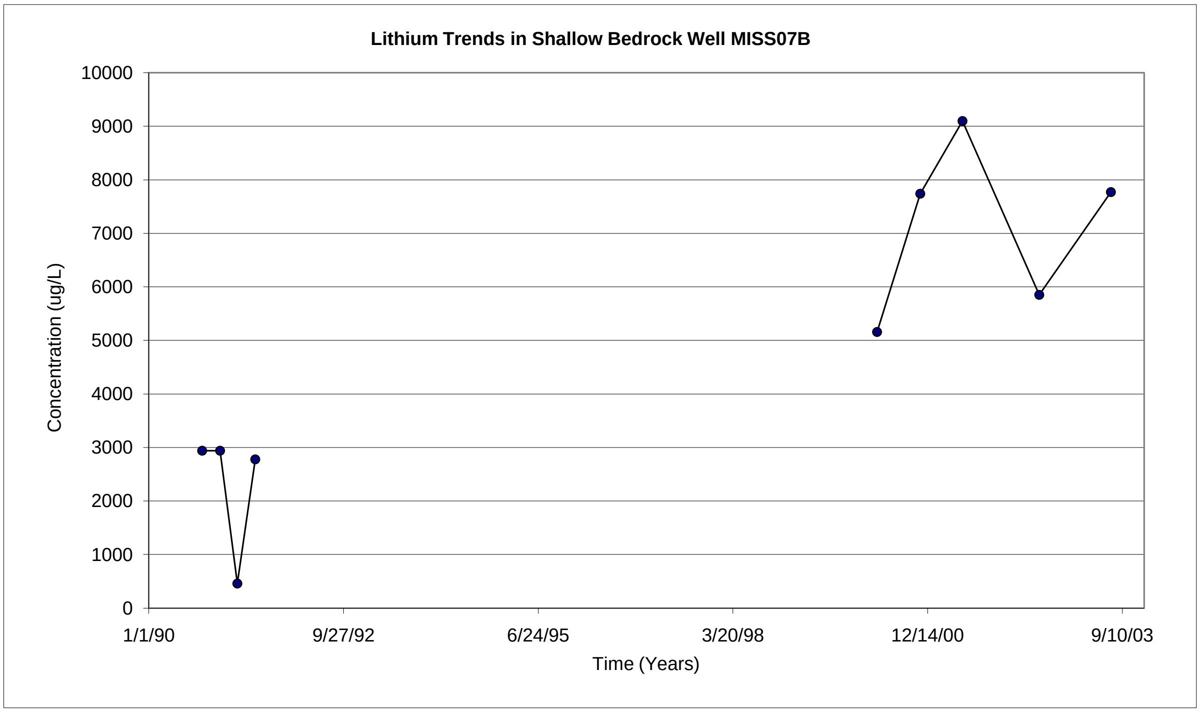

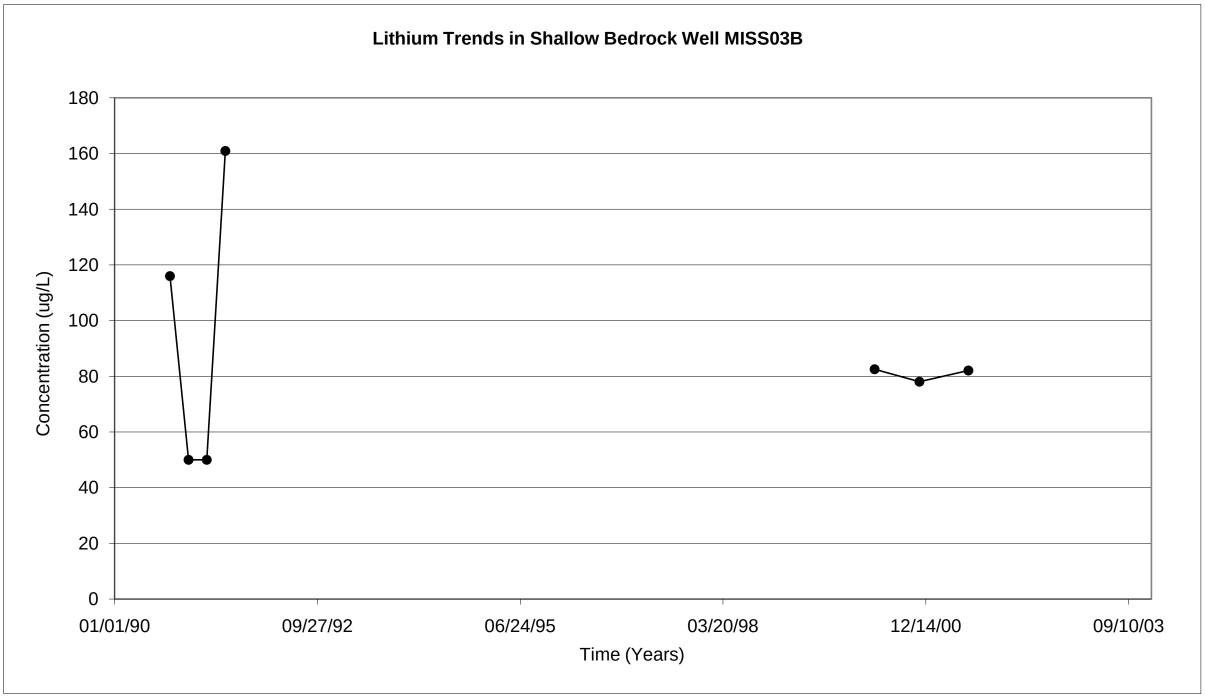

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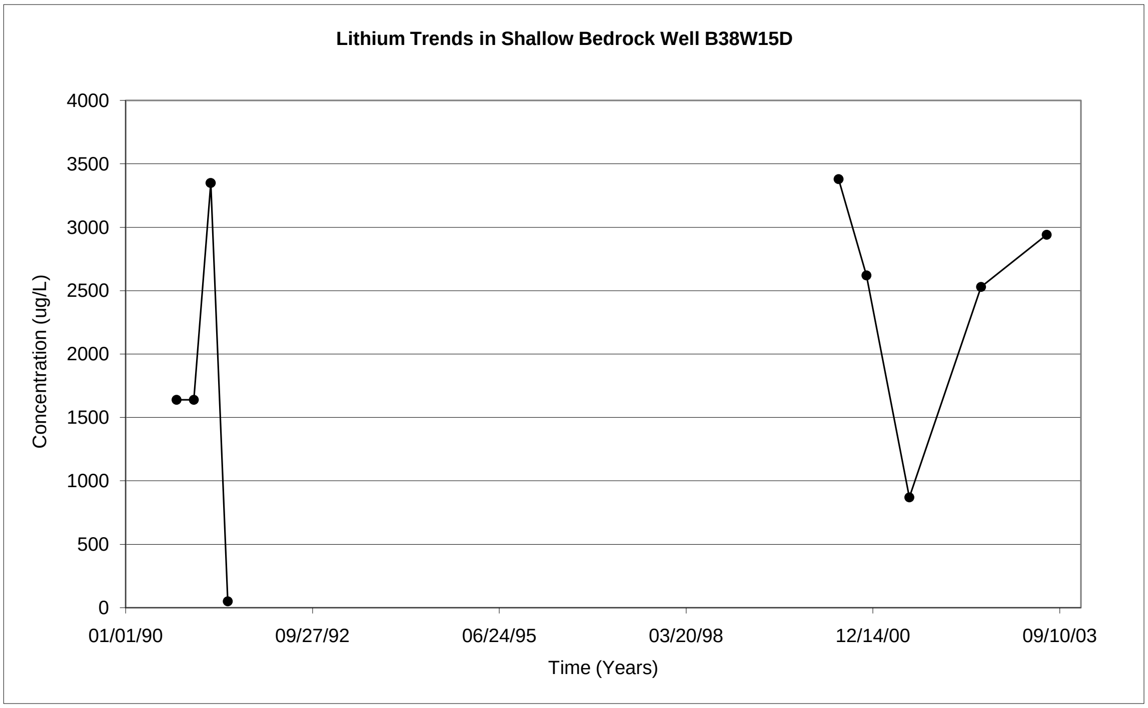

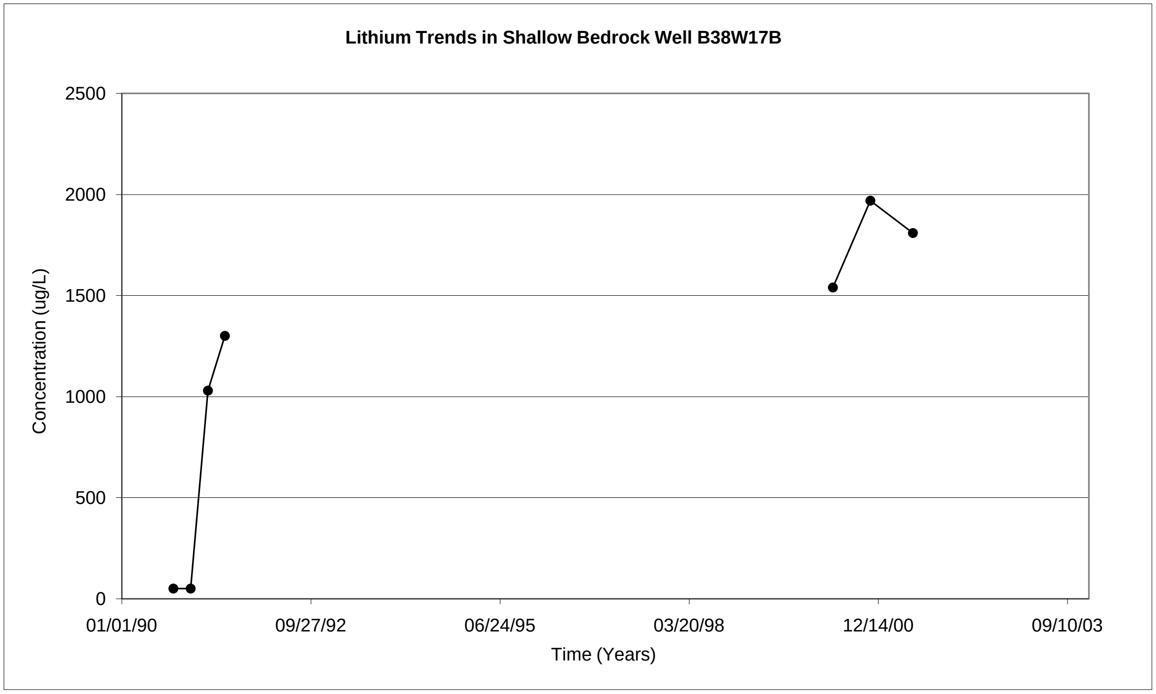

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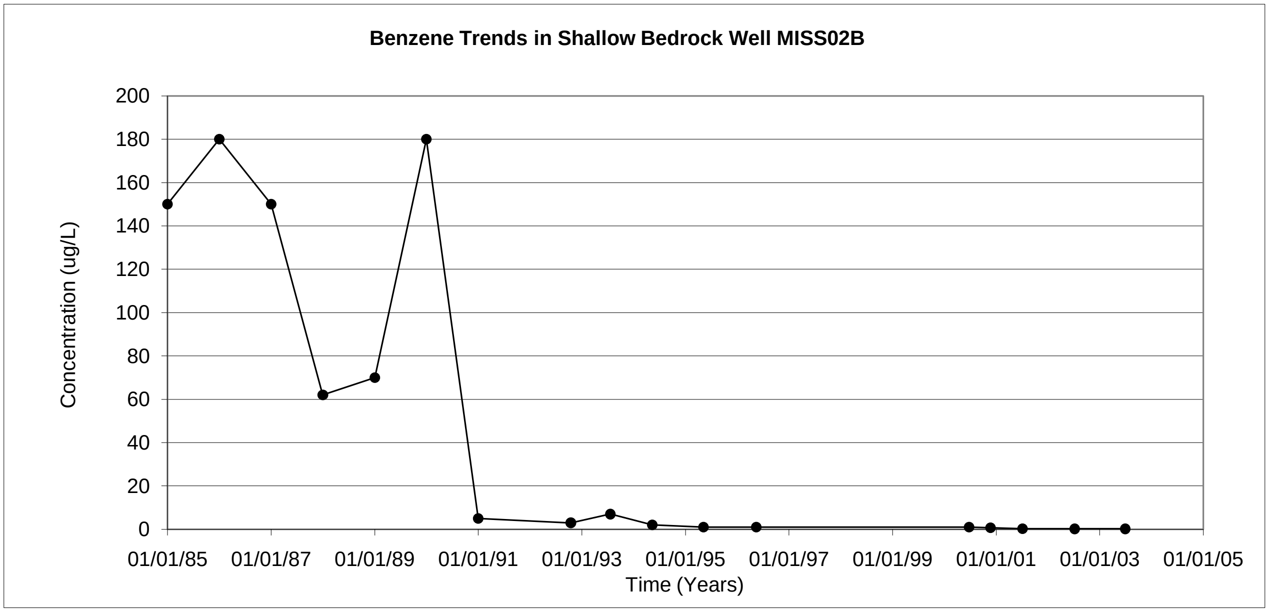

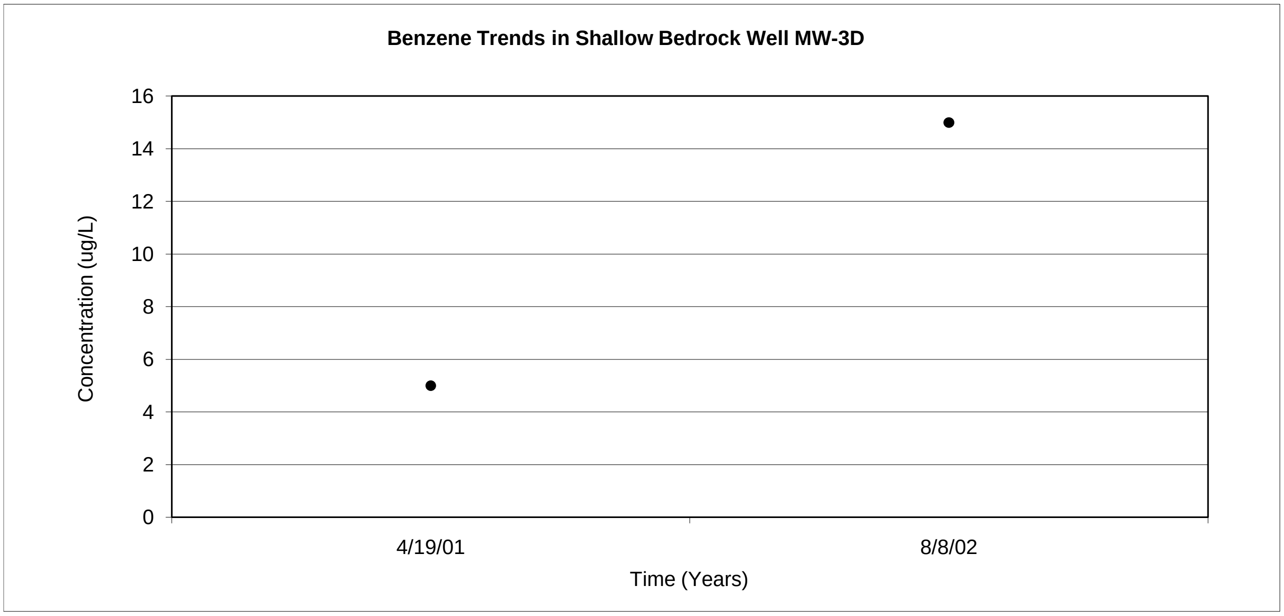

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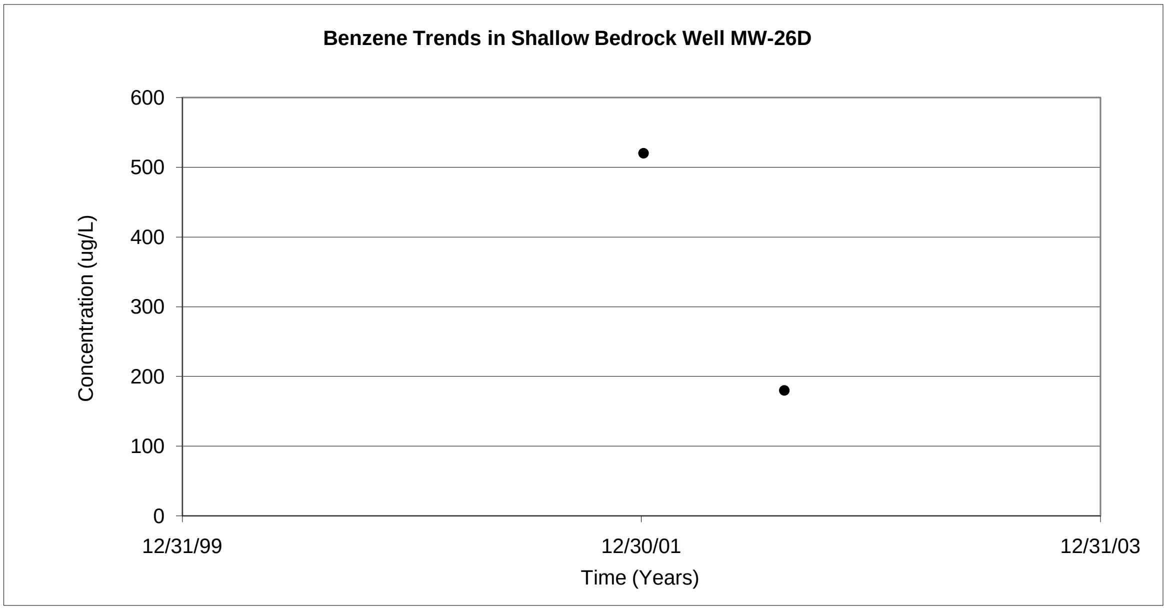

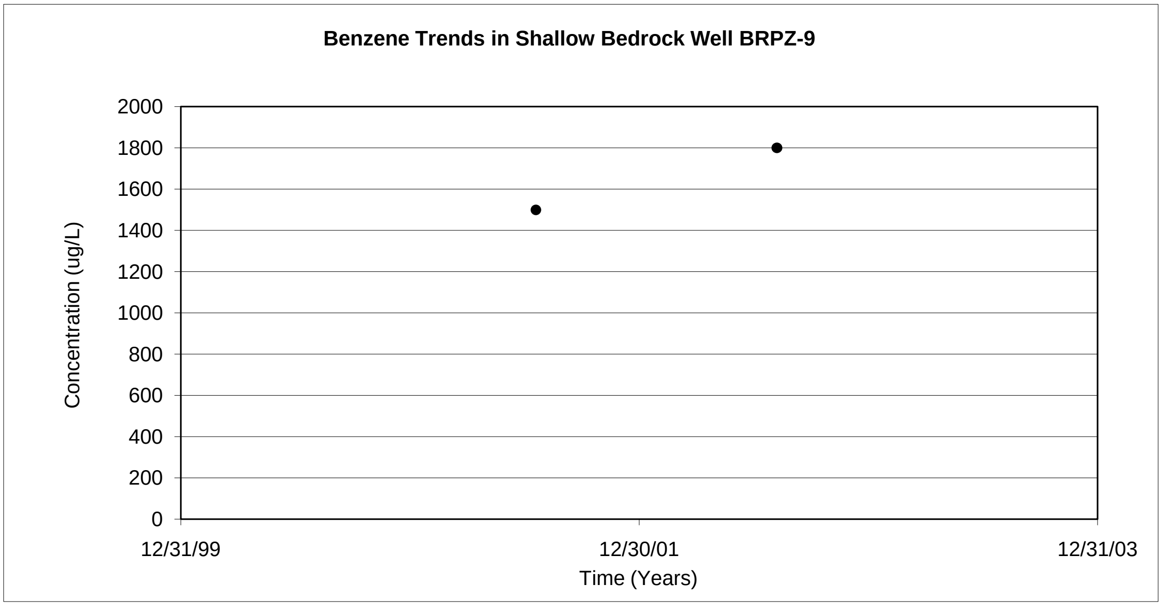

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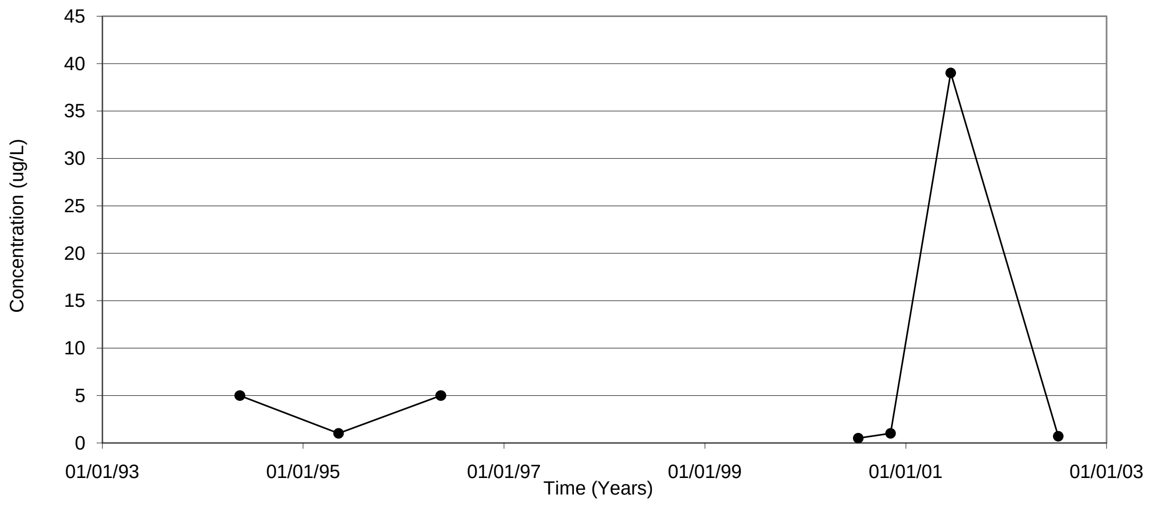
Benzene Trends in Shallow Bedrock Well B38W19D



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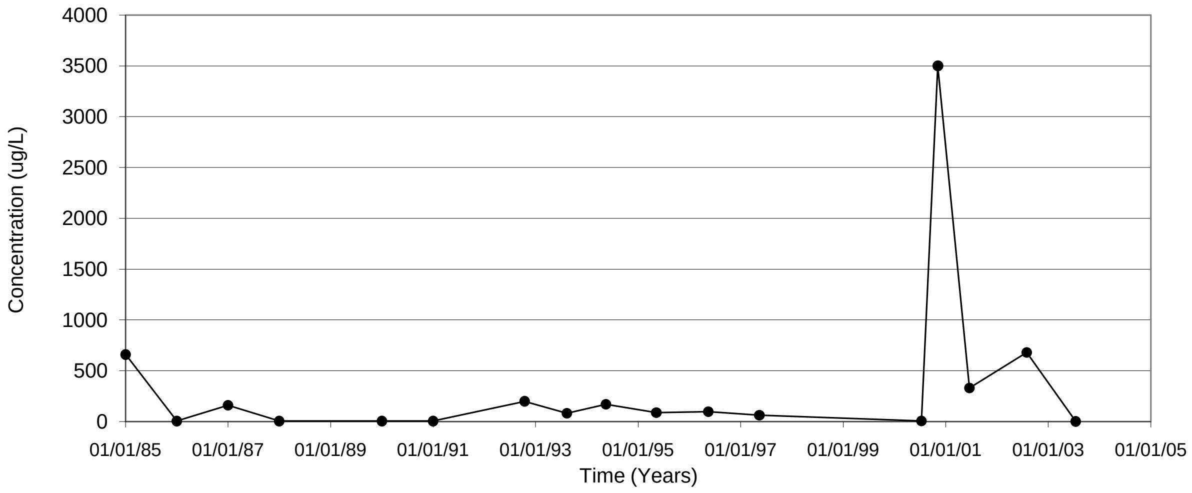

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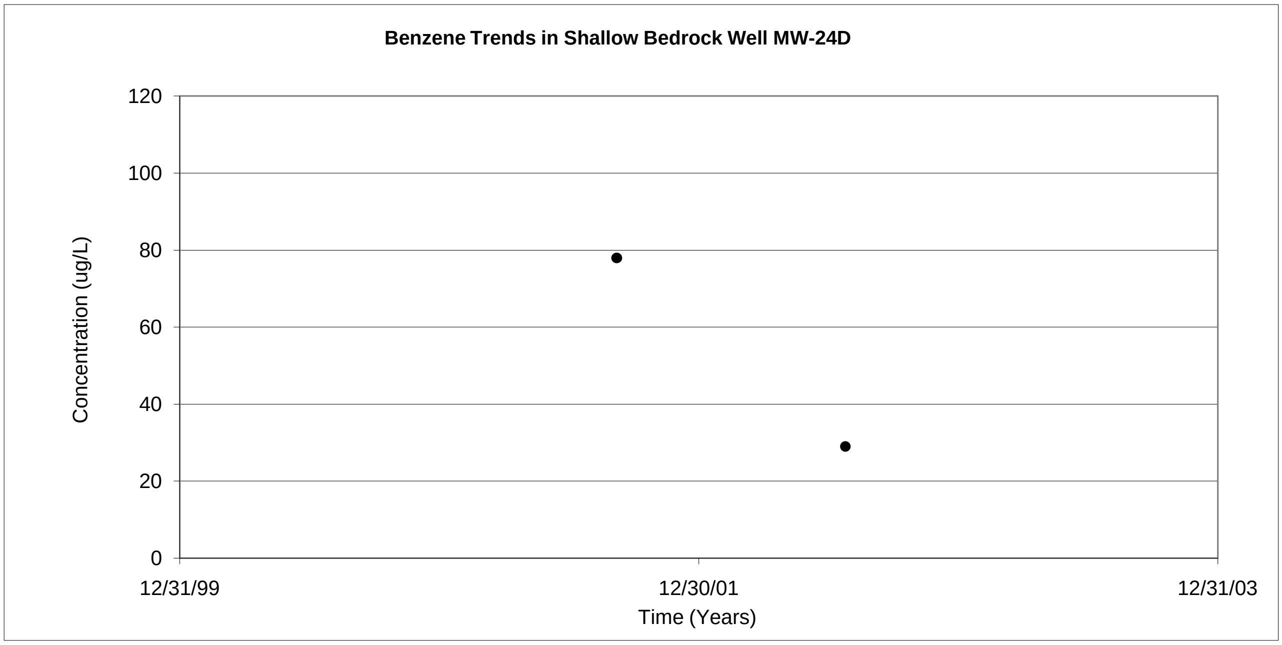

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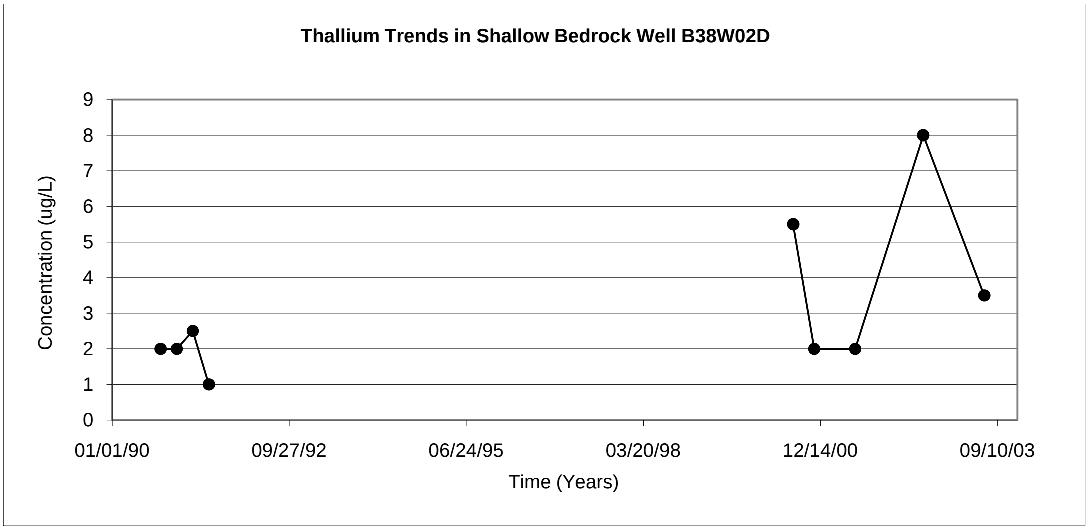

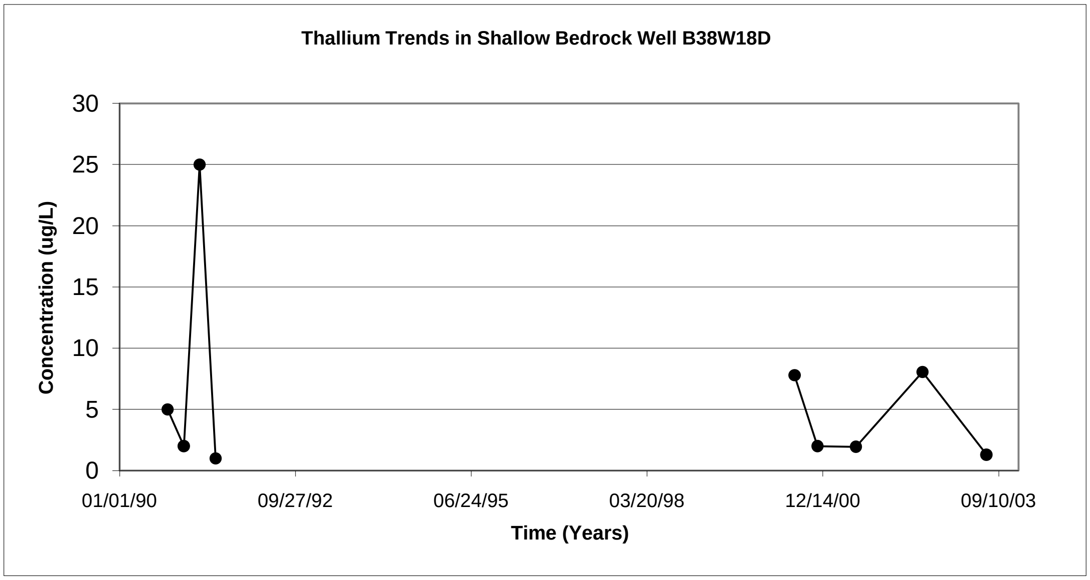

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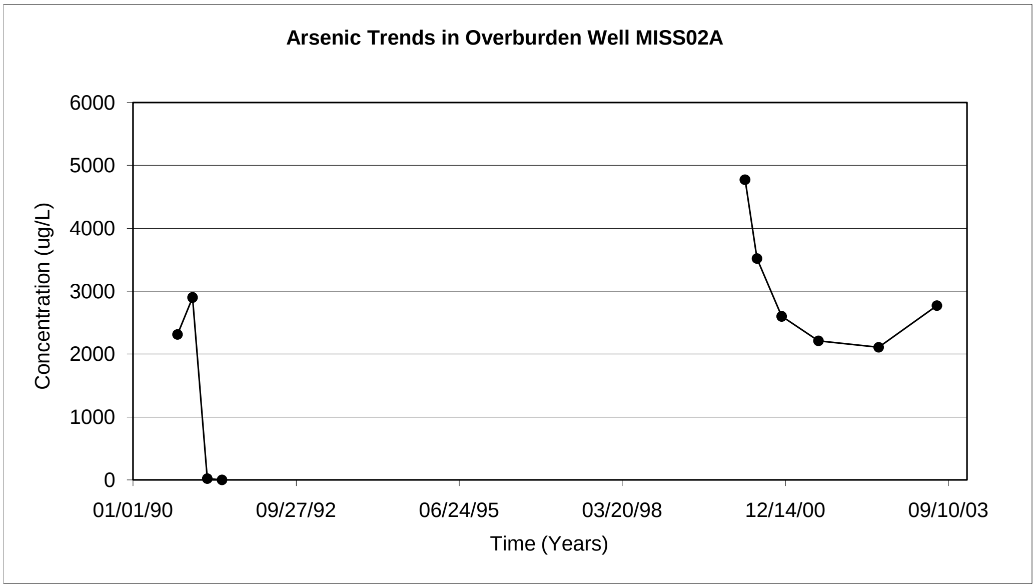

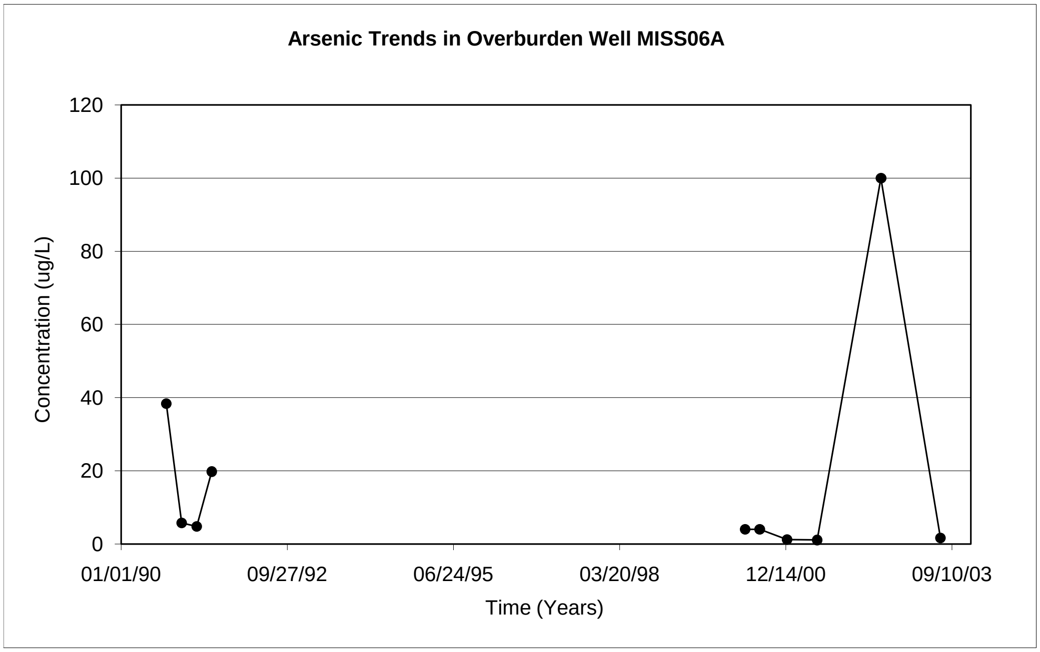

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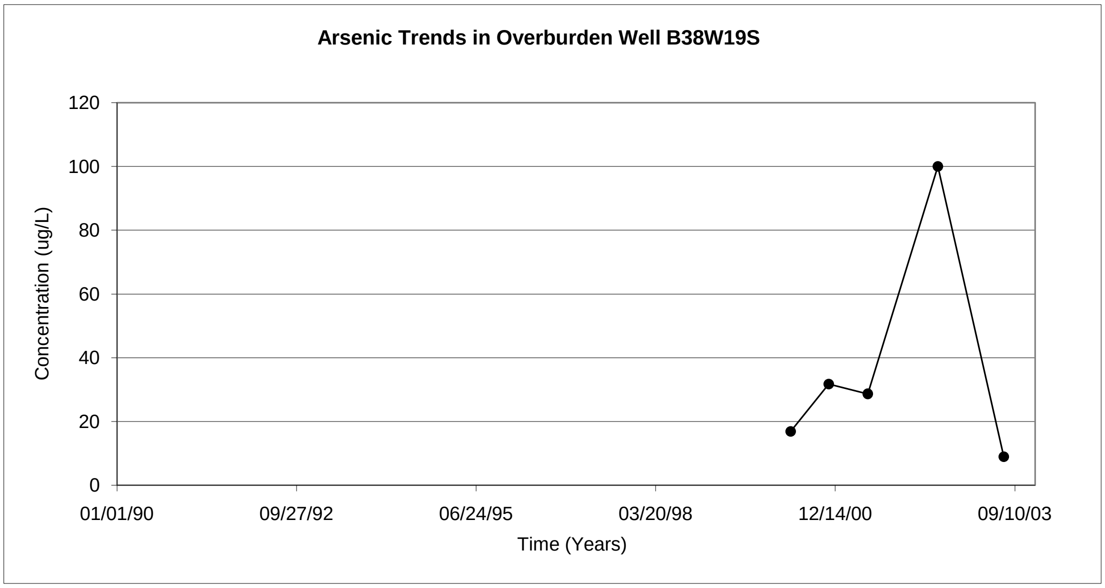

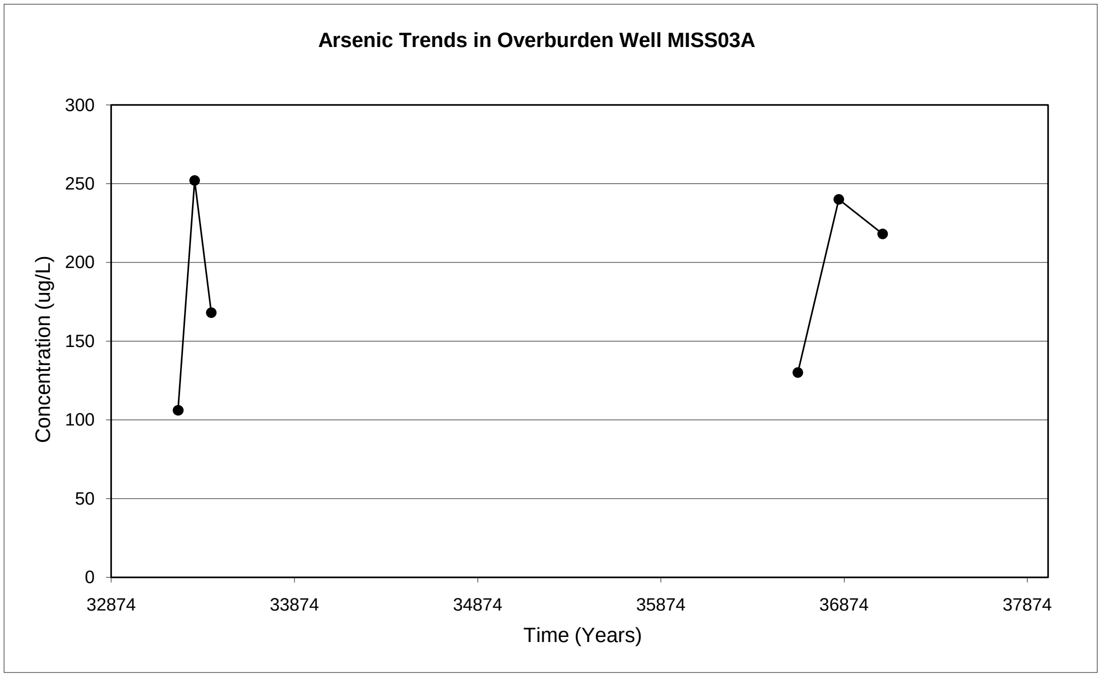

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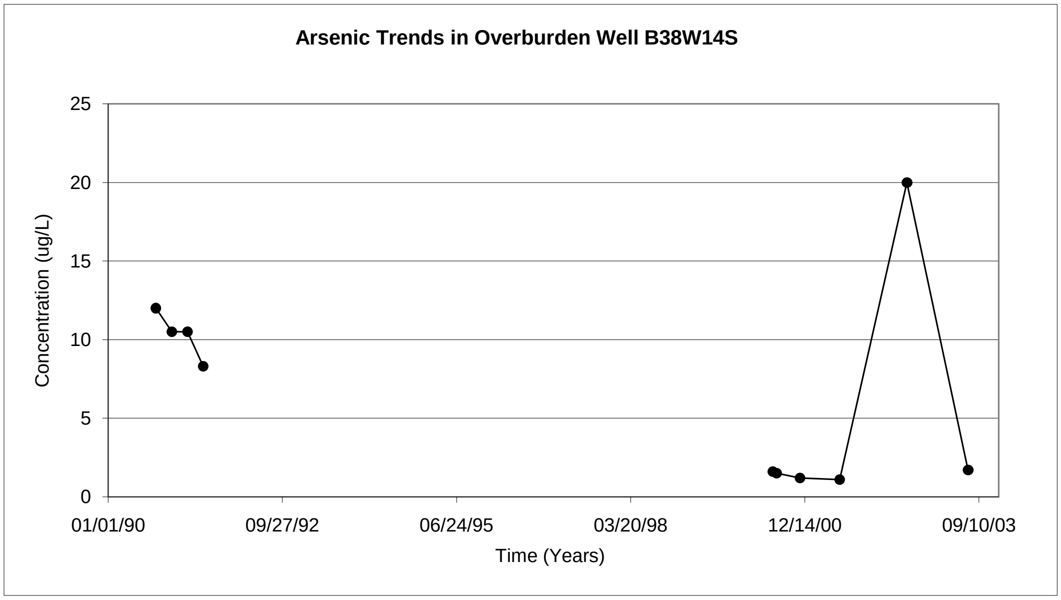

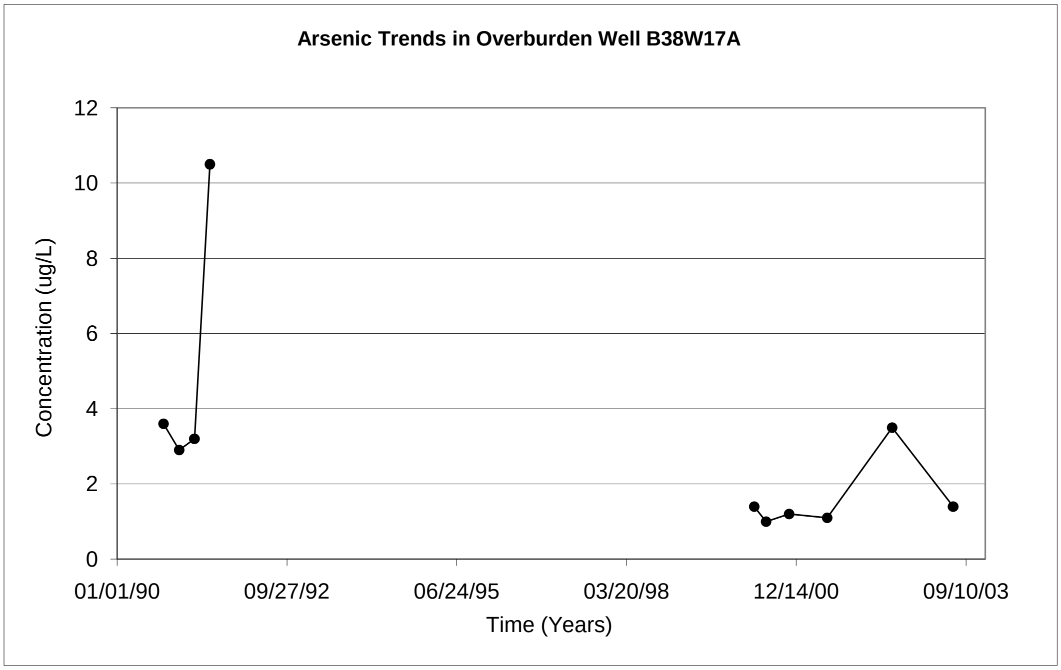

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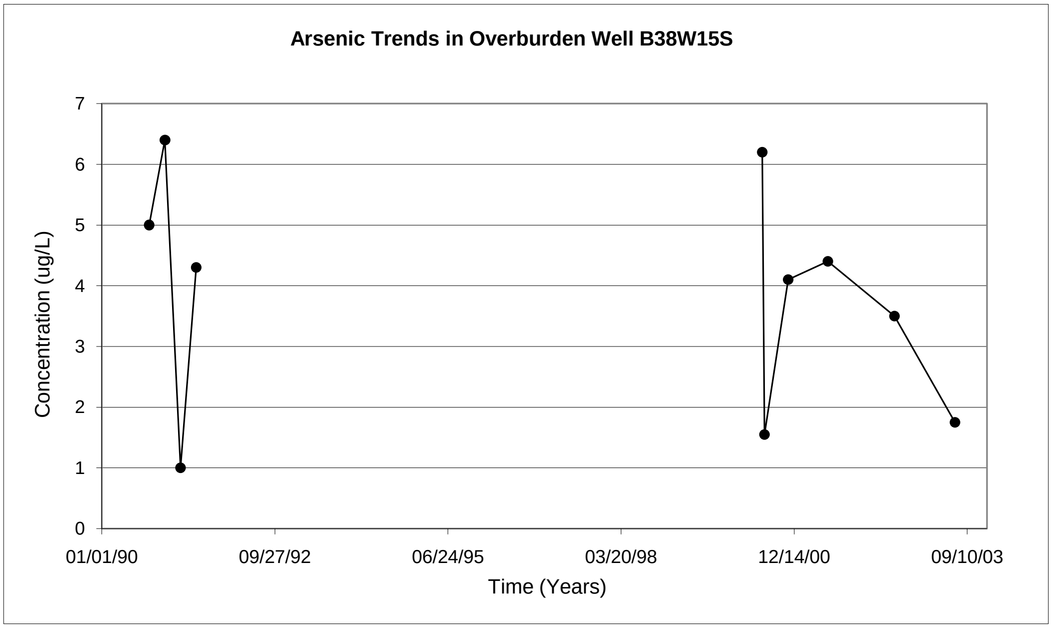

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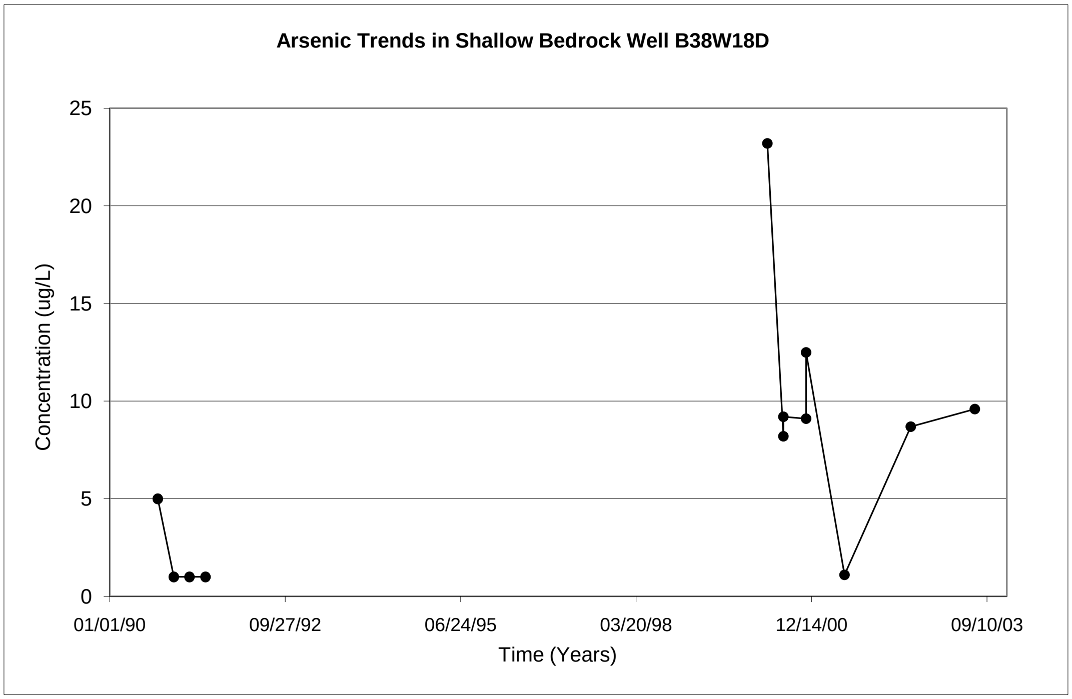

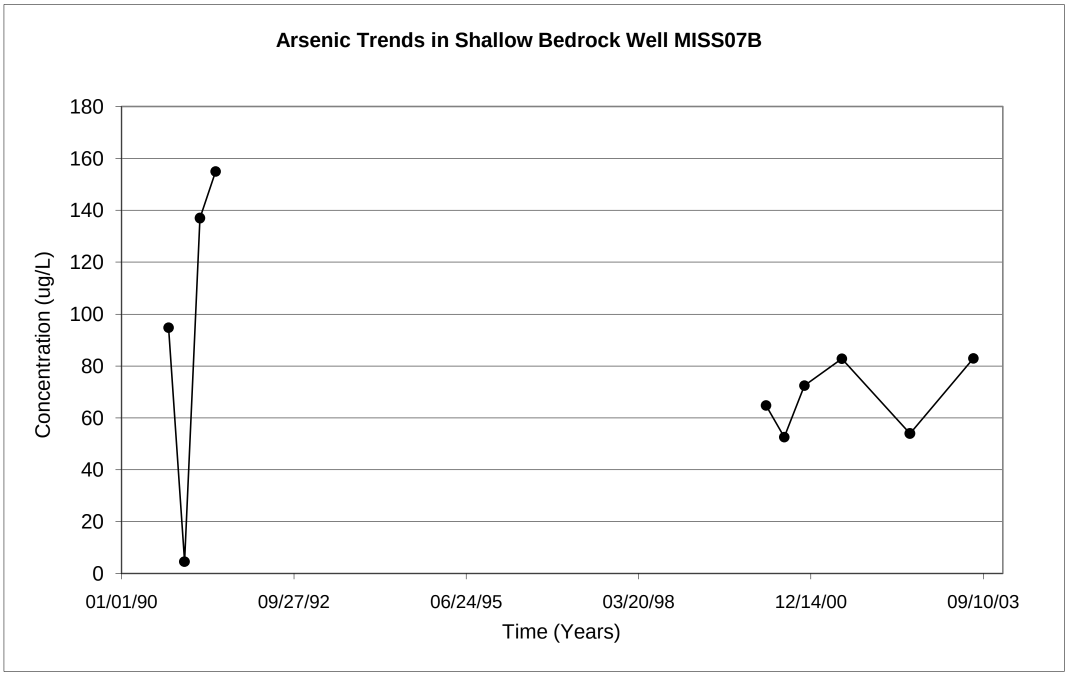

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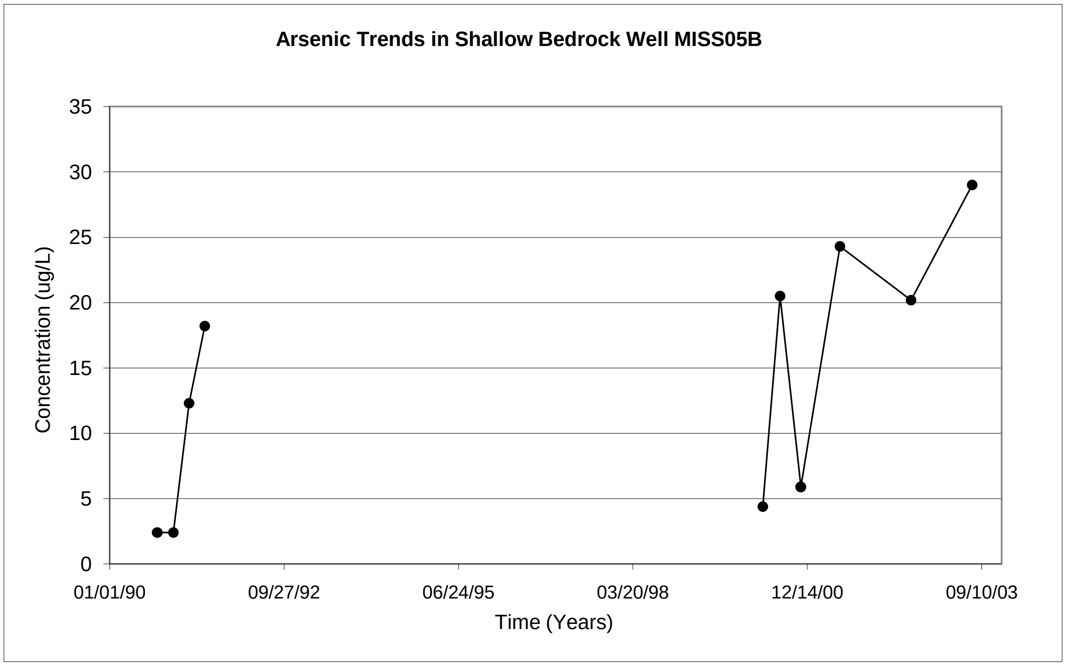

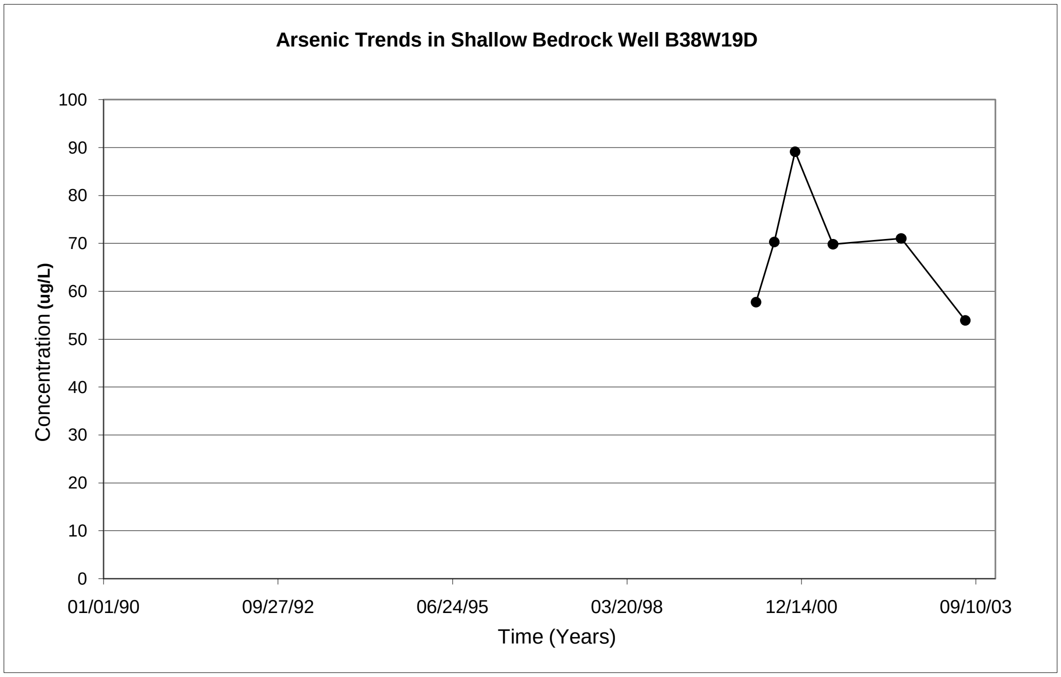

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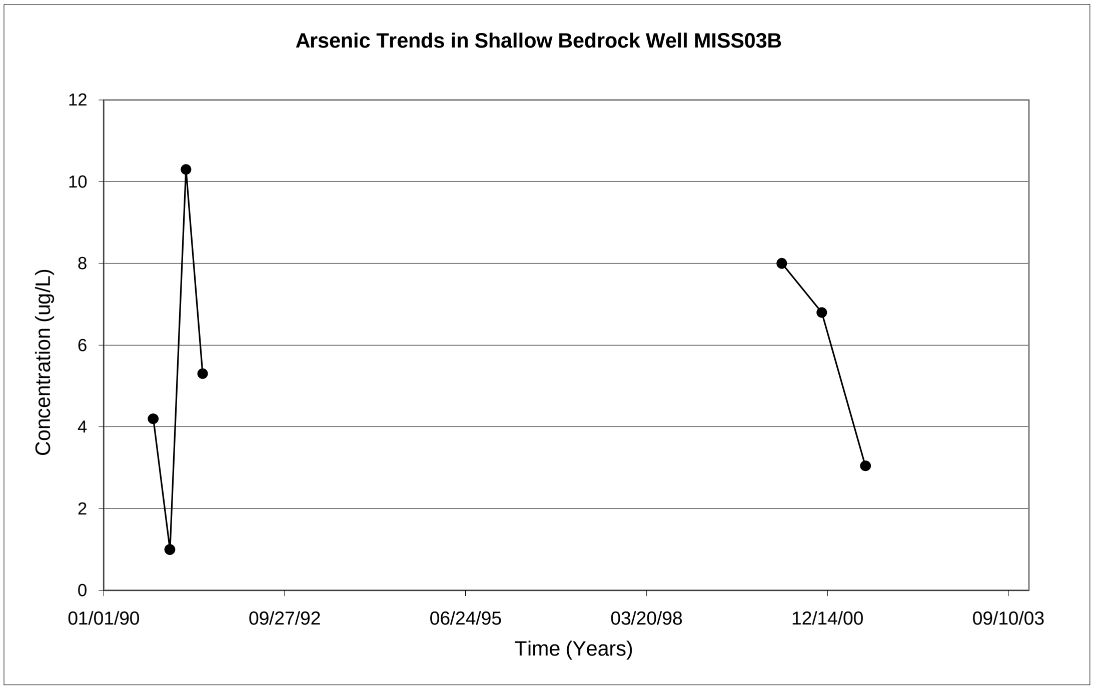

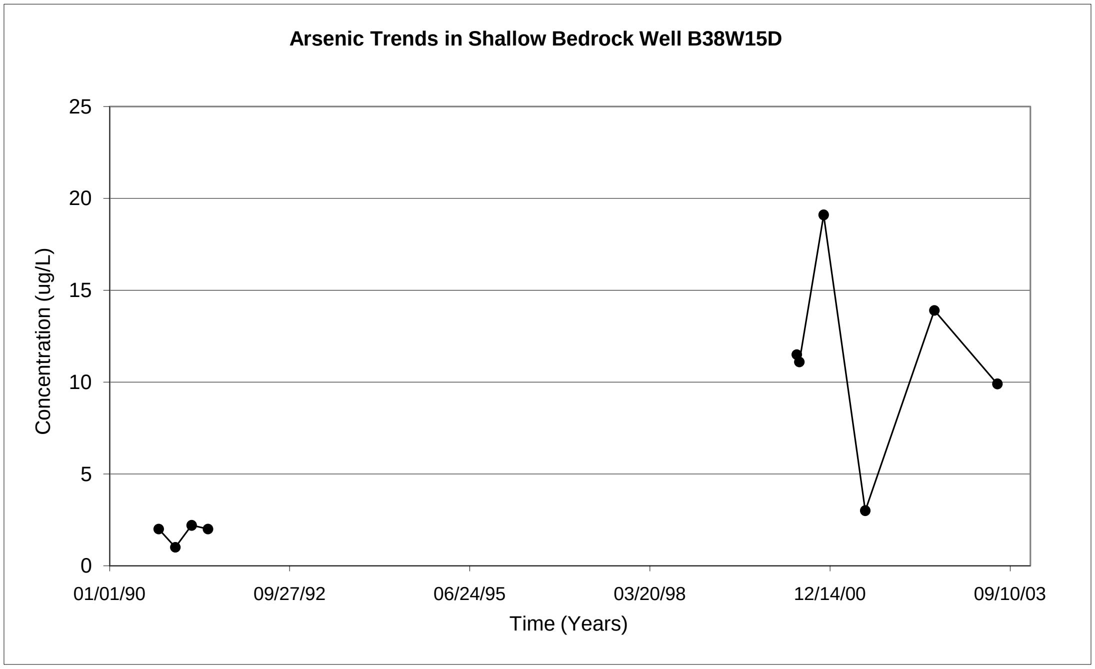

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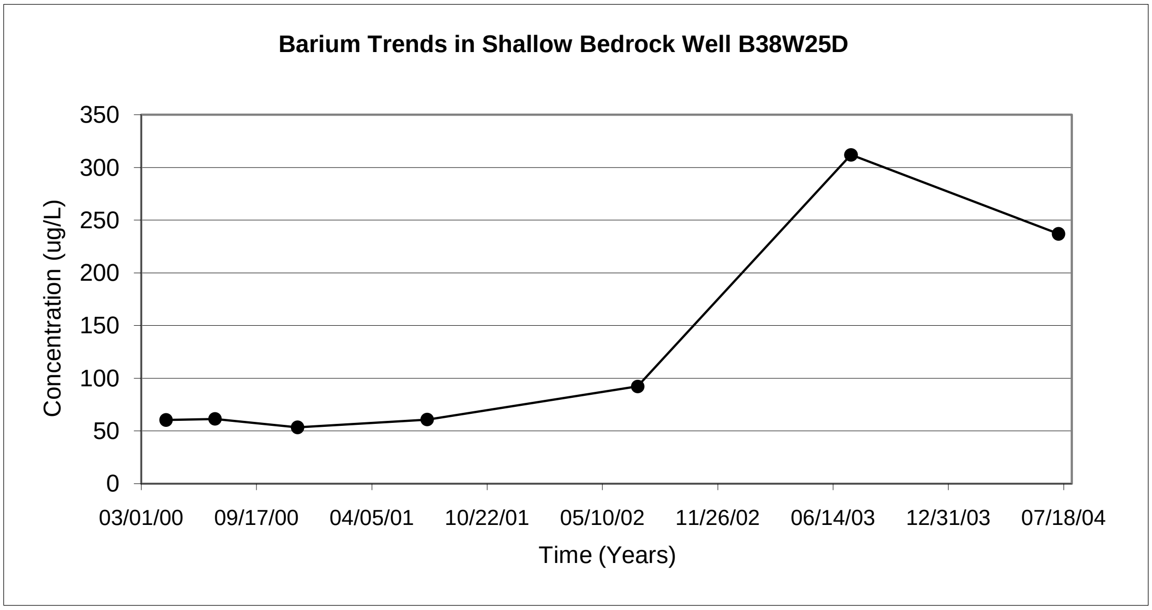

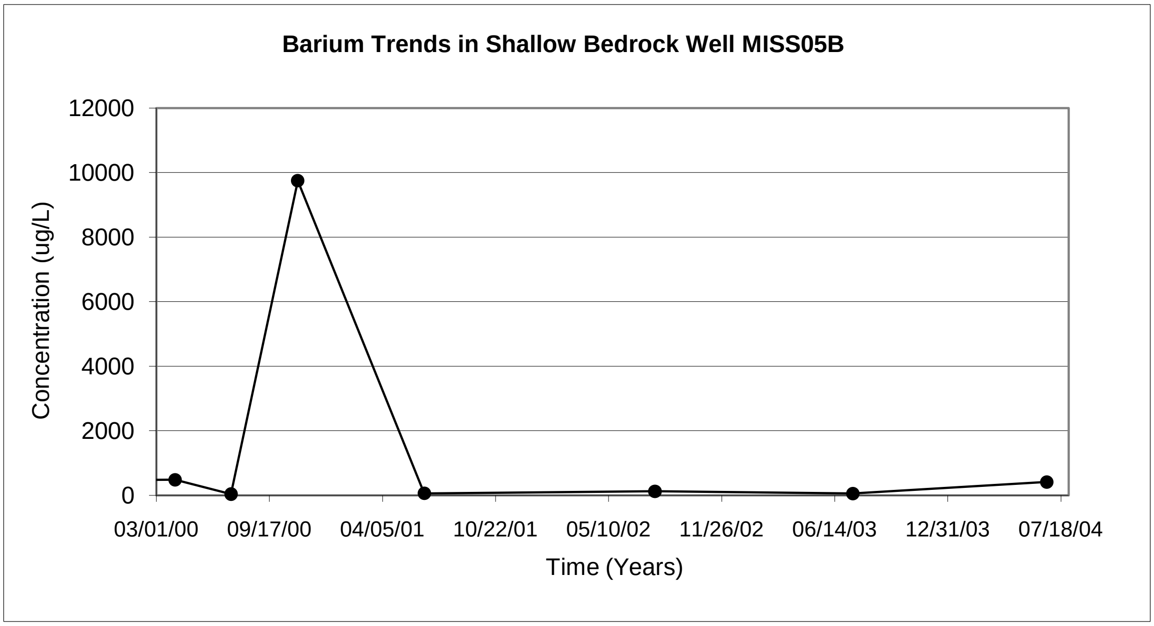

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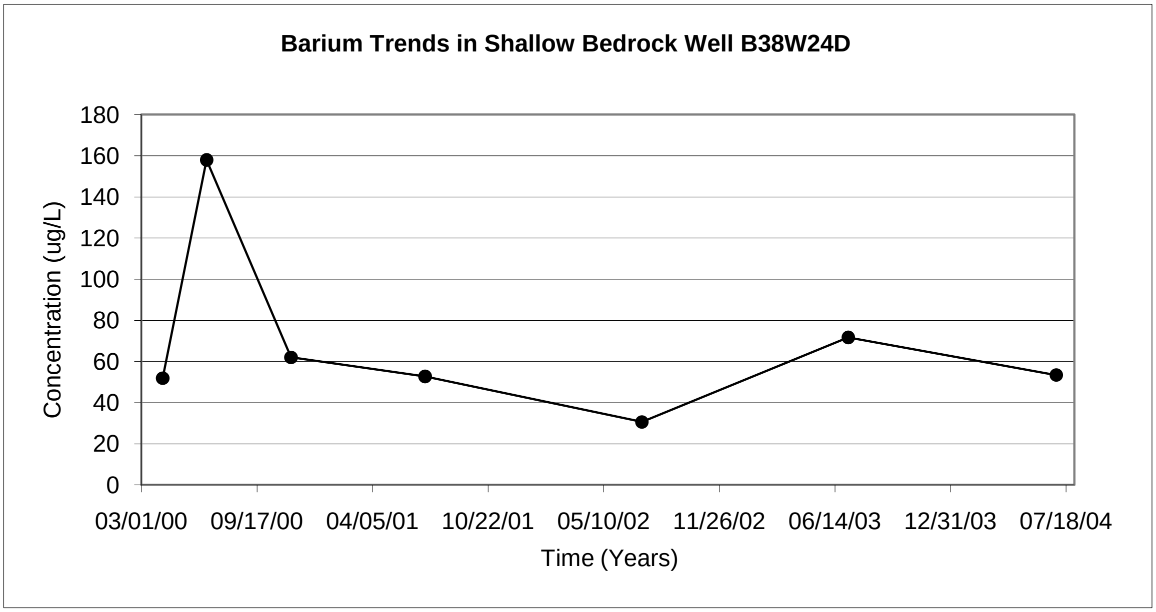

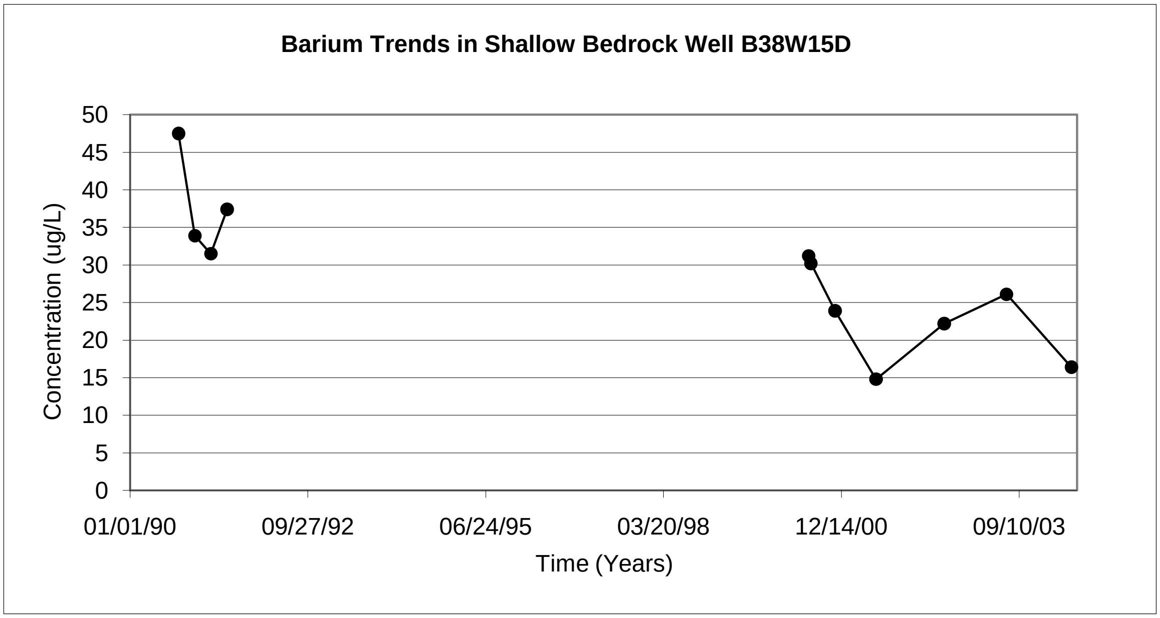

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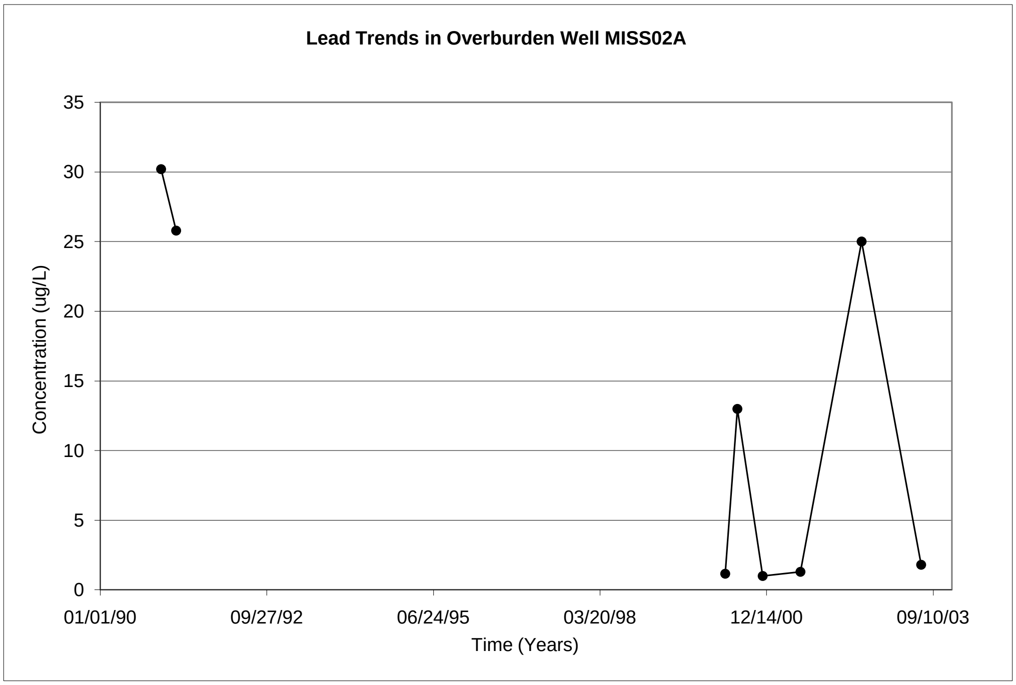

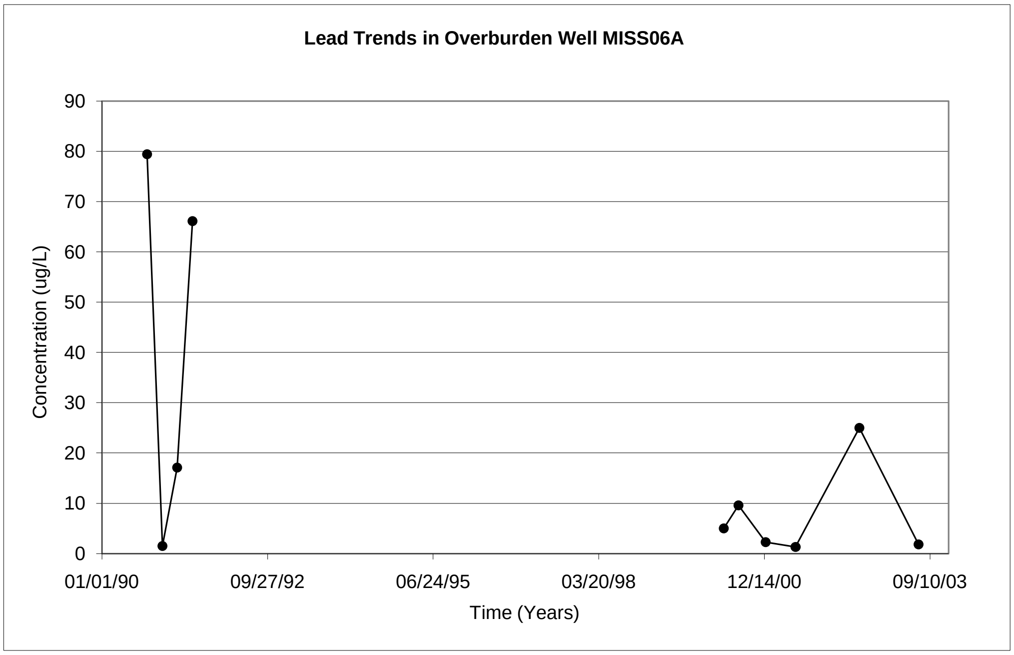

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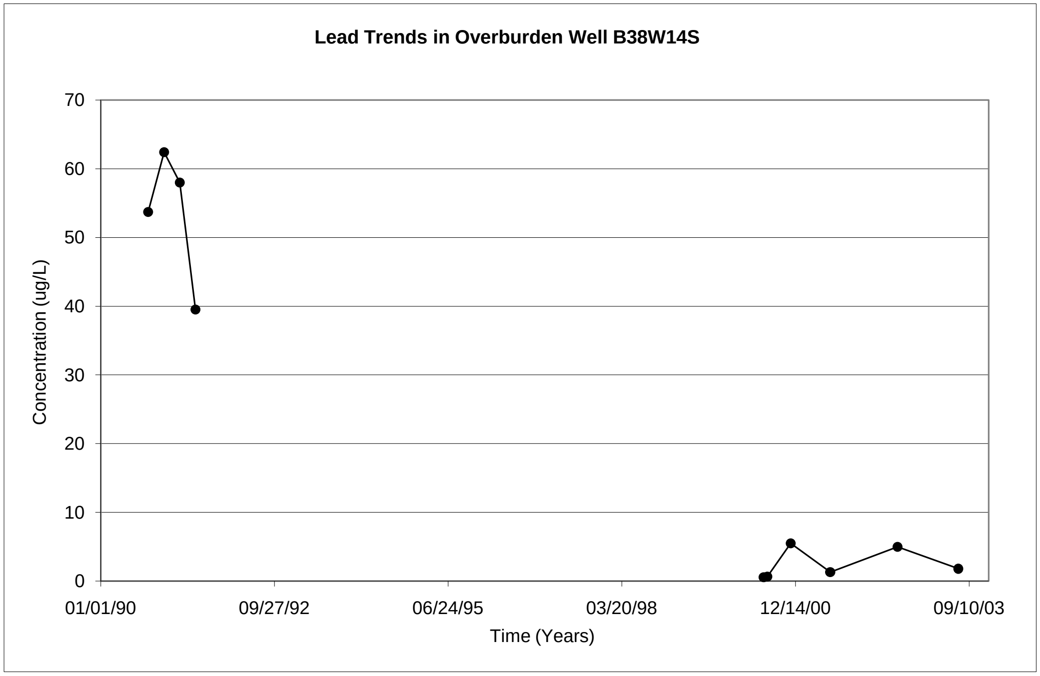

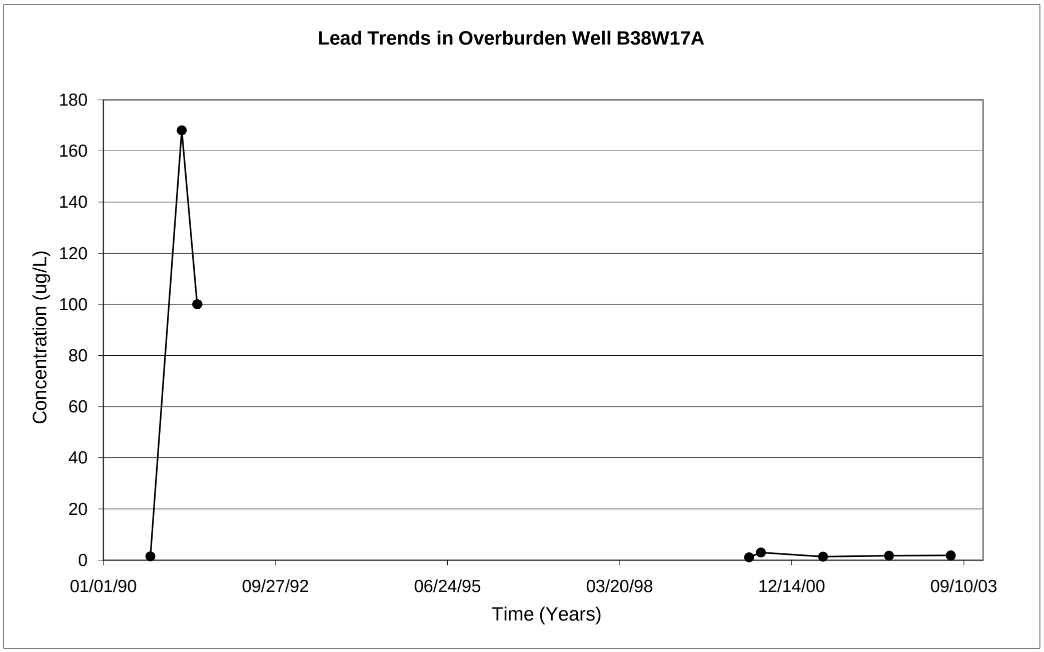

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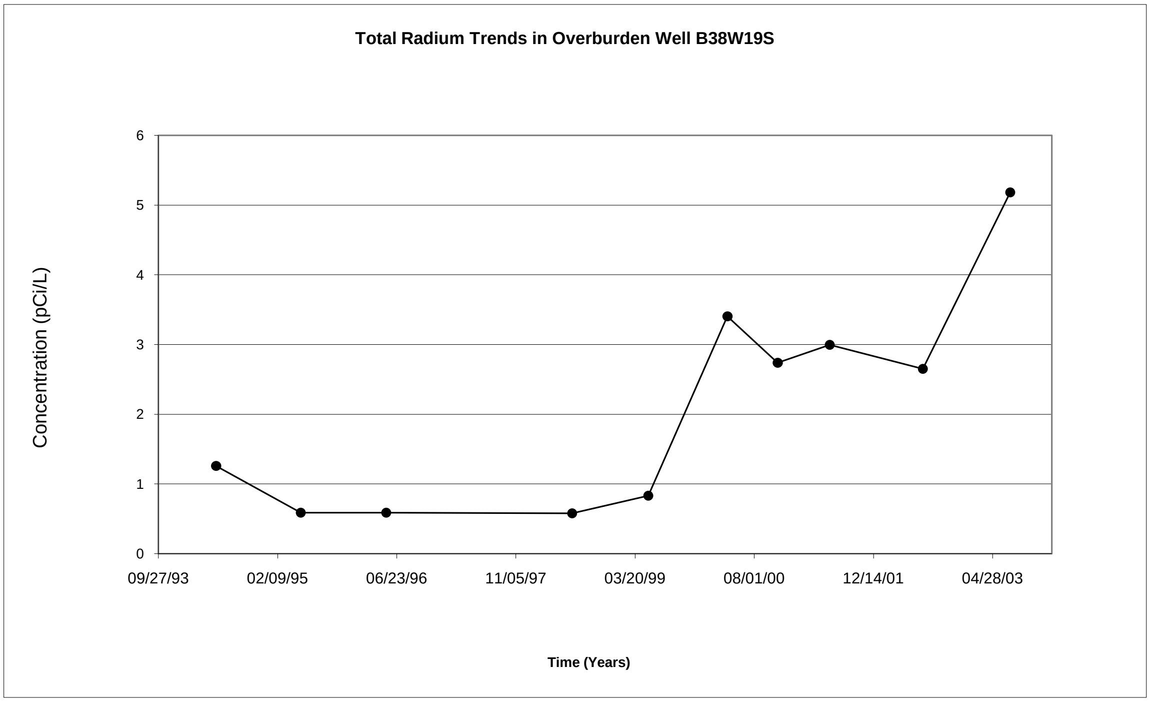

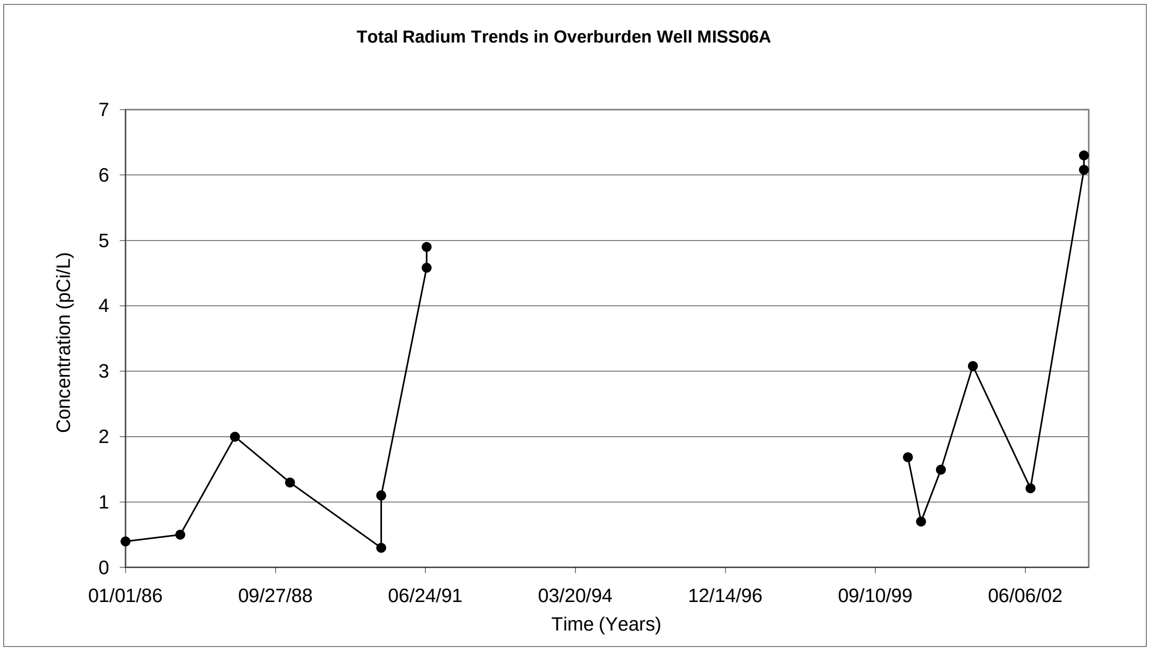

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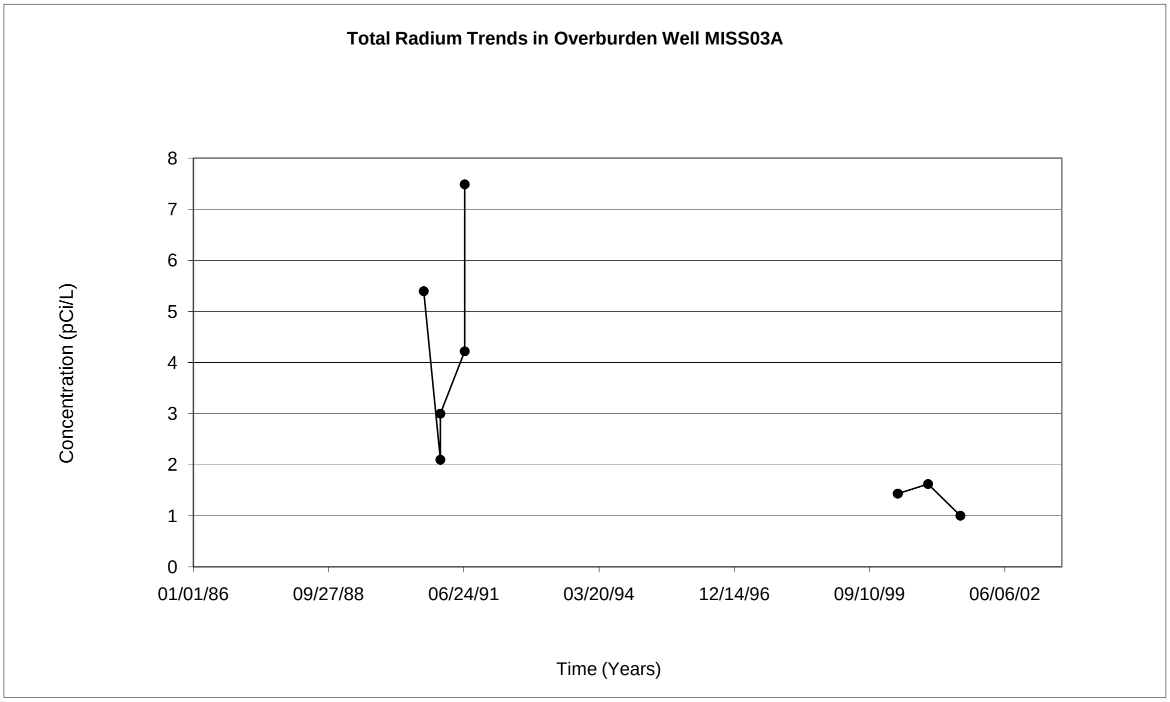

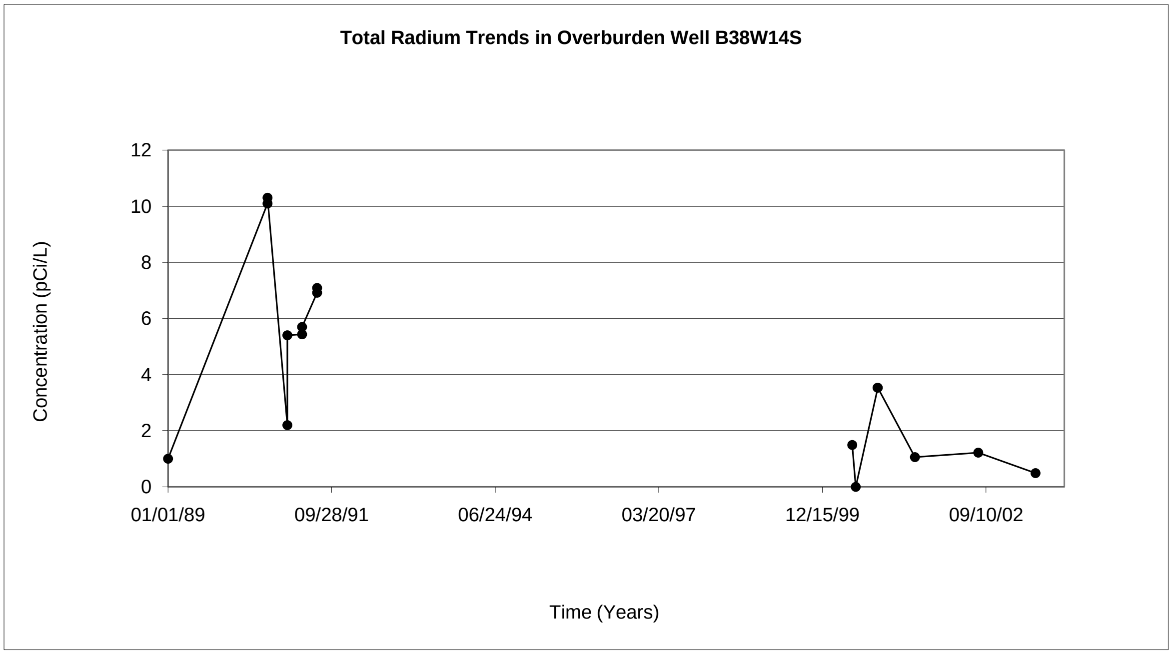

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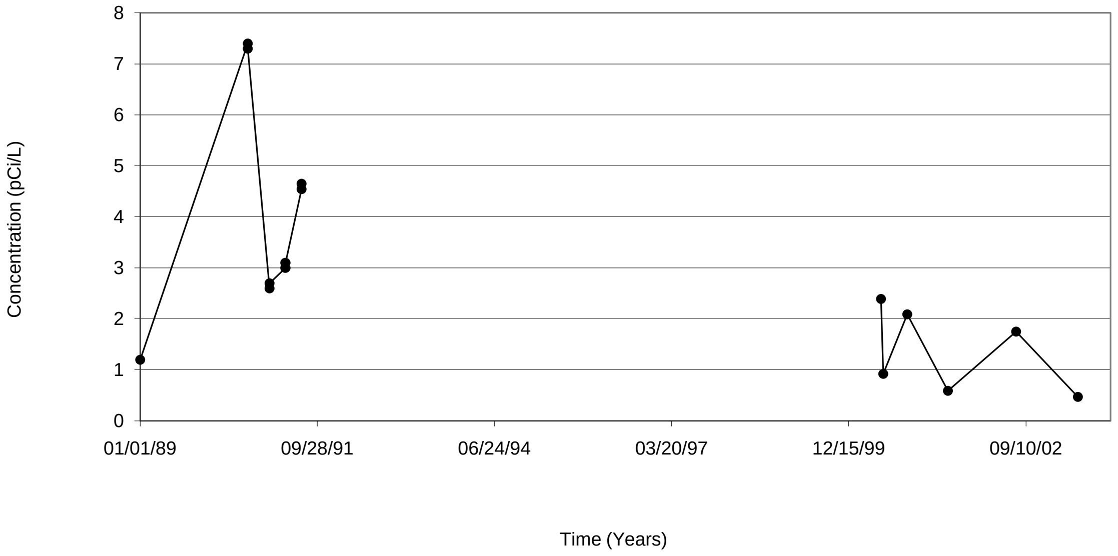
Total Radium Trends in Overburden Well B38W15S



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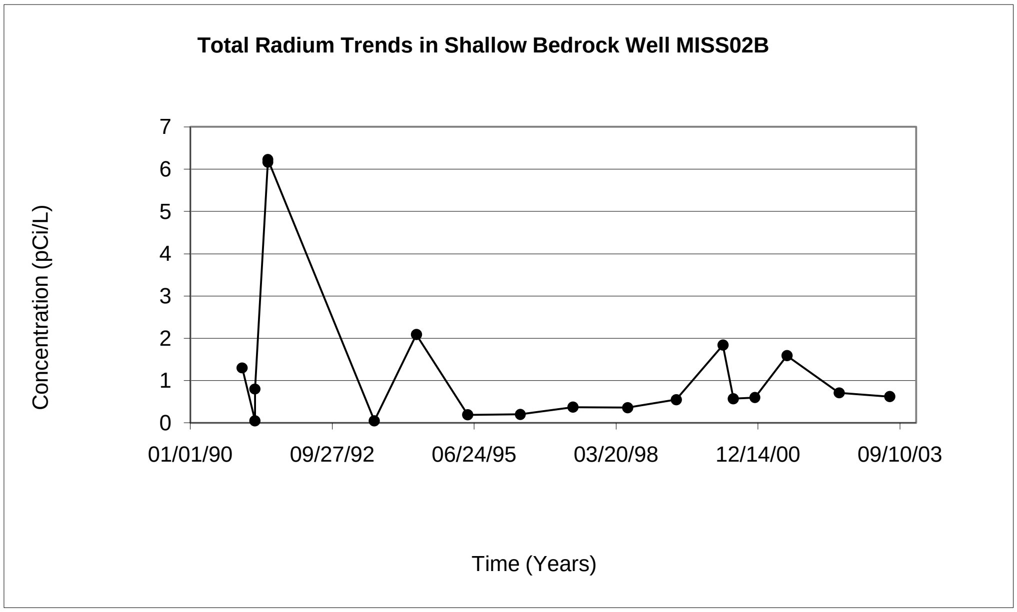

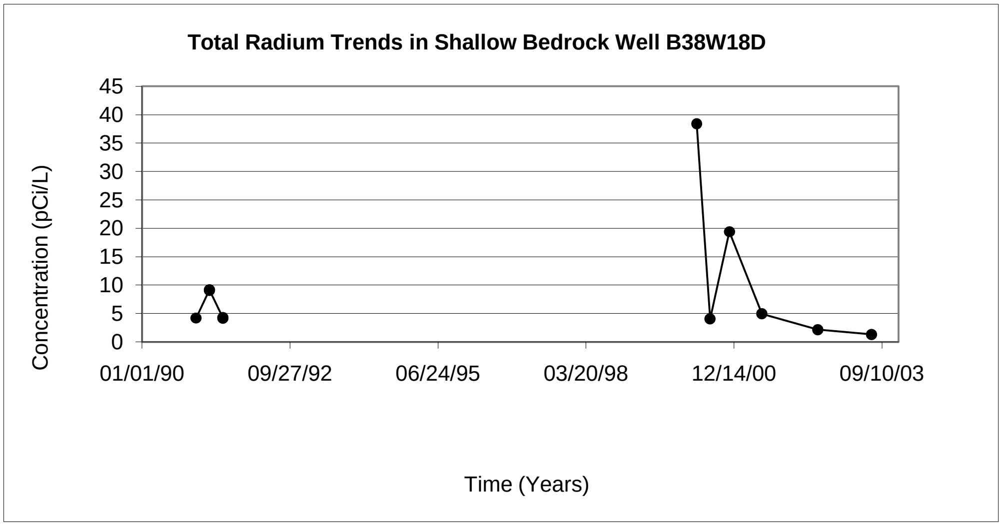

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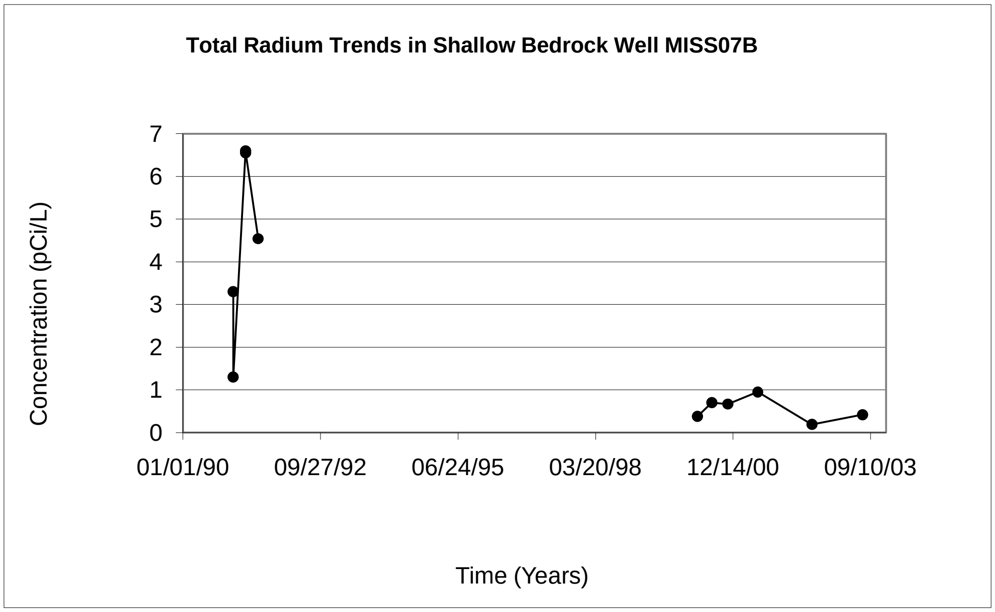

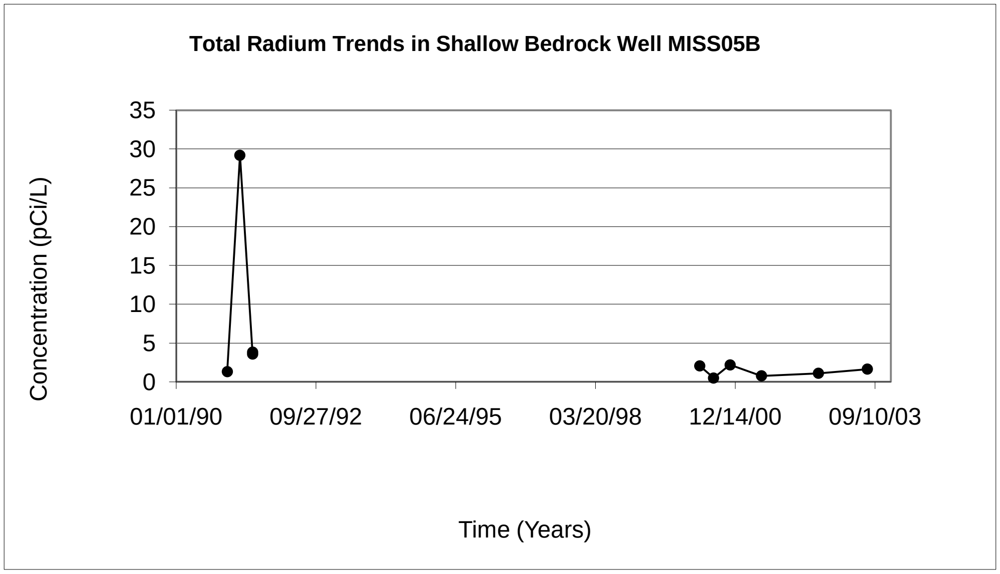

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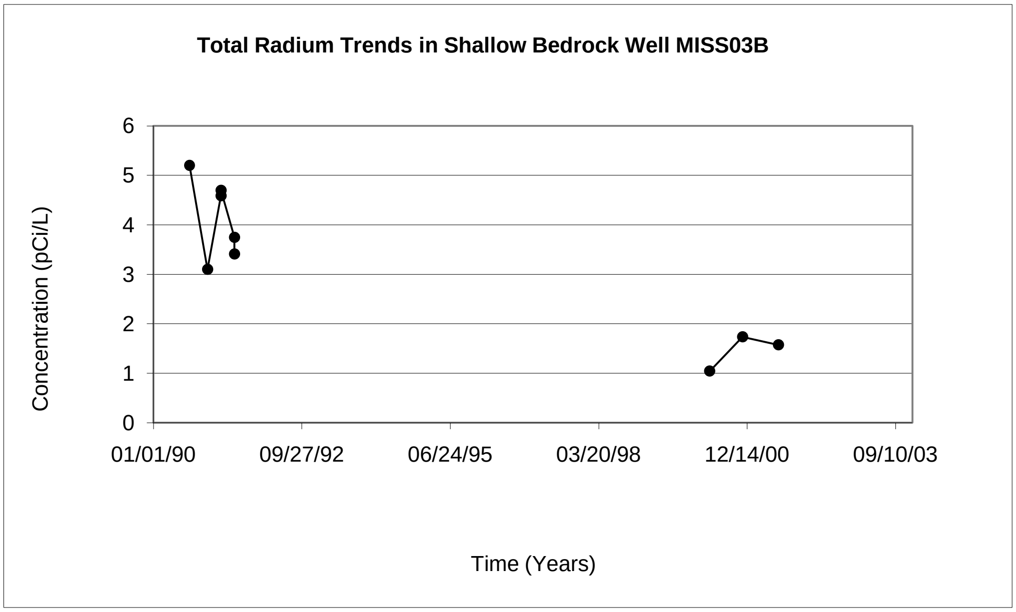

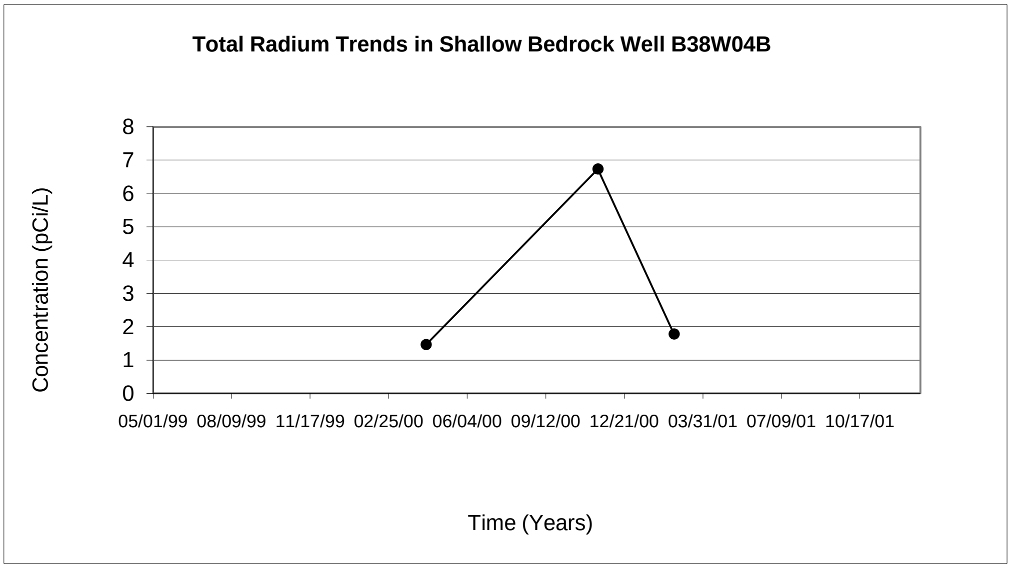

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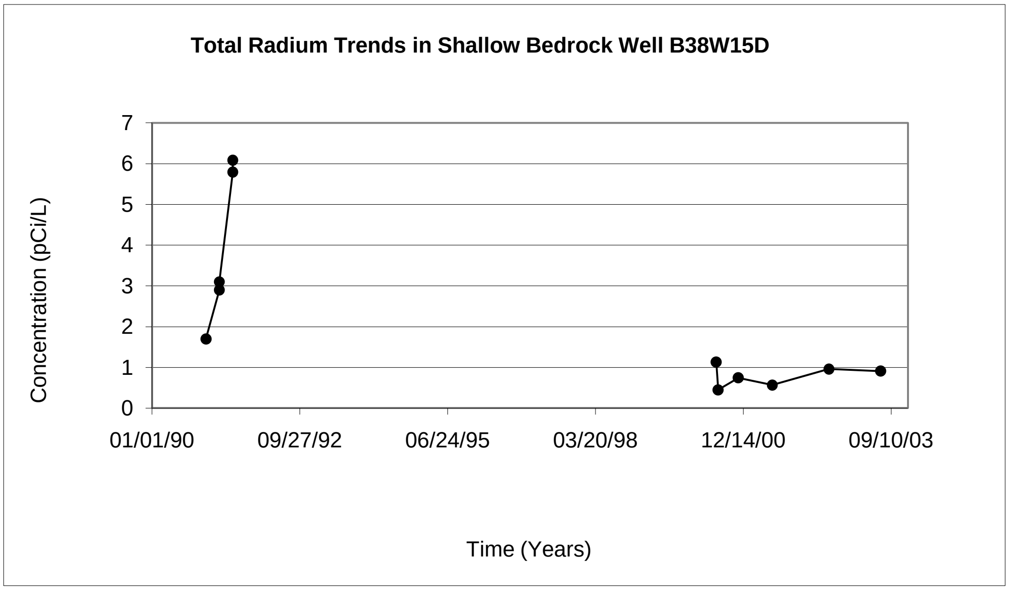

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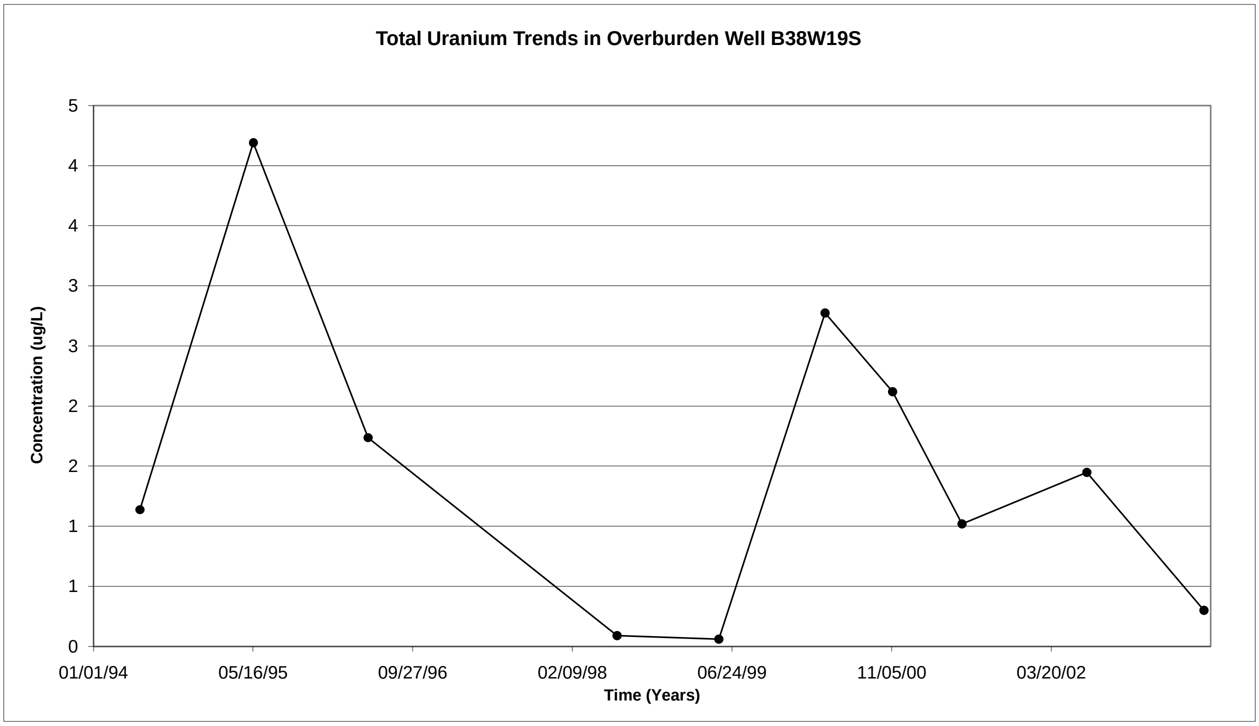

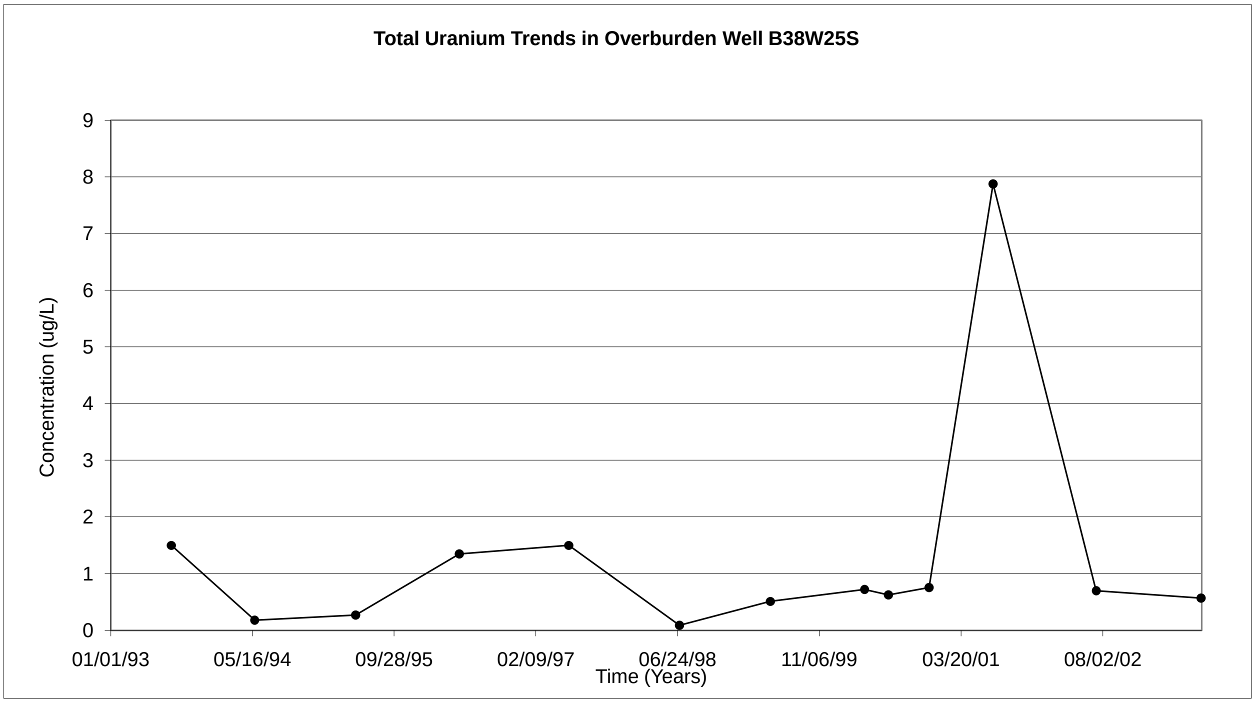

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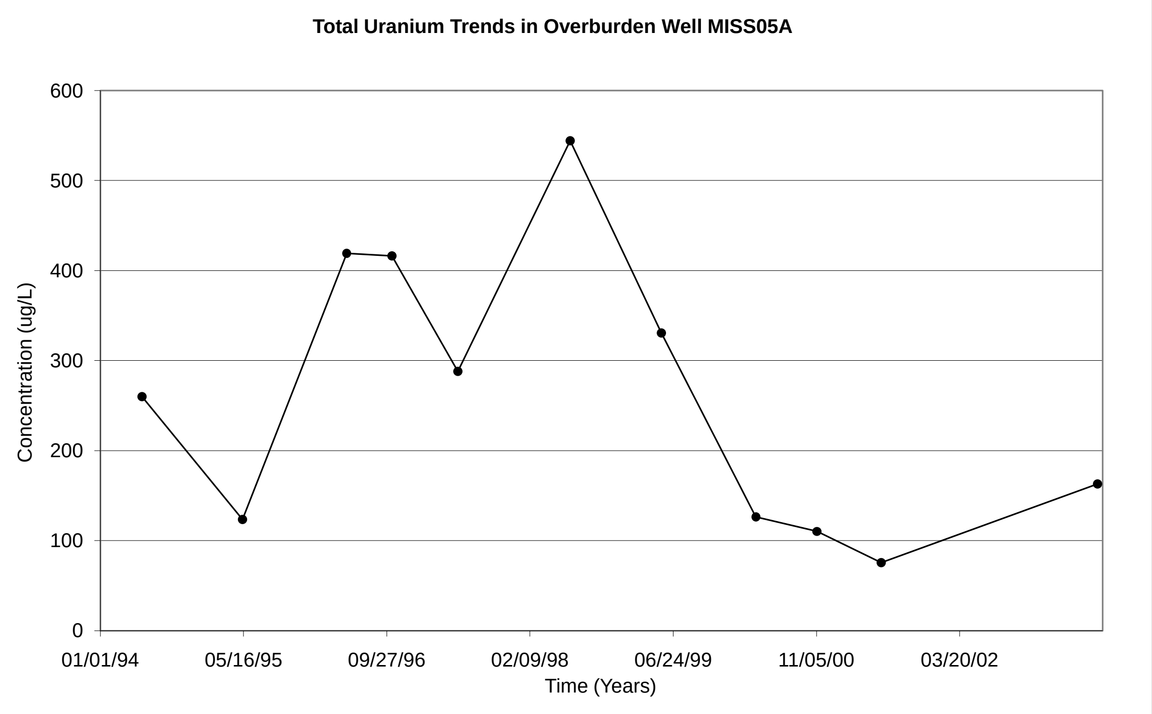

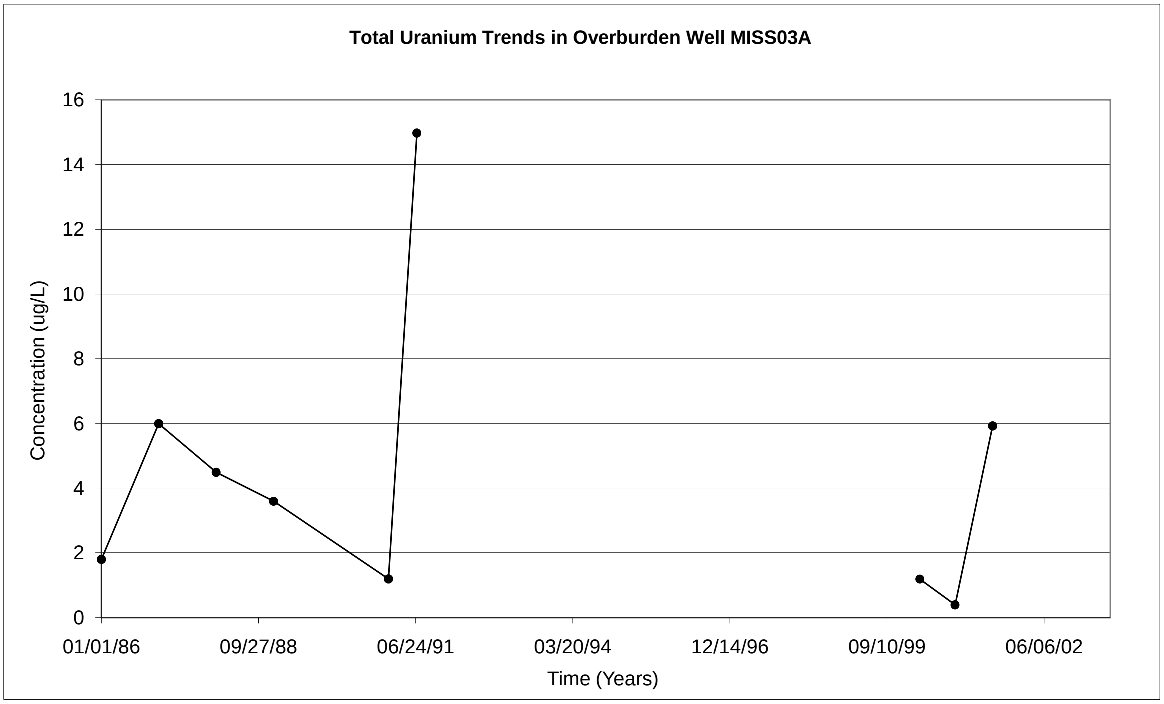

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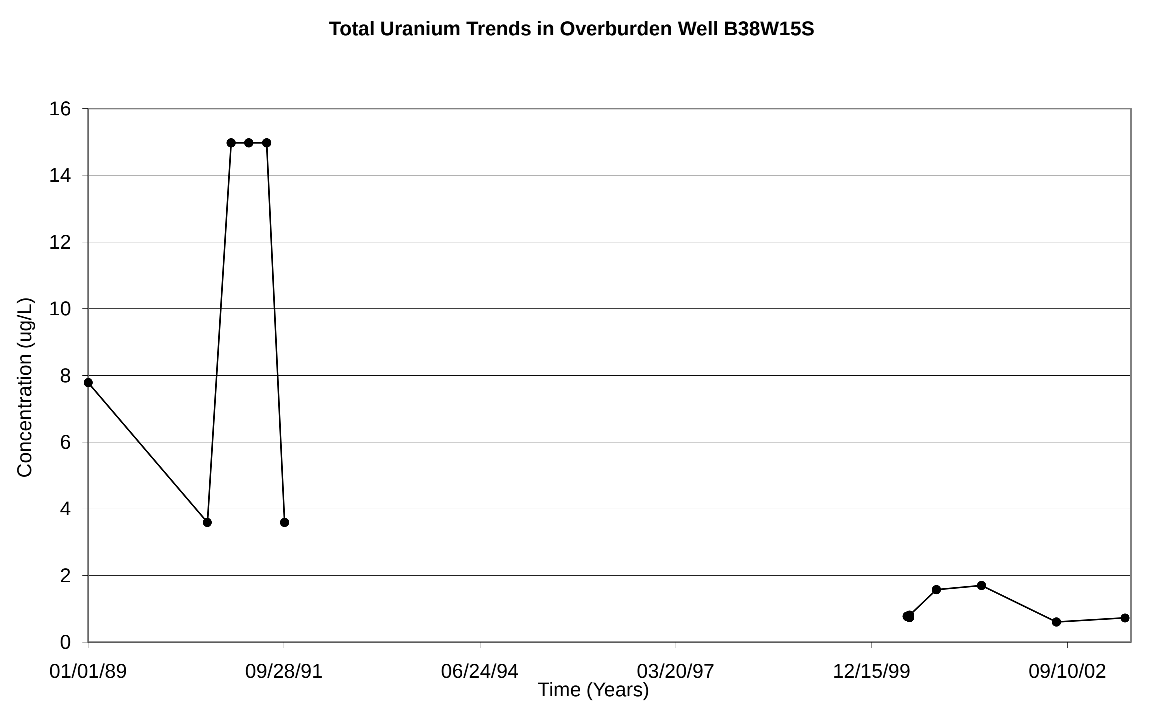

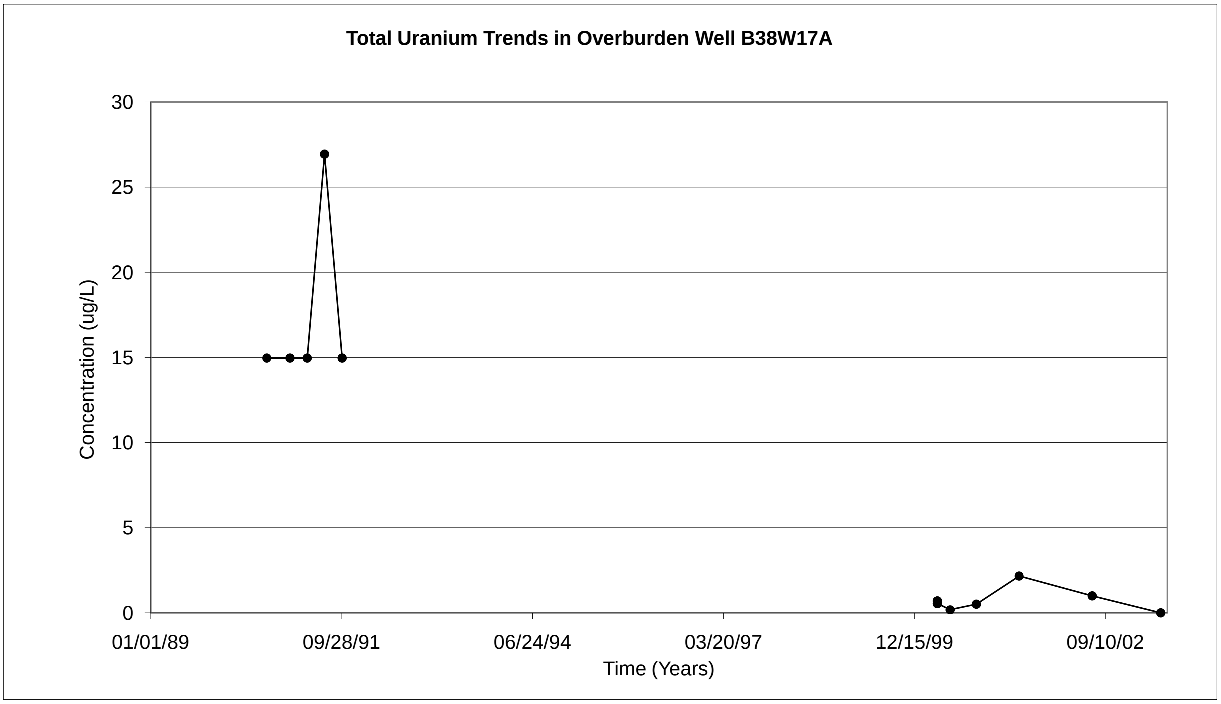

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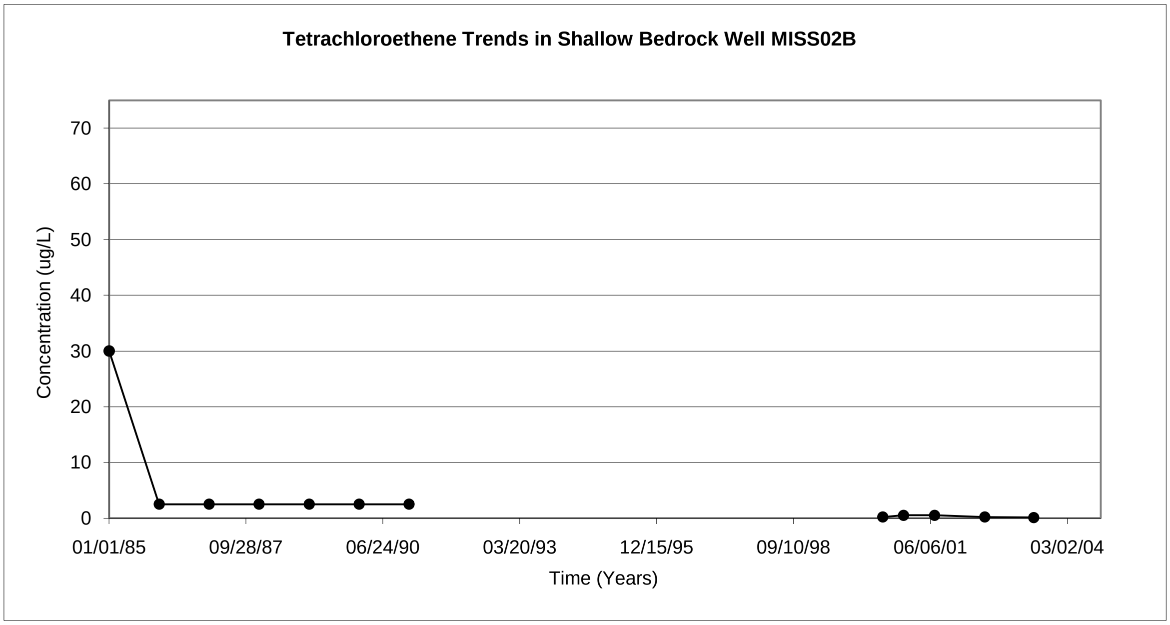

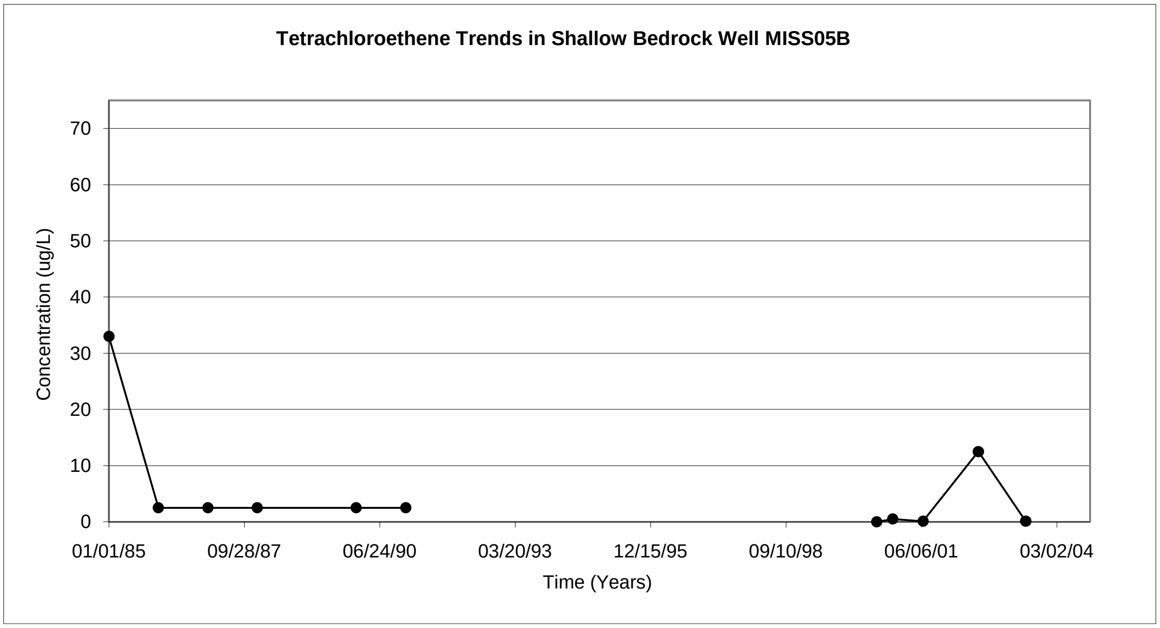

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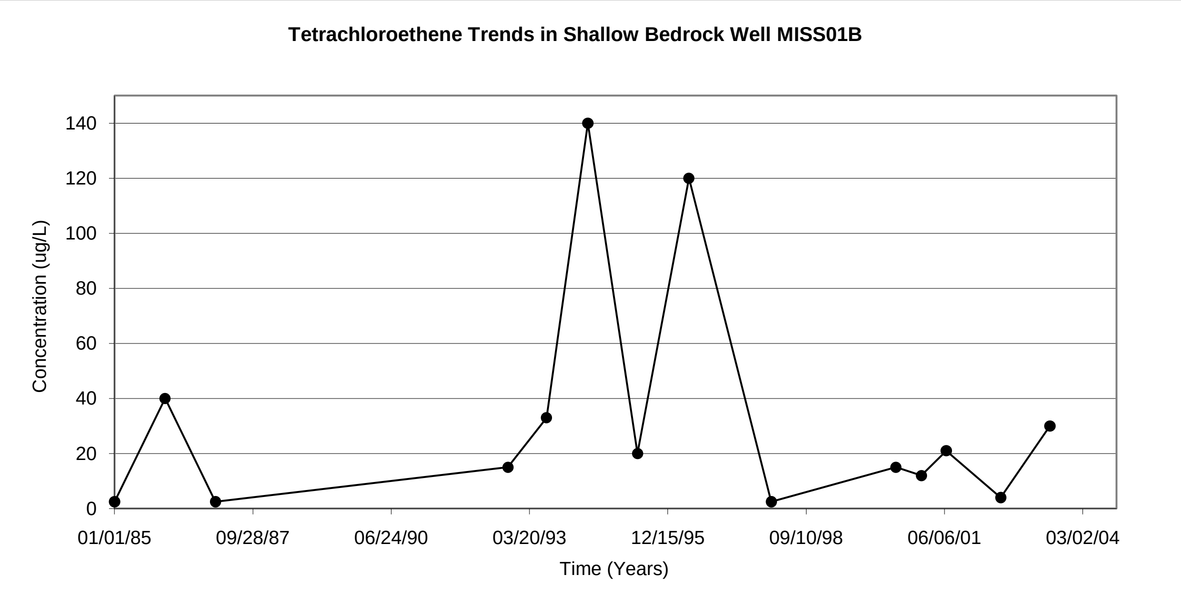

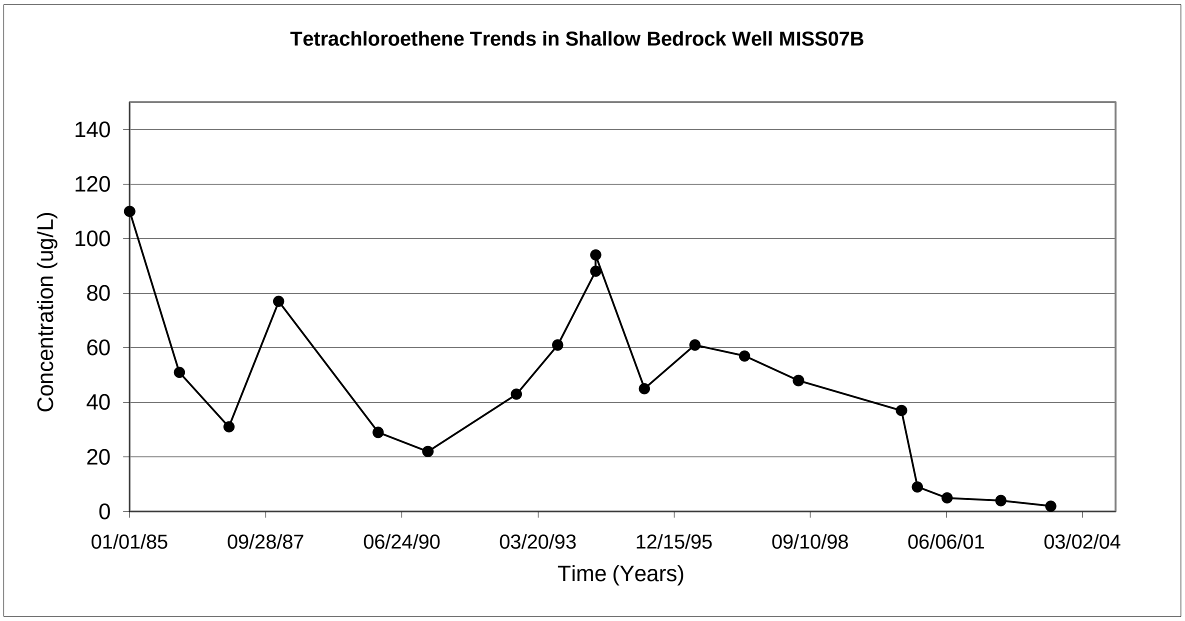

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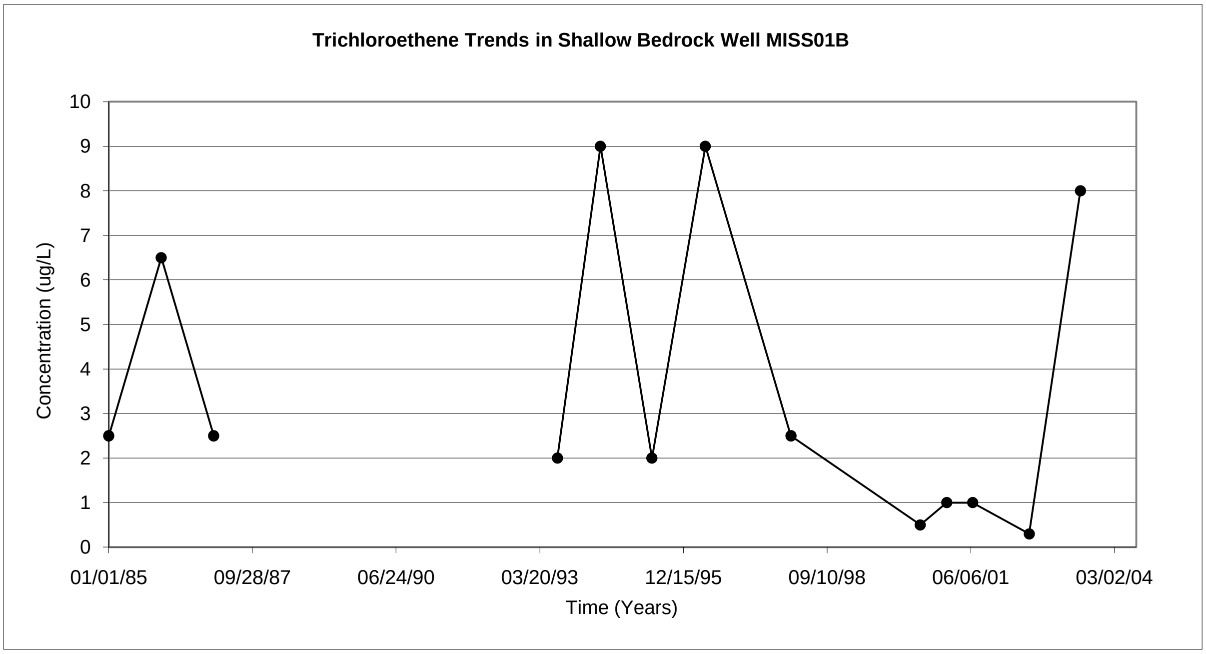

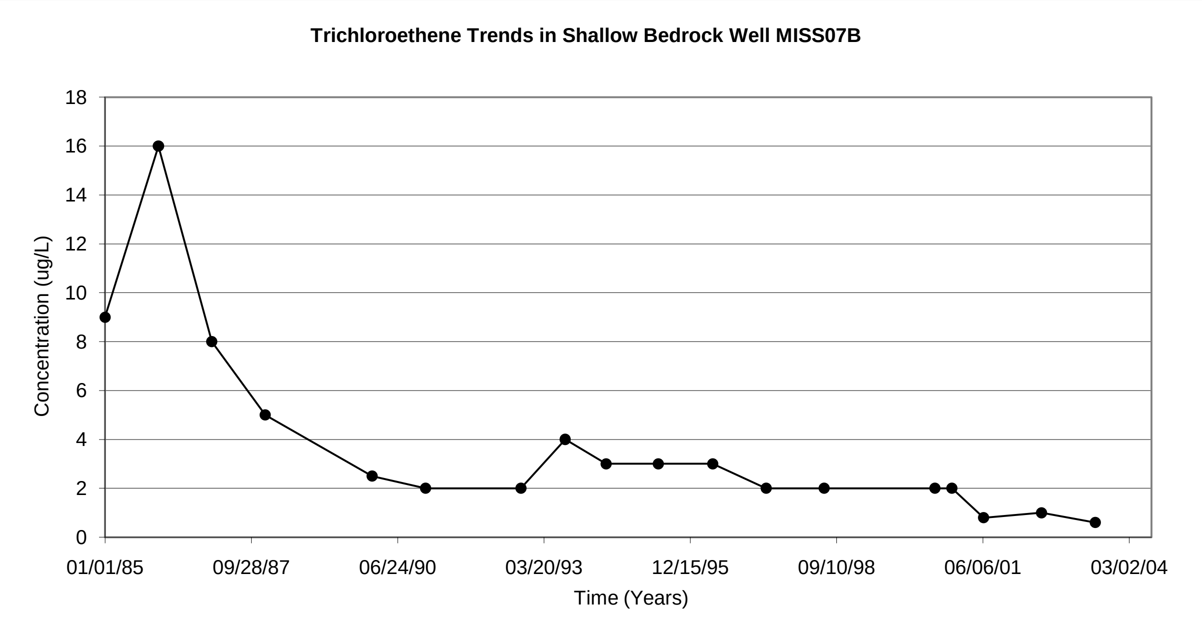

APPENDIX B

CONTAMINANT TRANSPORT PARAMETERS AND IN-SITU REMEDIATION METHODS FOR SELECTED METALS, RADIONUCLIDES, AND ORGANIC COMPOUNDS IN GROUNDWATER

(VOLUME 1)

APPENDIX B

Contaminant Transport Parameters and In-Situ Remediation Methods for Selected Metals, Radionuclides, and Organic Compounds in Groundwater at FUSRAP Maywood Superfund Site

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1.0 Introduction

This appendix provides contaminant transport parameters and discusses potential remediation methods for selected metals, radionuclides, and organic compounds in groundwater at the FUSRAP Maywood Superfund Site (FMSS). The purpose and objectives of this appendix are to support the detailed analysis of alternatives and contaminant transport modeling for the Groundwater Feasibility Study (GWFS) for the Maywood Interim Storage Site (MISS). The site-specific data used to support the derivation of transport parameters and discussions of potential in-situ remediation methods are from the *Final Groundwater Remedial Investigation Report (GWRI), Revision 4* (July 2005). An initial set of transport parameters was provided in Chapter 6 of the GWRI for some of the constituents. This appendix provides additional parameters that are required for the GWFS evaluations.

Transport parameters that are provided include adsorption coefficients for selected metals, radionuclides, and organic compounds (**Section 2.0**). Also provided are discussions of the geochemical behavior, in-situ treatment methods, and treatment half-lives of selected metals, organic compounds, and radionuclides (**Section 3.0**); half-lives and activity-to-mass conversion factors for selected radionuclides (**Section 4.0**); and an evaluation of the sources of gross alpha and gross beta activities detected in groundwater samples (**Section 5.0**).

2.0 Adsorption Coefficients

This section provides a compilation of adsorption coefficients (K_d) for use in contaminant transport modeling at the FMSS. Coefficients are provided for the metals barium, beryllium, iron, lead, and thallium; and the organic compounds 2-chlorotoluene, methylene chloride, tetrachloroethene (PCE), toluene, trichloroethene (TCE), vinyl chloride (VC), and total xylenes. Literature K_d values for benzene, thorium, uranium, radium, arsenic, chromium, and lithium have already been presented in the GWRI. Those values were reviewed as part of this evaluation, and were found to be acceptable.

Table 1 provides the recommended K_d values for the metals. **Table 2** provides the recommended values of the organic carbon adsorption coefficients (K_{oc}) for the organic compounds, and **Table 3** provides the corresponding K_d values for the organic compounds.

2.1 Metals

This section provides adsorption coefficients for barium, beryllium, iron, lead, and thallium.

2.1.1 Barium

Estimates of barium K_d values are provided in the *Soil Screening Guidance: Technical Background Document* (EPA,1996) as a function of pH. The K_d value at a pH of 6.8, which is close to the mean of site pH values, is 41 mL/g. An experimental study of barium sorption on glacial till at a site in Ohio (IT Corporation, 1993) yielded a range of K_d values from 66 to 128 mL/g. A realistic value to use for modeling purposes would be the geometric mean of these three values, which equals 70 mL/g.

2.1.2 Beryllium

Estimates of beryllium K_ds are provided in the *Soil Screening Guidance: Technical Background Document* (EPA,1996) as a function of pH. The K_d value at a pH of 6.8, which is close to the mean of site pH values, is 790 mL/g. This value is quite close to a K_d of 800 mL/g provided by Sheppard and Thibault (1990) for loam soil. A realistic value to use for modeling purposes would be 790 mL/g.

2.1.3 Iron

Iron can exist in the divalent [ferrous, or Fe (II)] or trivalent [ferric, or Fe (III)] forms in the sedimentary environment. These two valence states have very different behavior. Dissolved iron concentrations in groundwater are controlled mostly by dissolution–precipitation reactions rather than adsorption–desorption reactions. The oxidation-reduction (redox) state of the aquifer environment is the key parameter controlling iron concentrations in groundwater. Under oxidizing conditions where Fe (III) is stable, the solubility of iron is well below the standard analytical reporting limits. Detectable concentrations of iron in oxic groundwater samples are usually due to the presence of iron-bearing suspended particulates rather than dissolved iron. If the redox potential is below a critical value (which is a function of pH), then Fe (II) becomes stable. The solubility of Fe (II) can be as high as several tens of milligrams per Liter (mg/L).

The addition of organic contaminants such as fuel or solvents to an aquifer usually results in the establishment of locally reducing conditions within the contaminant plume. Within the reducing zone, naturally occurring iron and manganese oxides that are part of the aquifer matrix become soluble and dissolve, leading to elevated iron and manganese concentrations. Trace metals such as arsenic, nickel, and vanadium, which naturally adsorb on iron oxides, can also be released to the groundwater as the oxide minerals dissolve. Iron, manganese, and trace element concentrations will remain elevated within this zone, as along as reducing conditions prevail. Iron is most realistically simulated in a transport model by considering solubility as a function of local redox conditions rather than treating it as a sorbing solute. Therefore, adsorption coefficients for iron were not evaluated in this appendix.

2.1.4 Lead

A detailed literature review of lead adsorption behavior was performed by EPA (1999). The review concluded that the adsorption of lead in the environment is influenced by a number of factors such as the type and properties of adsorbing substrate, pH, the equilibrium concentrations of dissolved lead, and the type and concentrations of other competing cations and complex-forming inorganic and organic ligands. These data show that lead has a very strong affinity to adsorb onto soil constituent surfaces such as clays, oxides, hydroxides, oxyhydroxides, and organic matter. Studies of ion exchange reactions of lead on a number of clay minerals such as montmorillonite, kaolinite, illite, and vermiculite showed that lead was preferentially adsorbed by exchange on clays, readily replacing calcium and potassium. Other studies on montmorillonitic, illitic, and kaolinitic soils confirmed that lead would preferentially exchange for calcium. Experimental data also showed that goethite (FeO•OH) and manganese-oxide minerals have a high adsorption affinity for lead.

The EPA (1999) review of lead K_d values reported in the literature for a number of soils led to the development of a look-up table for K_d values. The table is based on the observation that the two most important parameters affecting lead adsorption are pH and the equilibrium dissolved lead concentration. One of the three pH categories in the EPA look-up table is a range of 6.4 to 8.7, within which most of the FMSS groundwater pH measurements fall. Maximum lead concentrations in the overburden and bedrock samples are in the range of 16 to 28 μg/L, which fall within the range of 10 to 100 μg/L in the EPA look-up table. The range of lead K_d values provided in EPA (1999) under these site-specific pH and dissolved lead concentration ranges is 900 to 4,970 mL/g. A realistic K_d value to use for modeling purposes would be the geometric mean of these range limits, which is 2,115 mL/g.

2.1.5 Thallium

Like iron, thallium is also a redox-active element. However, it is dominantly present in the monovalent form in groundwater. It will precipitate as a sulfide mineral under sulfate-reducing conditions. As long as the redox conditions are above the Eh-pH conditions where sulfide minerals are stable, the adsorptive behavior is most sensitive to pH, with K_d values increasing over a pH range from 5 to 8.

Estimates of thallium K_d values are provided in the *Soil Screening Guidance: Technical Background Document* (EPA,1996). Three K_d values of 44, 71, and 96 mL/g are provided for pH conditions of 4.9, 6.8, and 8.0, respectively. These experimentally determined K_d values were fit to a regression model as a function of pH, yielding the following relationship:

$$\mathrm{Log}_{10}\, K_d = 0.1093\ \mathrm{pH} + 1.1079$$

The pH of 38 groundwater samples from the bedrock aquifer ranges from 5.54 to 7.49, with a mean of 6.7. A set of 14 groundwater samples from the overburden aquifer has a very similar range, from 6.2 to 7.0, with a mean of 6.65. A realistic thallium K_d for the overburden and bedrock aquifer environments would thus be 69 mL/g, based on a mean pH of 6.7.

2.2 Organic Compounds

Adsorption coefficients for 2-chlorotoluene, methylene chloride, PCE, toluene, TCE, VC, and total xylenes are provided in **Table 3**. Adsorption coefficients for organic contaminants in groundwater are equal to the product of K_{oc}, and f_{oc}, the fraction of organic carbon that is present in the aquifer material.

$$K_d = f_{oc} \bullet K_{oc}$$

Values for K_{oc} are compound-specific, and are easily determined in the laboratory. The f_{oc} parameter is site-specific, and is calculated from the total organic carbon content of aquifer matrix material samples.

Experimentally determined K_{oc} values of many compounds have been published, and are often expressed in logarithmic units. One to three published K_{oc} values were found for the seven compounds of interest, as summarized in **Table 2**. If more than one K_{oc} was found, then the recommended value is based on the geometric mean of the published values. In the case of xylene, three published K_{oc} values were found for the *ortho*, *meta*, and *para* isomers. Since all three of the isomers are present in most fuel and solvent mixtures, the geometric mean of the three K_{oc} values is recommended.

The site-specific f_{oc} for the overburden is estimated at 1.6 percent (based on the average of five soil f_{oc} values). The published f_{oc} average for siltstone bedrock is 1.1 percent (Blatt, 1980). **Table 3** provides the recommended K_d values for overburden and bedrock aquifers based on these K_{oc} and f_{oc} values.

3.0 Methods for In-Situ Treatment of Contaminants in Site Groundwater

Several different remediation options have been considered and applied at sites where contamination of groundwater exists. Most of these remediation techniques involve manipulation of the redox state of the aquifer environment to cause the precipitation of metals, the adsorption of metals on mineral surfaces, or the enhancement of aerobic or anaerobic microbiological activity. The redox manipulation techniques are most effective for redox-active metals, which are metals that can exist in more than one valence state over the range of Eh, pH, temperature, and pressure conditions that exist in shallow groundwater environments. The different valence states of some of the metals of concern at the Site have very different solubilities and/or adsorption affinities, which translate into different mobilities. Other metals such as barium, beryllium, lead, and radium are not directly affected by redox conditions, but their mobilities can be indirectly affected. In some aquifer systems, the mobilities of beryllium and lead are controlled by sorption on iron and/or manganese oxides. These oxides are stable under oxidizing conditions, but if the redox potential falls below a threshold value (at sufficiently low pH), then these oxides can dissolve and can release any adsorbed trace elements to the groundwater. The mobilities of barium and radium are controlled in some aquifers by precipitation of barium sulfate (barite) and coprecipitation of radium sulfate, both of which have very low solubilities. Under sulfate-reducing conditions, sulfate gets reduced to sulfide, which drives the dissolution of these sulfate minerals and can release barium and radium to the groundwater.

Methods for increasing the redox potential of the aquifer include the injection of air, pure oxygen, ozone, hydrogen peroxide, and oxygen-releasing solid compounds such as magnesium peroxide and Oxygen Release Compound (ORC®, developed by Regenesis, 2004). More aggressive redox-increasing techniques include the injection of permanganate and persulfate compounds, and Fenton's reagent. These more aggressive techniques rapidly raise the redox potential to very high values in the treated areas.

Chemical techniques used to create reducing conditions include the injection of reducing agents such as calcium polysulfide, sodium thiosulfate, and proprietary compounds such as Metals Remediation Compound (MRC®, developed by Regenesis, 2004). Biological reduction techniques are most commonly used for in-situ treatment of organic contaminants, but have also been successfully used for metals. Biological reducing techniques involve the injection of compounds that provide a bio-available source of organic carbon thus stimulating anaerobic activity. Materials such as lactic acid, sodium lactate, molasses, cheese whey, emulsified soybean oil, and Hydrogen Release Compound (HRC® developed by Regenesis, 2004) have been successfully used for this purpose.

Caution should be exercised in the use of these redox manipulation techniques if more than one metal is of concern at a single location, because the mobilities of some metals have opposite behavior with respect to redox conditions. For instance, in high sulfate water, radium has a low mobility under oxidizing conditions, whereas uranium is the least mobile under reducing conditions. The in-situ application of a chemical oxidant in a reducing zone of an aquifer in which radium and uranium are present could have the effect of immobilizing radium, but mobilizing uranium. Adding a reducing agent to an oxic portion of an aquifer could have the opposite effect by mobilizing radium and immobilizing uranium.

3.1 Local Redox Conditions

Background groundwater conditions in the overburden layers at FMSS are oxidizing, and are oxidizing to mildly reducing in the bedrock units. However, within the benzene-impacted areas, redox conditions are strongly reducing, as evidenced by low to non-detectable dissolved oxygen; negative oxidation-reduction potential (ORP) measurements; conversion of nitrate to ammonia; and measurable dissolved iron, manganese, and methane. In addition, a large percentage of groundwater samples from monitoring wells located within the benzene plume had low but detectable concentrations of sulfide, indicating the presence of active sulfate-reducing anaerobes. Sulfate reduction only occurs under highly reducing conditions. High concentrations of dissolved sulfide are not expected in this environment because sulfide is quite reactive, and will combine with ferrous iron, as well as with trace elements such as arsenic, lead, and thallium, to precipitate as insoluble sulfide minerals. For this reason, the detection of even low levels of sulfide in groundwater usually indicates strongly reducing conditions.

3.2 Behavior and Treatment of Contaminants in Site Groundwater

Redox manipulation, via the creation of oxidizing or reducing conditions, is one of several remediation techniques that are under consideration at the Site. The introduction of oxygen to groundwater, via air sparging or the injection of ozone, hydrogen peroxide, or magnesium peroxide, has been shown to be effective in accelerating natural aerobic biodegradation rates of benzene, toluene, and xylene in systems where oxygen availability is the rate-limiting parameter. Oxygen addition may also be useful for causing in-situ adsorption of arsenic. The creation of reducing conditions may be useful in causing in-situ precipitation of arsenic, lead, thallium, and uranium. The effects of redox manipulation on all of the contaminants that are present within the plumes need to be considered. The effects of redox manipulation on the geochemical behavior of the metals arsenic, barium, beryllium, boron, chromium, iron, lead, lithium, radium, thallium, and uranium; and the organic compounds benzene, methylene chloride, PCE, toluene, TCE, VC, and xylene under various treatment scenarios, is discussed in the following paragraphs. A summary of the discussion with respect to metals is provided in **Table 4**.

<u>**Behavior and Treatment of Metals**</u>

Arsenic – Arsenic has two valence states (arsenite [+3] and arsenate [+5]) in the natural environment, so it qualifies as being directly redox-sensitive. Although there are two valence states, one really needs to think in terms of three redox zones when predicting arsenic mobility in groundwater, as summarized in **Table 5**. Under oxidizing conditions, inorganic arsenate is fairly immobile, because it speciates as oxyanions [$HAsO_4^{-2}$, $H_2AsO_4^{-}$] that strongly adsorb on the positively charged surfaces of iron oxides. Under intermediate redox conditions, arsenic will be present in the trivalent arsenite state, which speciates as a neutral form [$H_3AsO_3^{o}$ or $HAsO_2^{o}$]. Dissolved arsenite is soluble, and only weakly adsorbs to mineral surfaces because of its neutral charge. This form of arsenic is quite mobile. Under strongly reducing conditions where sulfate-reducing anaerobes are generating sulfide, arsenic will precipitate as one of several arsenic-sulfide minerals (orpiment, realgar, arsenopyrite) which have very low solubilities (Smedley and Kinniburgh, 2002; Sullivan and Aller, 1996). As a further complication, the adsorption of arsenate is pH dependent. Arsenate competes with hydroxy ions for sorption sites, resulting in increased mobility under pH conditions above approximately 8.5.

The addition of oxygen to the benzene-impacted areas may affect arsenic mobility in a few different ways, depending on the current conditions within the plume. If conditions within the benzene plume correspond to the “moderately reducing” redox conditions in **Table 5**, then arsenic is currently in the mobile trivalent arsenite form. The oxygen addition will oxidize dissolved arsenite to the less mobile pentavalent arsenate form. At the same time, dissolved ferrous iron, which is currently as high as a few tens of mg/L within the benzene plume, will rapidly oxidize to ferric iron and precipitate as $Fe(OH)_3$. Arsenate will adsorb on the $Fe(OH)_3$, and arsenic concentrations in groundwater will most likely return to background values. Alternatively, if current conditions within the benzene plume correspond to the “strongly reducing” conditions, and a significant mass of arsenic is currently present as sulfide minerals, then the oxygen addition will have a different effect. The addition of oxygen to a system containing metal-sulfide minerals results in the dissolution of the sulfide minerals and the generation of sulfuric acid. Arsenic released to groundwater by this process may remain mobile.

The amount (if any) of arsenic present as sulfide minerals within the benzene plume is not known, because these materials were not sampled and analyzed. Sulfide was detected in three of the nine groundwater samples analyzed for sulfide, including benzene plume Monitoring Wells BRPZ-9 (1.0 mg/L), BRPZ-4 (0.2 mg/L), and downgradient Monitoring Well MW-32D (0.5 mg/L). The presence of detectable sulfide in these groundwater samples suggest the presence of sulfide minerals within the benzene plume, but not necessarily arsenic-bearing sulfide minerals. It is recommended that the arsenic and sulfide content of solid material within the benzene plume be determined prior to the application of any oxidants to the plume.

Treatment of dissolved arsenite with an in-situ oxidant is predicted to be effective in causing oxidation to arsenate and subsequent adsorption on iron oxide surfaces. The oxidation rate of arsenite with a mild oxidant such as ORC® under these conditions is in the range of days to weeks, so a reasonably conservative treatment half-life is three days.

An alternative approach to in-situ treatment of arsenic is the use of MRC® or calcium polysulfide. The addition of calcium polysulfide provides a source of sulfide that will react with arsenic to precipitate an insoluble arsenic sulfide mineral. MRC® will hydrate and release an organosulfur compound that reacts to produce a stable metal-organosulfur complex. This complex sorbs strongly to soil and is immobile in the subsurface. Over time, the organic portion of the complex is biodegraded and the immobilized metals are incorporated into the soil matrix as sulfide solids. The sulfide solids tend to be stable under low redox potentials. The time required for arsenic to decrease to nondetectable concentrations in response to the injection of a reducing agent is in the range of days to weeks. A treatment half-life of 10 days in response to polysulfide or thiosulfate injection is a reasonable assumption.

Barium – Barium exists in groundwater as the divalent cation Ba^{+2}, and has similar geochemical properties as radium. Under oxidizing to mildly reducing conditions, its mobility is limited in many environments by the solubility of barite ($BaSO_4$), but those controls are removed under sulfate-reducing conditions when sulfate gets reduced to sulfide. Removal of barium in drinking water is usually performed in a treatment plant using lime softening, ion exchange, or reverse osmosis techniques. In-situ treatment of barium in groundwater is not a standard method, although permeable reactive barriers containing gypsum have been proposed at several sites.

Beryllium – Beryllium is always present in the divalent form in the natural environment, so it is not sensitive to redox conditions. Concentrations of beryllium in most aquifer systems are controlled by adsorption. EPA-approved treatment methods for the ex-situ removal of beryllium from water include activated alumina, coagulation/filtration, ion exchange, lime softening, and reverse osmosis. There is no proven in-situ method for immobilizing beryllium.

Boron – Boron is not redox-sensitive, and its mobility under the expected range of redox Eh conditions is high. Boron cannot be manipulated by changing redox conditions.

Chromium – Chromium can be present as the +3 or +6 valence states in the natural environment. The hexavalent form (chromate, or CrO_4^{-2}) is only stable under oxidizing conditions. This form is quite mobile due to high solubility and low affinity for adsorption. The trivalent form is immobile due to a combination of low solubility and high adsorption affinity (EPA, 1994). Creating a reducing environment is an effective way to immobilize hexavalent chromium. In-situ application of chemical or biological reducing agents has been shown to be effective in converting hexavalent chromium to the trivalent state and significantly lowering dissolved chromium concentrations.

Iron – Iron can exist in the divalent [ferrous, or Fe (II)] or trivalent [ferric, or Fe (III)] forms in aquifer environments. These two valence states have very different behavior. Dissolved iron concentrations in groundwater are controlled mostly by dissolution–precipitation reactions rather than adsorption–desorption reactions. The redox state of the aquifer environment is the most important parameter controlling iron concentrations in groundwater. Under oxidizing conditions where Fe (III) is stable, the solubility of iron is well below the standard analytical reporting limits. Detectable concentrations of iron in oxic groundwater samples are usually due to the presence of iron-bearing suspended particulates rather than dissolved iron. If the redox potential is below a critical value (which is a function of pH), then

Fe (II) becomes stable. The solubility of Fe (II), under reducing conditions, can be as high as several tens of mg/L.

The addition of organic contaminants such as benzene, fuel, or solvents to an aquifer initially stimulates aerobic activity, and results in the establishment of locally reducing conditions within the contaminant plume. Within the reducing zone, naturally occurring iron and manganese oxides that are part of the aquifer matrix become soluble and dissolve, leading to elevated iron and manganese concentrations. Trace metals such as arsenic, nickel, and vanadium, which naturally adsorb on iron oxides, can be released to the groundwater as the oxide minerals dissolve. Elevated iron, manganese, and trace element concentrations will remain elevated within this zone, as along as reducing redox conditions prevail.

A third condition corresponding to highly reducing redox potentials, where anaerobes are actively reducing sulfate to sulfide, needs to be considered as well. Under these conditions, iron reacts with sulfide produced by anaerobes to precipitate one or more sulfide minerals such as pyrite (FeS_2), pyrrhotite ($Fe_{1-x}S$), or marcasite (FeS_2) which have low solubilities.

The FMSS groundwater monitoring data illustrate the importance of redox in controlling iron concentrations. Iron concentrations are low outside of the benzene plume where redox conditions are mostly oxidizing, but are in the range of tens of mg/L within the plume. The zone within the plume is also characterized by low to nondetectable dissolved oxygen and strongly negative redox potentials.

It is important to take these processes into account when considering options for remediation of the organic contamination. Options that introduce oxygen into the aquifer to accelerate aerobic degradation of benzene (air sparging, ozone addition, ORC®, etc.), and the application of in-situ chemical oxidants (permanganate, persulfate, Fenton's reagent, etc.), will, as a side effect, rapidly oxidize and precipitate any excess iron and manganese that were mobilized within the reducing plume. Any trace elements that were also mobilized within the reducing zone will adsorb on the re-precipitated oxides, and usually return to background concentrations. Adding oxygen to a reducing zone where iron is soluble is a very effective method for precipitating iron. The only concern is that if iron concentrations are very high, and the permeability of the treatment zone is low, then plugging of the aquifer may result where iron precipitates.

Alternative remedial options that encourage reducing conditions, such as the application of lactic acid, molasses, soybean oil, or HRC®, will have the opposite effect on iron and manganese by promoting the dissolution of iron and manganese oxides in the aquifer matrix, thus raising dissolved concentrations, if moderately reducing conditions are established. If strongly reducing conditions are established, then iron may precipitate as sulfide minerals.

Lead – Dissolved lead is always divalent, so this metal is not directly affected by redox, but it can be indirectly controlled by redox under some conditions. Under oxic conditions, lead is soluble, but its concentrations in groundwater are usually limited by adsorption on the surfaces of clays, iron oxides, and manganese oxides (EPRI, 1984). Under sulfate-reducing conditions, lead will precipitate as a sulfide mineral (galena, PbS) that has a very low solubility. High concentrations of dissolved lead in an oxidizing environment can be lowered by injecting calcium polysulfide, or by creating sulfate-reducing anaerobic conditions. Lead concentrations will be controlled at low values under sulfate-reducing conditions by the solubility of lead sulfide. Low lead concentrations will persist, as long as the system remains reducing. A future return to natural oxic background conditions will result in the oxidation of sulfide minerals to yield sulfuric acid, accompanied by a release of lead into the solution.

Lead sulfide precipitation kinetics are fast (minutes to hours) in the laboratory. The rate-limiting step for in-situ lead immobilization in the field is subsurface mixing of the injected reagents with groundwater. Local site parameters such as porosity, permeability, and tortuosity (the average distance that water molecules travel between two points along a flow path relative to the linear distance between the points), and treatment parameters such as injection pattern and spacing, injection volumes, reagent concentration, and injection methods (surging, pulsing, recirculation, etc.), will all affect the actual treatment half-lives. Assuming that the treatment parameters are optimized for the site, a 10-day treatment half-life is a reasonable assumption for lead.

Lithium – This metal is not redox active, and will not be affected either directly or indirectly by redox manipulation. Lithium mobility is mostly controlled by adsorption on clay surfaces along the groundwater flow path. Lithium can be removed from water in a treatment plant via ion exchange or reverse osmosis, but no proven in-situ remedy is available.

Radium – Radium exists in groundwater as the divalent cation Ra^{+2}, and has similar geochemical properties as barium. Radium is not directly redox-sensitive, because it is always present in groundwater in the divalent state. However, radium mobility can be indirectly affected by redox. Radium concentrations in groundwater are often limited by the solubility of radium sulfate ($RaSO_4$), which is low. In systems where radium is controlled by $RaSO_4$, a solubility-product constraint exists where equilibrium radium concentrations are inversely proportional to sulfate concentrations. Under sulfate-reducing conditions, sulfate gets reduced to sulfide, so the solubility-limiting control of radium concentrations by $RaSO_4$ precipitation is no longer active, and radium can be mobile. Removal of radium in drinking water is usually performed in a treatment plant using lime softening, cation exchange, or reverse osmosis. In-situ treatment of radium in groundwater is not a standard method.

Thallium – Thallium is redox-sensitive and can exist in three different valence states (Tl^{+}, Tl^{+3}, and Tl^{+4}) under the range of environmental conditions. Under highly oxidizing conditions, it forms several different oxide minerals (Tl_2O_4, Tl_2O_3, Tl_2O) that limit thallium mobility. Under intermediate redox conditions, it is present in the monovalent state, and is fairly mobile. It will precipitate as a sulfide with a low solubility under sulfate-reducing conditions. Low concentrations will persist under sulfate-reducing conditions, as long as the system remains reducing. A future return to natural oxic background conditions will result in the oxidation of sulfide minerals to yield sulfuric acid, accompanied by a release of thallium into solution.

The injection of a reducing agent such as polysulfide, MRC®, or thiosulfate will rapidly precipitate thallium as a sulfide. The time required for thallium to decrease to nondetectable concentrations in response to the injection of a reducing agent is in the range of days to weeks. A treatment half-life of 10 days in response to polysulfide or thiosulfate injection is a reasonable assumption. Treatment half-lives for biological approaches, such as lactic acid or HRC® injection, are more uncertain because they are a function of several site-specific parameters, but a half-life of 40 days is a reasonable value for these techniques.

Uranium – Uranium has two valence states of +4 and +6, which have very different solubilities and mobilities. Uranium is fairly mobile under oxidizing conditions, where it exists as the hexavalent uranyl ion [UO_2^{+2}]. The uranyl ion forms a series of anionic carbonate complexes [$UO_2(CO_3)_2^{-2}$, $UO_2(CO_3)_3^{-4}$] that are soluble and do not strongly adsorb (Davis et al., 2004). Under reducing conditions, uranium will reduce to the tetravalent state, and will precipitate as the mineral uraninite (UO_2) which has very low solubility. The differences in uranium solubility under oxidizing versus reducing conditions can be as great as a factor of 1×10^5.

Insight into uranium behavior can be gained by considering the natural occurrences of the element. Uranium deposits in Colorado and Wyoming formed when oxic surface water carrying small amounts of dissolved uranium recharged aquifers that had local reducing conditions. Uranium precipitated to form commercial deposits at locations along the aquifer flow path, where the redox conditions fell below a threshold value below which uranium reduced from the hexavalent to the tetravalent state.

Some of these deposits have been exploited using in-situ mining techniques that reverse the natural redox conditions. A dilute solution of hydrogen peroxide and sodium carbonate is pumped into the ore zone. The hydrogen peroxide oxidizes the uranium to the hexavalent state, and the carbonate acts as a complexing agent that forms soluble uranyl-carbonate species. The injected solution is then pumped back to the surface where the uranium is extracted by anion exchange, and the reagents are recycled.

Imposing reducing conditions in a uranium-contaminated aquifer can be very effective in immobilizing uranium, as long as the redox remains low. The application of chemical or biological reducing agents to cause the precipitation of uranium under reducing conditions should be effective, although this is not a proven technology. Injection of chemical reducing agents, such as polysulfide or thiosulfate, should cause the rapid precipitation of uranium, with treatment half-lives in the range of 10 days. Treatment half-lives for biological approaches, such as lactic acid or HRC® injection, are more uncertain because they are a function of several site-specific parameters, but a half-life of 40 days is a reasonable value for these techniques. The injection of MRC® may be effective for immobilization of uranium also, although there is no data available on it's effectiveness for this application. Uranium does not precipitate as a sulfide, but MRC® promotes a highly reducing environment that will cause the precipitation of uranium as an insoluble oxide. The time required for uranium to decrease to nondetectable concentrations in response to the injection of a reducing agent would probably be in the range of days to weeks. A treatment half-life of 10 days in response to polysulfide or thiosulfate injection is a reasonable assumption.

Behavior and Treatment of Organic Compounds

The seven organic constituents (benzene, methylene chloride, PCE, toluene, TCE, VC, and xylene) are discussed in three groups below.

Benzene, Toluene, and Xylene – Benzene is a key constituent at FMSS. Toluene and xylene are also present at lower concentrations, and have chemical properties and degradation rates that are similar to benzene. All three compounds are in the "aromatic hydrocarbon" family, and consist of a benzene ring with varying degrees of methylation (toluene has one methyl group and xylene has two methyl groups). These three compounds, along with ethylbenzene, are major components of automotive fuel, and have been extensively studied at sites where fuel releases have occurred.

The microbial degradation of benzene, toluene, and xylene occur by the same pathways which are classified as aerobic or anaerobic. The three compounds will degrade fastest under aerobic conditions, but oxygen is consumed and rapidly depleted during this process in the absence of any active measures to resupply oxygen to the system (air sparging, ozone or hydrogen peroxide addition, ORC® injection, etc.). Once oxygen is depleted by the aerobes, then anaerobic microbes will take over, and degradation will continue at some rate by nitrate-reducing, manganese-reducing, iron-reducing, sulfate-reducing, or methanogenic anaerobes. These degradation processes generally occur in sequence, and one process yields to the next as the required nutrients are depleted. Following a benzene release, aerobic degradation will initially be dominant until the dissolved oxygen is consumed and falls below a concentration of 0.5 mg/L. Nitrate-reducing anaerobes then dominate, and will be effective at some rate until the available nitrate gets consumed. At that point, manganese- and/or iron-reducing anaerobes will dominate until the ferric iron and oxidized forms of manganese are converted to ferrous iron and reduced forms of manganese. At that point, sulfate-reducing anaerobes will reduce sulfate to sulfide until most of the dissolved sulfate is reduced. Methanogenic anaerobes will then dominate the degradation process, and will proceed at some rate until the available organic carbon is converted to methane.

Each of these steps is characterized by progressively lower redox potentials, which is measured as ORP in the field. Each step is also characterized by the sequential depletion of dissolved oxygen, conversion of nitrate to nitrogen or ammonia, increases in dissolved manganese and iron, conversion of sulfate to sulfide, and finally, conversion of carbon dioxide and organic carbon to methane.

The GWRI Report provides data on the ORP and concentrations of these microbial indicators, including dissolved oxygen, nitrate, ammonia, dissolved manganese, dissolved iron, sulfate, sulfide, and methane in samples from benzene-impacted and non-impacted locations. Results from the benzene-impacted locations clearly show lower ORP, corroborated by oxygen depletion, conversion of nitrate to ammonia, solubilization of manganese and iron, and methane production.

These results indicate that anaerobic conditions are firmly established within the benzene-impacted area, so the local benzene degradation rates will be limited by the rates that are specific to these various anaerobe populations. Remedial methods that supply the system with oxygen by air sparging, ozone injection, hydrogen peroxide injection, and the use of oxygen-releasing compounds such as magnesium peroxide and ORC®, are standard techniques implemented at sites impacted by benzene, toluene, and xylene. These techniques return the system to oxic conditions under which the faster aerobic degradation processes become re-established. Many sites where these techniques have been implemented have experienced greatly increased benzene, toluene, and xylene degradation rates.

Degradation rates are highly site-specific, but do provide an estimate of what can be expected after these remediation techniques are applied. The actual rate increases that will be observed at a given site cannot be accurately predicted, but positive improvements are expected. Published case histories from these sites, where enhanced biodegradation by oxygen addition was employed, can serve as a qualitative guide (Bohan and Schlett, 1997; Chapman et al., 1997; Duffy et al., 1999; Fischer et al., 2001; Hicks et al., 2001; Johnson, et al., 1997; Kao and Borden, 1994; Muniz et al., 2001; Mysona and Hughes, 1999; Oudijk, et al., 1999; Reed et al., 2001).

Published case histories regarding the effects of oxygen addition techniques on the degradation rate of benzene were evaluated for applicability to the FMSS. Benzene was conservatively selected to represent the three aromatic hydrocarbons, because benzene contamination is more widespread than toluene or xylene at the FMSS, and the degradation rate of benzene is lower than toluene and xylene (Lu and Zheng, 2003).

Most of these case histories express degradation in terms of a percentage or concentration decrease after a specific period of time. Contaminant fate and transport models require degradation rates, usually in the form of half-lives, that are used to predict the effects of enhanced degradation on the size and shape of the groundwater plume as a function of time. If the concentrations at three or more points in time are provided in a case history, then a degradation rate expressed as a half-life can be calculated from the data, based on an exponential decay model.

Several investigations have demonstrated that the biodegradation of fuel hydrocarbons can be approximated by first-order rate constants that can be expressed as half-lives (Wiedemeier et al., 1995 and 1996). To convert benzene concentration versus time data to a degradation half-life, benzene concentrations were first plotted on a time-trend graph. The trends were then fit with an exponential least squares decay curve of the form:

$$y = N_0 e^{-kt}$$

where: y = concentration

N_0 = concentration at $t = 0$

e = base of the natural logarithm

k = decay rate

t = time

The decay rate is equal to:

$$k = \frac{1}{t} \ln \frac{N_0}{N}$$

where N is the concentration after time t. The half-life ($t_{1/2}$) of the decay process is the time after which the original concentration has decayed to one-half of it's value, or $N = N_0/2$. The half-life is thus related to the decay rate as:

$$t_{1/2} = \frac{\ln 2}{k} = \frac{0.693}{k}$$

The correlation coefficient (R^2) provided with each of the calculated half-lives is a measure of the goodness-of-fit, or the degree to which the data deviate from the fitted exponential decay curve. The R^2 parameter ranges from 0.0 to 1.0. An R^2 of 1.0 indicates a perfect fit in which the curve passes through each data point, and an R^2 of 0.0 indicates no correlation between the data and an exponential decay curve.

Example: One applicable case history is the use of ORC® at a former gasoline service station that had gasoline subsurface free product contamination (Mysona and Hughes, 1999). The ORC® compound is a proprietary form of slow-releasing magnesium peroxide (MgO_2), which releases oxygen by the reaction:

$$MgO_2 + H_2O \rightarrow \tfrac{1}{2}O_2 + Mg(OH)_2$$

Results of five groundwater sampling events conducted at three monitoring wells during the remediation operations at the service station provide a good data set for the calculation of enhanced benzene degradation rates. **Table 6** provides the calculated treatment half-lives and correlation coefficients of the exponential fit to the benzene monitoring data at three wells. The correlation coefficients of the exponential fit indicate good agreement with an exponential decay model. The half-lives at the three wells, calculated from five samples from each well obtained over a 1.3 year monitoring period, range from 0.29 to 0.76 years, with a mean of 0.51 years. In conclusion, a benzene half-live degradation rate in the range of six months has been observed at three locations where oxygen addition has been used to enhance the natural degradation rates.

Methylene Chloride – Methylene chloride, also known as dichloromethane, is a colorless liquid that has a mild sweet odor, evaporates very quickly, and will not easily burn. It is widely used as an industrial solvent and as a paint stripper. It can also be found in certain aerosol and pesticide products, and is used in the manufacture of photographic film. Methylene chloride does not appear to occur naturally in the environment. It is also an intermediate anaerobic degradation product of carbon tetrachloride that eventually further degrades to methane (Davis, et al. 2003).

Rapid biodegradation rates have been observed under laboratory-controlled aerobic and anaerobic conditions, but actual rates vary under natural conditions (ATSDR, 2004). Regenesis claims that HRC® is effective in promoting the dechlorination of methylene chloride to methane under anaerobic conditions, and can be treated in a similar manner as PCE, TCE, and VC.

PCE, TCE, and VC – The compounds PCE, TCE, dichloroethene (DCE), and VC are part of a degradation series. Under favorably reducing conditions, anaerobic microbial activity will sequentially replace a chlorine atom with a hydrogen atom to yield the reductive dechlorination sequence:

PCE → TCE → *cis*-1,2-DCE → VC → Ethene

Ethene will eventually degrade to carbon dioxide and water. The compounds PCE and TCE are commonly used industrial cleaners and solvents, but *cis*-1,2-DCE and VC are mostly used in the manufacturing of plastics, and are not usually used at other industrial facilities. Therefore, the presence of *cis*-1,2-DCE and VC indicate that degradation is occurring via reductive dechlorination (EPA, 1998). Eventually, all of the compounds will degrade to nondetectable concentrations when these sequential reactions go to completion; but temporary increases in daughter products are expected as the parent and daughter compounds degrade at different rates. In fact, temporary increases in daughter products provide evidence that microbial degradation is effectively proceeding.

Each of the sequential steps requires progressively lower redox conditions. If only moderately reducing conditions are achieved, then the reductive dechlorination reaction sequence may stall, resulting in conversion of the original solvents to DCE or VC with no further degradation. A common limiting factor in the establishment of highly reducing conditions at many sites is the concentration of bio-available forms of organic carbon that anaerobes can utilize. EPA (1998) guidance suggests that total organic carbon concentrations of at least 20 mg/L are required to achieve the reducing conditions necessary for complete degradation of the sequence of compounds via anaerobic reductive dechlorination pathways. At sites that are limited by natural organic carbon concentrations, the injection of some bio-available form of carbon, such as molasses, unrefined soybean oil, sodium lactate, lactic acid, or HRC®, can be effective in driving the redox potential to lower values, thus promoting the complete degradation of the compounds.

It should be noted that VC is the only compound in the sequence that can also be degraded at a reasonable rate under aerobic, as well as anaerobic, conditions. Taking advantage of this can be problematic, because it may not be possible to maintain the reducing conditions necessary for degradation of all of the PCE, TCE, and DCE to VC, while maintaining oxic conditions for degradation of VC. This has been achieved at some sites in a two phase process, where reducing conditions are maintained for a period of time to allow conversion to VC, followed by the imposition of oxic conditions in a later phase to degrade the VC.

3.3 Summary and Recommendations for In-Situ Treatment of Contaminants in Site Groundwater

In-situ remediation of benzene, toluene, and xylene can be accomplished by oxygen-addition techniques that stimulate aerobic microbial activity such as the application of ozone, peroxide, or ORC®. Remediation of the chlorinated compounds PCE and TCE is best accomplished by stimulating anaerobic microbial activity thorough the application of bioavailable sources of organic carbon (lactic acid, soybean oil, etc), or proprietary compounds such as HRC®. VC can be remediated by encouraging either aerobic or anaerobic conditions. However, anaerobic techniques are usually more appropriate for VC because it is a degradation product of PCE and TCE, so it is usually co-located with these compounds.

A summary of the previous discussions for metals is provided in **Table 4**. The terms *high* and *low* used in the table to describe the mobility of the metals are relative terms. A high potential for mobility does not imply that high concentrations will actually be present. It is certainly possible to have high mobility and low concentrations, if the local concentrations are limited by availability of the metal.

It is apparent from **Table 4** that there is no unique set of conditions that will limit the mobilities of all of the metals of concern, because some of the metals have opposite behavior with respect to their mobilities under different redox conditions. The following recommendations follow from this discussion.

1. In the selection of remedial options for metals in groundwater, it is recommended that the Site be considered as consisting of two zones: an oxic zone that is outside of the benzene plume, and a reducing zone that is within the benzene plume. Within each of the zones, the metals of key concern should be prioritized because it may not be technologically feasible to treat all of the metals, especially those with opposite redox behavior.

2. The addition of oxygen is being considered to accelerate the natural attenuation of benzene within the benzene plume. It is recommended that the arsenic, lead, thallium, uranium, and sulfide content of solid material within the benzene plume be determined prior to the application of oxygen to the plume. If a significant mass of these metals has precipitated within the benzene plume as sulfide minerals, then the addition of oxygen to accelerate the natural attenuation of benzene may have the unwanted side effect of mobilizing these metals.

3. An additional point to consider is that any in-situ remedy expected to be effective on a long-term basis should be compatible with natural background conditions that will exist over the long-term. For instance, consider the case of injecting calcium polysulfide or creating in-situ sulfate-reducing conditions by stimulating anaerobes within an otherwise oxic aquifer. The solubilities of several metals, including arsenic, lead, and thallium, will be maintained at very low concentrations as long as the Eh-pH conditions remain below the sulfate/sulfide boundary. However, if the redox buffer capacity of the system becomes exhausted and oxic conditions return at some point in the future, then the sulfide minerals will oxidize to yield sulfuric acid, and the sequestered metals will be remobilized. Likewise, if in-situ oxidation is applied at a site where the natural background redox conditions are low [below the Fe(III)/Fe(II) curve in Eh-pH space], then manganese oxides and iron oxides could dissolve when low redox conditions return, and any adsorbed trace metals could then be released back to solution. On a long enough time scale, the system will eventually return to its original redox state. If the natural conditions are oxidizing, then in-situ sulfide precipitation is only a temporary remedy. Likewise, if the natural conditions are reducing, then in-situ oxidation is only a temporary remedy, although these temporary conditions may persist for a significant period of time.

4.0 Radionuclide Half-Lives and Specific Activities

Each radionuclide has a unique half-life, which is the time required for a given mass of the radionuclide to be reduced by one-half as a result of radioactive decay. Each radionuclide also has a unique specific activity, which is defined as the radioactivity (number of disintegrations per unit time) released by a mass of one gram. The Curie is a unit of radioactivity originally based on the disintegration rate of one gram of Ra-226, but is now defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.7×10^{10} (Friedlander et al., 1981). Half-life and specific activity are related by the relationship:

$$SA \times t_{1/2} \times M = 1.1283 \times 10^{13}$$

where: SA = Specific activity (Ci/g)

$t_{1/2}$ = Half-life (seconds)

M = Atomic mass of the nuclide (g/mole)

Half-lives and specific activities for Ra-226, Ra-228, Th-228, Th-230, Th-232, U-234, U-235, and U-238 are provided in **Table 7**. Specific activities are useful for converting activities to mass in transport calculations.

5.0 Evaluation of the Sources of Gross Alpha and Gross Beta Activity in Groundwater

This section provides the methodology and results of a statistical evaluation of the gross alpha, gross beta, and other radiological analyses of GWRI Phase II bedrock groundwater samples. The objective of the evaluation is to identify the principal sources of gross alpha and gross beta activities in groundwater samples.

The Federal/New Jersey Maximum Contaminant Level (MCL) for gross alpha is 15 pCi/L, which excludes uranium and radon activities. Radon was not analyzed in groundwater samples, so its contributions to the gross alpha measurements is unknown. The Federal/NJDEP gross beta screening value is 50 pCi/L, which excludes the contributions from naturally occurring K-40.

One of the overburden groundwater samples exceeded the gross alpha MCL, and none of them exceeded the gross beta MCL. The only gross alpha exceedance in the overburden samples (292.91 J [±131.71] pCi/L) was detected at Monitoring Well OBMW10. A large measurement error was associated with this sample, due to the small sample volume analyzed and high total dissolved solids present in the sample. A larger number of bedrock samples exceeded both the gross alpha and gross beta MCLs. Three gross alpha exceedances were detected in bedrock groundwater samples. The maximum detected gross alpha result was present in the groundwater sample obtained from Monitoring Well BRPZ-5 (57.47 pCi/L), which is located in Former Retention Pond C on the MISS. Exceedances were also detected at Monitoring Wells BRPZ-2 (27 pCi/L) and MW-3D (18.42 pCi/L). Four samples contained adjusted gross beta at a concentration exceeding the screening standard, including MISS Monitoring Wells BRPZ-2RE (168.02 pCi/L), BRPZ-5 (53.41 pCi/L), MW-26D (117.51 pCi/L), and off-site Monitoring Well MW-13D (68.98 pCi/L).

It has been suggested that gross alpha and gross beta be treated as contaminants and simulated using a fate and transport model, along with other contaminants. However, if it can be shown that there are several significant contributors to these gross measurements (i.e. if isotopes of uranium, radium, thorium, and other radioelements all contribute more or less equally), then gross alpha or gross beta cannot be modeled as a contaminant, because these elements have very different transport properties. Alternatively, if it can be shown that a significant fraction of the gross measurements can be attributable to a single radioelement, then the gross measurements do not need to be modeled, because the key radioelement that is contributing to the gross measurements has already been modeled.

Gross alpha and gross beta measurements are expected to exceed the sum of the analyzed alpha (α) and beta (β) emitters, because of the presence of many short-lived daughters that were not analyzed. For instance, in the U-238 decay chain:

> U-238(α) → **Th-234(β) → Pa-234(α)** → U-234(α) → Th-230(α) → Ra-226(α) → **Rn-222(α) → Po-218(β) → Pb-214(β) → Bi-214(β) → Po-214(α) → Pb-210(β) → Bi-210(β) → Po-210(α) → Pb-206(stable)**

for the Th-232 chain:

> Th-232(α) → Ra-228(β) → **Ac-228(β)** → Th-228(α) → **Ra-224(α) → Rn-220(α) → Po-216(α) → Pb212(β) → Bi-212(α) → Po-212(α) → Pb-208(stable)**

and for the U-235 chain:

> U-235(α) → **Th-231(β) → Pa-231(α) → Ac-227(β) → Th-227(β) → Ra-223(α) → Rn-219(α) → Po-215(α) → Pb-211(β) → Bi-211(α) → Tl-207(β) → Pb-207(stable).**

The eight radionuclides that were analyzed are shown in bold. Gross measurements, even after subtracting contributions from U-234(α), U-235(α), U-238(α), and K-40(β), will still get contributions from many of the other α and β emitters in these decay chains, if they are present at secular equilibrium (a condition where the daughters of a long-lived parent achieve activities that are equal to the activity of the parent). The extent of these contributions depends on the degree of secular equilibrium that has been established between the daughters, and the extent to which the aquifer acts as a closed system (i.e. does radon [Rn] escape as a gas).

Although the sum of the analyzed emitters (bold above) will be less than the gross measurements, the activities of a parent should be correlated with the gross measurements, if that parent (and associated daughters) was the dominant contributor to the gross measurements.

5.1 Methodology

Correlations between the gross measurements and the individual analyzed radionuclides were evaluated to determine if most of the gross activity can be attributed to a main contributor, or if multiple radioelements are all significant contributors. Analyses of the Phase II GWRI samples from the bedrock aquifer were used in the evaluation. Analyses of samples from the overburden aquifer were not used, because activities were lower, percentages of nondetects were higher, there were no exceedances of the gross beta MCL, and only one exceedance of the gross alpha MCL in the overburden data set.

Correlation is a measure of the relationship between two or more variables. The *correlation coefficient* is a measure of the extent to which values of two variables are proportional or linearly related to each other. The most widely-used type of correlation coefficient is Pearson *R*, also called linear, or product-moment correlation. The Pearson product moment correlation coefficient is calculated as:

$$R_{12} = \Sigma(Y_{i1} - \mu_1) * (Y_{i2} - \mu_2) / [\Sigma(Y_{i1} - \mu_1)^2 * \Sigma(Y_{i2} - \mu_2)^2]^{(1/2)}$$

where: R_{12} = Correlation coefficient between variables 1 and 2

Y_{i1} = The i^{th} value of variable 1

Y_{i2} = The i^{th} value of variable 2

μ_1 = Mean of variable 1

μ_2 = Mean of variable 2

Correlation coefficients for a pair of variables can range from -1.00 to +1.00. The value of -1.00 represents a perfect negative correlation, while a value of +1.00 represents a perfect positive correlation. A value of 0.00 represents a lack of correlation.

5.2 Results

A table of correlation coefficients between gross alpha and gross beta versus the activities of the specific radionuclides that were analyzed in the Phase II GWRI bedrock groundwater samples is provided in **Table 8**. Summary statistics, including the number of samples, percent non-detects, minimum, median, mean, and maximum activities for the radiological parameters are provided in **Table 9**. Results for gross beta and gross alpha are discussed below.

Gross Beta – Elemental potassium and K-40 are the only parameters that are highly correlated with gross beta. The K-40 values are calculated by multiplying the elemental potassium concentration by a constant representing the fraction of total potassium present as K-40. Elemental potassium and K-40 are thus perfectly correlated with each other, so both parameters show the same degree of correlation with gross beta. The correlation coefficient of 0.99 between gross beta and K-40 suggests that the variance in gross beta is almost entirely due to the variance in potassium concentrations. Calculated K-40 activities in the bedrock groundwater samples have a considerable range of 0.62 (±0.12) to 593.49 (±119) pCi/L, or nearly three orders of magnitude, with a mean of 45.46 (±9.1). Measured gross beta activities in the bedrock samples range from 0.02 (±1.35) to 711 (±0.84), with a mean of 52.96 (±10.3) pCi/L, which is a similar range.

The relationship between calculated K-40 and gross beta activities is shown on **Figure 1**. The high degree of correlation is evident in the plot. The same data is shown on **Figure 2**, along with error bars indicating the uncertainties of the point positions, and a diagonal line with a slope of unity. If all of the gross beta was due to K-40, then one would expect a slope of unity. This perspective shows that the line with a slope of unity passes through the points, when the uncertainties are considered.

The only other beta emitter besides K-40 analyzed was Ra-228. Radium-228 activities in the 54 bedrock samples range from 0.05 to 2.08 pCi/L, and 40 of those measurements were considered to be nondetects. Activities attributable to Ra-228 are less than the uncertainties of the K-40 and gross beta measurements, indicating that Ra-228 is not a significant contributor to gross beta activities. In conclusion, activities detected by the gross beta measurements are mostly due to the presence of elemental potassium in the groundwater.

Adjusted Gross Beta – Adjusted gross beta is defined as a gross beta measurement minus the contribution from K-40. There were four exceedances of the adjusted gross beta criteria of 50 pCi/L at the following bedrock aquifer Monitoring Wells: MW-13D (68.98 pCi/L), BRPZ-2RE (168.02 pCi/L), BRPZ-5 (45'-55') (53.41 pCi/L), and MW-26D (117.51 pCi/L). One explanation for these exceedances is that other beta emitters besides K-40 are present in the samples. However, the uncertainties of these adjusted activities are fairly high. **Table 10** provides the gross beta, elemental potassium, calculated K-40 activity, and adjusted gross beta results for the four samples in question. Uncertainties in these parameters are also provided in the table. Measurement errors for gross beta are provided by the laboratory, and range from ± 4 percent to ± 24 percent of the reported activities in the four samples. The post-analysis data validation process assigned the analysis of the sample from Monitoring Well BRPZ-2RE, which had the highest gross beta activity of 473.16 (±39.98) pCi/L, a J-flag, indicating that the results are estimated, and are more uncertain than the laboratory-provided uncertainty.

The K-40 activities are calculated based on the elemental potassium in the samples. Uncertainties in the potassium concentrations were not provided by the laboratory, but are generally considered to be in the range of ±15 to 20 percent. Two of the four potassium concentrations are J-flagged, indicating that the uncertainties in these results may be higher than 20 percent. The uncertainty (σ) in a value c that is calculated by the difference between two uncertain values a and b is equal to:

$$\sigma_c = (\sigma_a^2 + \sigma_b^2)^{1/2}$$

Adjusted gross beta activities and their uncertainties calculated by this method are provided in **Table 10** for the four samples in question. The samples from Monitoring Wells BRPZ-5 and MW-26D actually have greater uncertainties than the reported activities themselves. The sample from Monitoring Well BRPZ-2RE has the highest adjusted gross beta activity of 168.02 (±72.96) pCi/L; however, both the gross beta and potassium results are qualified with J-flags, so this calculated activity is highly uncertain. The remaining sample from Monitoring Well MW-13D has an adjusted gross beta activity of 68.98 (±4.76) pCi/L. Other beta emitters that were not analyzed for may be present in this sample, although none of the analyzed radiological parameters were elevated.

Gross Alpha – Gross alpha (GA) measurements range from 0.0 (±2.98) to 67.74 (±20.25), with a mean of 8.58 (±11.1) pCi/L. The measurements are correlated most strongly with U-234, U-238, and total uranium, as shown on **Table 8**. (Total uranium is the calculated sum of U-234, U-235, and U-238 activities.) The correlation of total uranium versus GA is shown on **Figure 3**. Activities of U-234 and U-238, which are members of the same decay chain, are the dominant contributors to GA activities. Uranium-235 activities are mostly nondetectable (91 percent not detected). The maximum reported U-235 activity of 0.7 pCi/L was considered to be a nondetected result.

The three thorium isotopes (Th-228, Th-230, and Th-232) are all alpha emitters, but they show poor correlations with GA (R^2= 0.14, 0.17, and 0.04, respectively). In addition, the range of activities of the three thorium isotopes in the bedrock groundwater samples are much lower than the GA activities, as shown in **Table 9**. Radium-226 is an alpha emitter that was analyzed, but the low GA correlation coefficient of 0.16, and the maximum Ra-226 activity of only 2.28 pCi/L, indicate that it is not a significant contributor to GA.

Adjusted Gross Alpha – Adjusted gross alpha (AGA) activity is defined as the GA activity minus any contributions from isotopes of uranium and radon. The Federal/New Jersery MCL for AGA is 15 pCi/L. Radon was not analyzed, so its effect on the GA value is unknown. As a result, the AGA activities may be biased high, because of the unknown contributions from Rn-220 and Rn-222, which are daughters of the U-238 and Th-232 decay chains, respectively. AGA is defined in the absence of radon data as GA minus the uranium contributions, or:

$$\mathrm{AGA} = \mathrm{GA} - {}^{234}\mathrm{U} - {}^{235}\mathrm{U} - {}^{238}\mathrm{U}$$

The uncertainty in the calculated AGA is equal to

$$\sigma_{AGA} = (\sigma_{GA}{}^2 + \sigma_{U\text{-}234}{}^2 + \sigma_{U\text{-}235}{}^2 + \sigma_{U\text{-}238}{}^2)^{1/2}$$

An additional, but unquantifiable, component of error is from R-220 and Rn-222 values which were not determined or subtracted from GA. Three AGA exceedances of the MCL were detected in bedrock groundwater samples. Gross and AGA activities, uranium isotope activities, and associated uncertainties are provided for these three samples in **Table 11**. The maximum AGA result of 57.47 (±20.37) pCi/L was present in the groundwater sample obtained from Monitoring Well BRPZ-5, which is located in Former Retention Pond C on the MISS. A second exceedance of 27.0 (±25.1) pCi/L was detected at well BRPZ-2. This result is highly uncertain when the measurement errors are considered. The third exceedance at Monitoring Well MW-3D of 18.42 (±17.2) pCi/L is also highly uncertain when measurement errors are considered. In fact, the GA measurement, and all three uranium isotope measurements in the Monitoring Well MW-3D sample, are considered to be nondetected.

The only statistically significant AGA exceedance of the MCL is the sample from Monitoring Well BRPZ-5 of 57.47 (±20.37) pCi/L, which is located in Former Retention Pond C on the MISS. Other alpha emitters that were not analyzed may be present in this sample, although none of the analyzed alpha emitters (Ra-226 and three thorium isotopes) were elevated.

5.3 Conclusions

Evaluations of the correlations of analyzed radionuclides versus GA and gross beta activities, and comparisons of the ranges of activities for all of the radiological parameters were performed. Results indicate that K-40 is the dominant contributor to gross beta activities; and that U-234 and U-238, which are members of the same decay chain, are the dominant contributors to GA activities. Based on the observed correlations, GA will closely follow the movement of uranium in the bedrock aquifer. The only statistically significant exceedance of AGA was observed at Monitoring Well BRPZ-5, which is in the vicinity of the Former Retention Pond source area. This indicates that one or more non-uranium alpha emitters are present in the bedrock groundwater only at this source area location. This observation suggests that the mobility of the alpha emitters are low.

Gross beta will closely follow the movement of elemental potassium in the aquifer. The only statistically significant exceedance of adjusted gross beta was at Monitoring Well MW-13D, which is due to the presence of one or more beta emitters other than K-40.

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TABLE 1

Adsorption Coefficients for Barium, Beryllium, Lead, and Thallium in Overburden and Bedrock Aquifers

Element	Adsorption Coefficients[1]	Substrate	Source	Range[2]
Barium	$K_d = 66$ $K_d = 128$ $K_d = 41$	Unweathered Glacial Till Weathered Glacial Till pH = 6.8	IT, 1993 IT, 1993 EPA, 1996	$K_d = 41$ to 128 **Recommended value = 70**
Beryllium	$K_d = 790$ $K_d = 800$	pH = 6.8 Loam soil	EPA, 1996 Sheppard and Thibault,1990	$K_d = 790$ to 800 **Recommended value = 790**
Lead	$K_d = 19$ $K_d = 270$ $K_d = 1405$ $K_d = 900$ $K_d = 4970$ $K_d = 2115$	Sand Soil, minimum Sand Soil, geometric mean (n=3) Sand Soil, maximum Minimum for site pH and Pb G.W. Conc. Maximum for site pH and Pb G.W. Conc. Site-specific pH and Pb concentration	Sheppard and Thibault,1990 Sheppard and Thibault,1990 Sheppard and Thibault,1990 EPA, 1999 EPA, 1999 EPA, 1999	$K_d = 19$ to 4970 **Recommended value = 2115**
Thallium	$K_d = 44$ $K_d = 71$ $K_d = 96$	pH = 4.9 pH = 6.8 pH = 8.0	EPA, 1996 EPA, 1996 EPA, 1996	$K_d = 44$ to 96 **Recommended value = 69**

(1) Adsorption coefficients in units of mL/g.

(2) The recommended value for use in the contaminant transport model is based on the geometric mean of the published values.

TABLE 2

Organic Carbon Adsorption Coefficients for Seven Organic Compounds

Compound		Log K_{oc} (mL/g)	K_{oc} (mL/g)	Recommended K_{oc}^* (mL/g)	Reference
2-Chlorotoluene		2.28	191	191	Chiou et al., 1979
Methylene Chloride		0.94	8.7	8.7	Schwille, 1988
Tetrachloroethene		2.42	263	272	Abdul et al., 1987
		2.56	363		Schwille, 1988
		2.322	210		Chiou et al., 1979
Toluene		2.06	115	132	Abdul et al., 1987
		2.18	151		Garbarini and Lion, 1986
Trichloroethene		1.81	64.6	95	Abdul et al., 1987
		2.1	126		Schwille, 1988
		2.025	106		Garbarini and Lion, 1986
Vinyl Chloride		0.39	2.5	2.5	Karickhoff, 1979
Xylene	ortho	2.11	129	347	Abdul et al., 1987
	meta	3.2	1585		Abdul et al., 1987
	para	2.31	204		Abdul et al., 1987

* Based on geometric mean of referenced values

TABLE 3

Adsorption Coefficients for Seven Organic Compounds

Compound	**Recommended** ***K_{oc}*** **(mL/g)**	**Overburden** ***Kd**** **(mL/g)**	**Bedrock** ***Kd***** **(mL/g)**
2-Chlorotoluene	191	3.05	2.10
Methylene Chloride	8.7	0.14	0.10
Tetrachloroethene	272	4.35	2.99
Toluene	132	2.11	1.45
Trichloroethene	95	1.52	1.05
Vinyl Chloride	2.5	0.039	0.027
Total Xylenes	347	5.55	3.81

* Based on an f_{oc} of 1.6%

** Based on an f_{oc} of 1.1%

TABLE 4

Summary of the Mobilities of Elements Under Varying Redox Conditions

Element	Oxidizing	Intermediate	Sulfate-Reducing
Arsenic	Low	High	Low
Barium	Low	Low	High
Boron	High	High	High
Chromium	High	Low	Low
Iron	Low	High	Low
Lead	High	High	Low
Lithium	High	High	High
Radium	Low	Low	High
Thallium	Low	High	Low
Uranium	High	High	Low

TABLE 5

Mobility of Arsenic Under Different Redox Conditions

Redox Conditions	Arsenic Mobility	Arsenic Valence	Arsenic Species	Sulfur Species	Arsenic Precipitates
Oxidizing	Low	+5	$HAsO_4^{-2}$, $H_2AsO_4^{-}$	SO_4^{-2}	None
Moderately Reducing	High	+3	$HAsO_2^{o}$, $H_3AsO_3^{o}$	SO_4^{-2}	None
Strongly Reducing	Low	+3	$HAsO_2^{o}$, $H_3AsO_3^{o}$	H_2S, HS^{-}	As-Sulfides

TABLE 6

Enhanced Benzene Degradation Rates at a Gasoline Service Station Site

(Calculated from the data of Mysona and Hughes, 1999)

Well	Number of Samples	Observation Period (yrs)	Exponent	Half-Life (yrs)	Correlation Coefficient
MW-1	5	1.3	-0.0025	0.76	0.39
MW-2	5	1.3	-0.0065	0.29	0.91
MW-3	5	1.3	-0.0039	0.49	0.93

TABLE 7

Radionuclide Half-Lives and Specific Activities

(from Friedlander et al., 1981)

Radionuclide	**Half-Life (years)**	**Specific Activity (Ci/g)**
Ra-226	1600	0.99
Ra-228	5.76	234
Th-228	1.91	821.2
Th-230	8×10^4	0.019
Th-232	1.41×10^{10}	1.09×10^{-7}
U-234	2.45×10^5	0.006
U-235	7.038×10^8	2.16×10^{-6}
U-238	4.5×10^9	3.34×10^{-7}

TABLE 8

Correlation Coefficients for Gross Alpha and Gross Beta versus Analyzed Radionuclides

Parameter	Gross Alpha	Gross Beta
Gross Alpha	1.00	0.40
Gross Beta	0.40	1.00
Potassium (elemental)	0.43	**0.99**
Calculated K-40	0.43	**0.99**
Ra-226	0.16	0.53
Ra-228	0.45	0.11
Total Radium	0.44	0.47
U-234	**0.61**	0.32
U-235	-0.06	-0.22
U-238	**0.53**	0.19
Total Uranium	**0.60**	0.27
Th-228	0.14	0.00
Th-230	0.17	0.02
Th-232	0.04	-0.02
Total Thorium	0.22	0.01

TABLE 9

Summary Statistics for Radiological Parameters

Parameter	Count	% ND	Minimum (pCi/L)	Median (pCi/L)	Mean (pCi/L)	Maximum (pCi/L)
Gross Alpha	54	39	0.00	4.80	8.42	67.74
Gross Beta	53	17	0.02	8.07	52.96	711.00
Calculated K-40	53	0	0.62	5.20	45.46	593.49
Ra-226	54	26	-2.30	0.39	0.45	2.28
Ra-228	54	74	0.05	0.80	0.75	2.08
Total Radium	54		0.12	1.17	1.25	3.34
U-234	54	6	0.00	1.19	2.66	11.01
U-235	54	91	-0.03	0.18	0.23	0.70
U-238	54	26	0.00	0.74	1.34	5.01
Total Uranium	54		0.25	2.14	4.22	15.81
Th-228	54	80	0.00	0.23	0.27	0.81
Th-230	54	28	0.00	0.55	0.58	2.01
Th-232	54	72	0.00	0.21	0.23	0.63
Total Thorium	53		0.43	1.07	1.10	2.85

ND = Not Detected

TABLE 10

Adjusted Gross Beta Exceedances

Well **S&W Lab Sample ID** **Screened Interval (ft bgs)**	**MW-13D** **05a-021542** **25'-50'**		**BRPZ-2RE** **12b-021607** **44'-64'**		**BRPZ-5** **12b-021576** **45'-55'**		**MW-26D** **12b-021642** **35'-60'**	
	Result	**Uncertainty**	**Result**	**Uncertainty**	**Result**	**Uncertainty**	**Result**	**Uncertainty**
Gross Beta β (pCi/L)	84.75	± 3.56	473.2 J	± 39.98	205.98	± 49.22	711.0	± 84.0
Potassium (µg/L)	21,600	± 4,320	418,000 J	± 83,600	209,000 J	± 41,800	813,000	± 162,600
Calculated K-40 (pCi/L)	15.77	± 3.15	305.14	± 61.03	152.57	± 30.51	593.49	± 118.70
Adjusted Gross β (pCi/L)	68.98	± 4.76	168.02	± 72.96	53.41	± 57.91	117.51	± 145.41

Table 11

Adjusted Gross Alpha Exceedances

Well Screened Interval (ft bgs)	MW-3D 30'-55'		BRPZ-2RE 44'-64'		BRPZ-5 69'-79'	
	Result	**Uncertainty**	**Result**	**Uncertainty**	**Result**	**Uncertainty**
Gross Alpha (pCi/L)	18.93 UJ	± 17.19	33.96	± 25.03	67.74	± 20.25
U-234 Result (pCi/L)	0.126 U	± 0.24	5.10	± 1.58	6.75	± 1.86
U-235 Result (pCi/L)	0.38 U	± 0.04	0.075 U	± 0.18	0.177 U	± 0.29
U-238 Result (pCi/L)	0.00 U	± 0.19	1.78	± 0.81	3.33	± 1.14
Adjusted Gross Alpha (pCi/L)	18.42 U	± 17.2	27.00	± 25.10	57.47	± 20.37

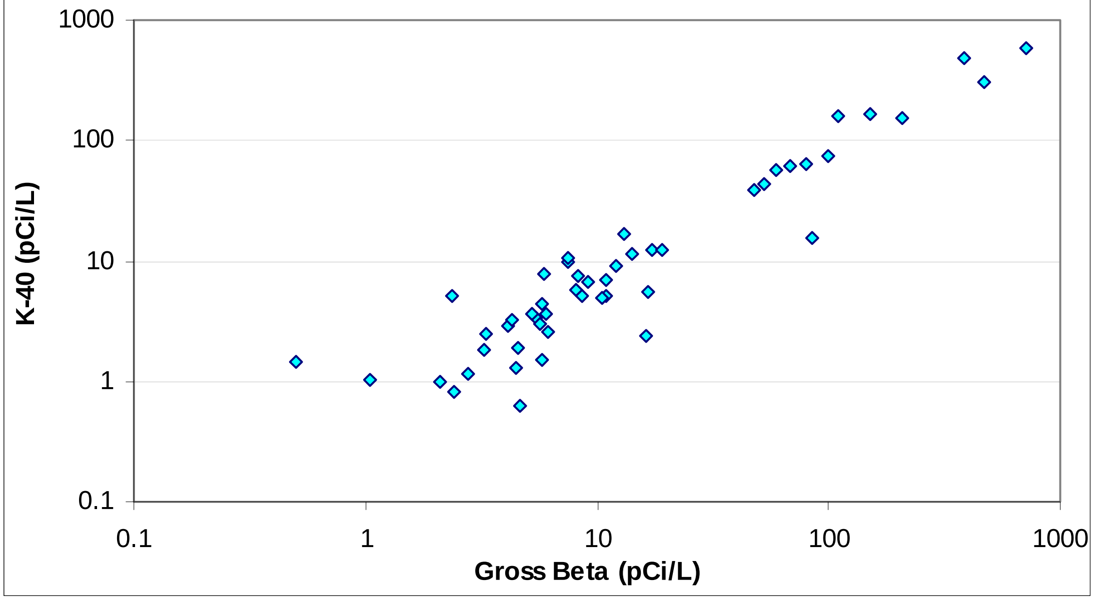

Figure 1. Potassium-40 vs. Gross Beta Activities in Bedrock Groundwater Samples

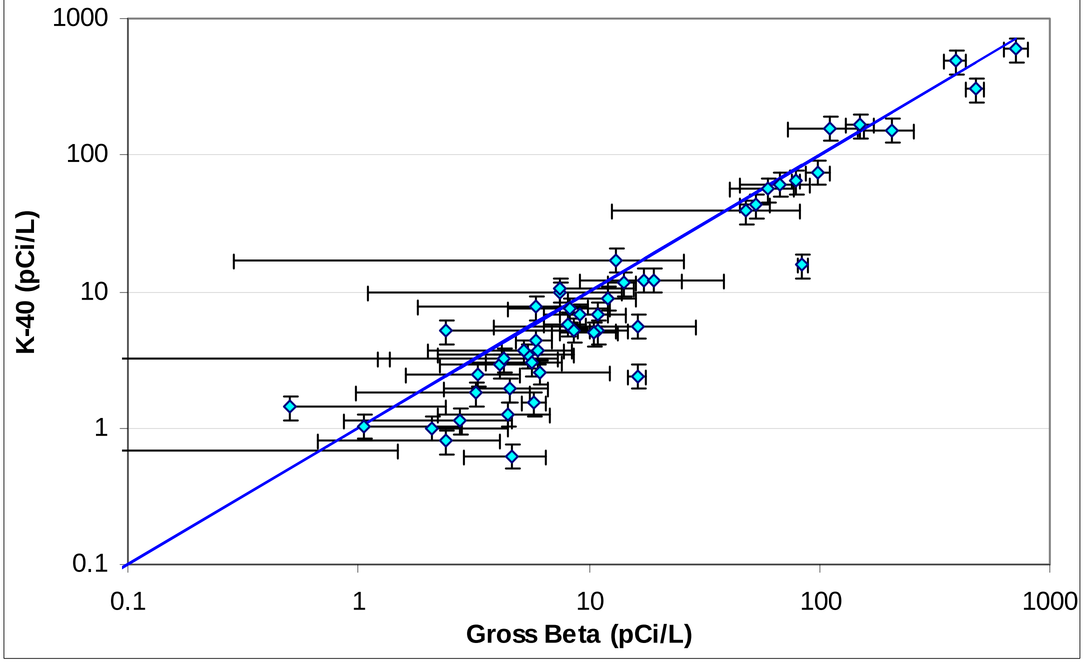

Figure 2. Potassium-40 vs. Gross Beta Activities in Bedrock Groundwater Samples (with uncertainties)

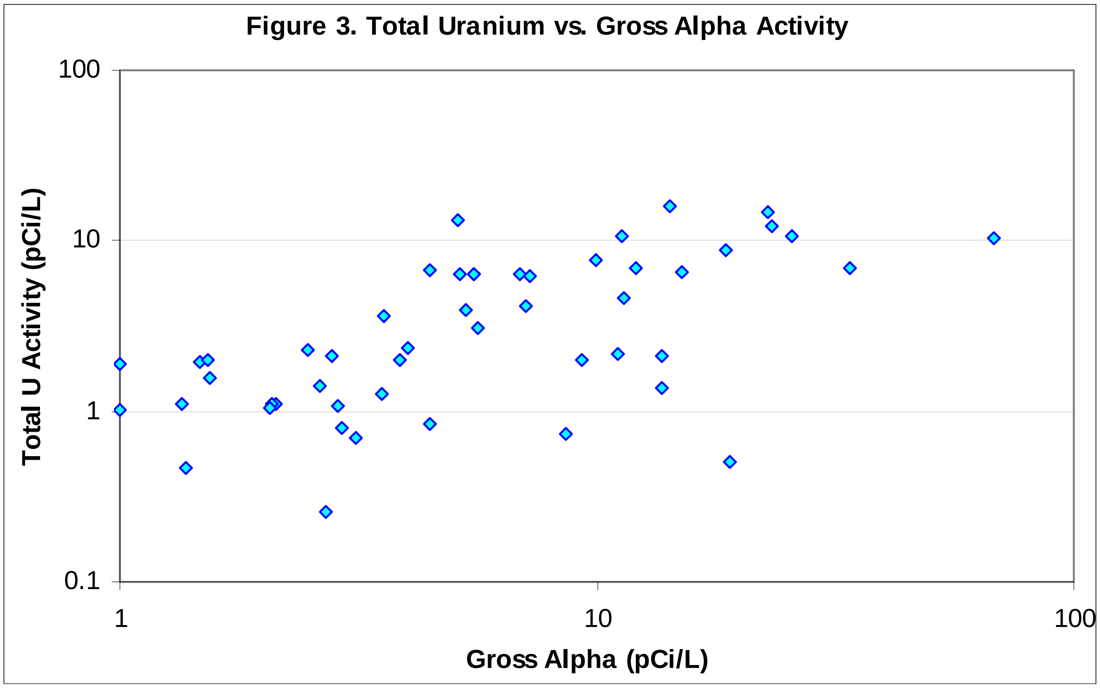

Figure 3. Total Uranium vs. Gross Alpha Activity

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APPENDIX C

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELING RESULTS

(VOLUME 2)

APPENDIX D

DETAILED COST SUMMARIES
(VOLUME 1)

Appendix D
Table 1
Summary of Costs
Maywood GWFS
Maywood, New Jersey

ALTERNATIVE NUMBER	CAPITAL COSTS	O & M TOTAL	PRESENT WORTH [1]
Alternative 1 - No Action	$0	$0	$0
Alternative 2 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, and Non-Radiological Soil Remediation	$10,332,000	$20,122,000	$30,454,000
Alternative 3 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, In Situ Treatment with Redox Alteration, and Non-Radiological Soil Remediation	$14,482,000	$21,447,000	$35,929,000
Alternative 4 - Use Restrictions, Groundwater Monitoring, Groundwater Extraction with Ex Situ Treatment, Groundwater Discharge, and Non-Radiological Soil Remediation	$12,936,000	$109,266,000	$122,202,000

NOTES:

1. The 30 year present worth costs are for capital and O&M. Present worth calculated based on 2.7% annual discount rate.

Appendix D
Table 2
Alternative 1 - No Action
Capital Costs and Cost Summary
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity	Units	Unit Cost	Item Cost
General Remedial Activities				
No Actions Taken				$0
Remedial Action Costs Subtotal				**$0**
Overhead/QA Costs		30%		$0
Contingency Costs		20%		$0
Remediation Costs Subtotal				**$0**
Lifetime O&M Costs (Present Worth)		NA		**$0**

Total Present Worth for Alternative 1	**$0**

Appendix D
Table 3
Alternative 1 - No Action
Operation and Maintenance Costs
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity Per Year	Units	Unit Cost	Annual Cost	Number of Yearly Events	Present Worth Cost
Not Applicable No Actions Taken				$0		$0

Lifetime O&M Costs (Present Worth)	**$0**

Appendix D
Table 4

Alternative 2 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, and Non-Radiological Soil Remediation

Capital Costs and Cost Summary
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity	Units	Unit Cost	Item Cost
General Remedial Activities				
Project QA / QC Plan	1	LS	$50,000	$50,000
Project O&M Plan	1	LS	$50,000	$50,000
Natural Attenuation/Groundwater Monitoring Work Plan	1	LS	$50,000	$50,000
Professional Surveying	1	LS	$20,000	$20,000
Cleanup and Demobilization	1	LS	$15,000	$15,000
Classification Exception Area (CEA)	1	LS	$19,400	$19,400
CEA Deed Notice	20	Each	$696	$13,900
Notification of Property Owners (registered mail)	20	Each	$116	$2,300
Non-Radiological Soil Remediation				
Above Water Table	8000	CY	$500	$4,000,000
Below Water Table	2000	CY	$900	$1,800,000
Project Management				$602,100
Remedial Action Costs Subtotal				**$6,623,000**
Overhead/QA Costs	30%			$1,986,900
Contingency Costs	20%			$1,722,000
Remediation Costs Subtotal				**$10,332,000**
Lifetime O&M Costs (Present Worth)	From Appendix D Table 5			**$20,122,000**
Total Present Worth for Alternative 2				**$30,454,000**

Notes:
1. Site closeout activities are presented on the accompanying O & M cost table.
2. Soil remediation includes all labor, materials, equipment, testing, and disposal costs. Excavation will occur above and below the water table. Water treatment is included for excavations below the water table.

Appendix D
Table 5

Alternative 2 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, and Non-Radiological Soil Remediation

Operation and Maintenance Costs
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity Per Year	Units	Unit Cost	Annual Cost	Number of Yearly Events	Present Worth Cost
Quarterly Monitoring (Years 1 and 2)						
Well installation, Well Rehab, Sampling, Lab Analysis, and Validation	1	LS	$380,696	$380,696	1	$595,600
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$296,696	$296,696	1	$451,900
Annual Monitoring (Years 3 through 13)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$190,000	$190,000	11	$2,796,400
Annual Monitoring (Years 14 through 30)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$168,100	$168,100	17	$2,646,300
Monitoring Report						
Annual Monitoring Report	1	Each	$60,000	$60,000	30	$2,017,900
Year Two Report - from Quarterly Monitoring Data	1	Each	$60,000	$60,000	1	$93,900
Five Year Report - CERCLA Review	1	Each	$60,000	$60,000	6	$382,400
Non Radiological Soil Remediation (Years 2 and 3)						
Above Water Table (Year 2)	7600	CY	$500	$3,800,000	1	$5,944,700
Below Water Table (Year 2)	3400	CY	$900	$3,060,000	1	$4,787,000
Above Water Table (Year 3)	0	CY	$500	$0	1	$0
Below Water Table (Year 3)	0	CY	$900	$0	1	$0
Site Closeout (Year 3)						
Abandonment of Monitoring Wells - Bedrock Wells	49	Each	$2,500	$122,500	1	$186,600
Abandonment of Monitoring Wells - Overburden Wells	34	Each	$2,500	$85,000	1	$129,500
Site Closeout (Year 30)						
Abandonment of Monitoring Wells - Bedrock Wells	24	Each	$2,500	$60,000	1	$44,500
Abandonment of Monitoring Wells - Overburden Wells	24	Each	$2,500	$60,000	1	$44,500

Lifetime O&M Costs (Present Worth)	**$20,122,000**

Notes:

1. O&M costs are totaled as a present worth cost based on a 2.7% net investment rate for the period of time noted.
2. Lifetime O&M costs include annual QA and contingency costs.
3. The O&M costs include 25% for overhead / QA costs, 20% for O&M contingency costs, and 10% for project management.

Appendix D
Table 6
Alternative 3 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, In Situ Treatment with Redox Alteration, and Non-Radiological Soil Remediation
Capital Costs and Cost Summary
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity	Units	Unit Cost	Item Cost
General Remedial Activities				
Project QA / QC Plan	1	LS	$50,000	$50,000
Project O&M Plan	1	LS	$50,000	$50,000
In Situ Groundwater Monitoring Work Plan	1	LS	$50,000	$50,000
Utility Clearance and Injection Point Layout	1	LS	$25,000	$25,000
Professional Surveying	1	LS	$20,000	$20,000
Cleanup and Demobilization	1	LS	$15,000	$15,000
Construction Reports, Completion Reports, As-Built Drawings	1	LS	$30,000	$30,000
Classification Exception Area (CEA)	1	LS	$19,400	$19,400
CEA Deed Notice	20	Each	$696	$13,900
Notification of Property Owners (registered mail)	20	Each	$116	$2,300
Non-Radiological Soil Remediation				
Above Water Table	8000	CY	$500	$4,000,000
Below Water Table	2000	CY	$900	$1,800,000
In Situ Treatment				
Bench-Scale Study, Health and Safety Plan, Materials List, and Procurement	1	LS	$188,400	$188,400
Site Preparation	1	LS	$25,100	$25,100
Design	1	LS	$60,000	$60,000
Treatment Injection for Bedrock Areas	1	LS	$0	$0
Treatment Injection for Overburden Areas	1	LS	$2,090,000	$2,090,000
Project Management				$843,900
Remedial Action Costs Subtotal				**$9,283,000**
Additional Costs - % of Remedial Costs				
Overhead/QA Costs		30%		$2,784,900
Contingency Costs		20%		$2,413,600
Remediation Costs Subtotal				**$14,482,000**
Lifetime O&M Costs (Present Worth)	From Appendix D Table 7			**$21,447,000**
Total Present Worth for Alternative 3				**$35,929,000**

Notes:

1. Site closeout activities are presented on the accompanying O & M cost table.
2. Soil remediation includes all labor, materials, equipment, testing, and disposal costs. Excavation will occur above and below the water table. Water treatment is included for excavations below the water table.

Appendix D
Table 7
Alternative 3 - Use Restrictions, Groundwater Monitoring, Monitored Natural Attenuation, In Situ Treatment with Redox Alteration, and Non-Radiological Soil Remediation

Operation and Maintenance Costs
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity Per Year	Units	Unit Cost	Annual Cost	Number of Yearly Events	Present Worth Cost
In Situ Treatment						
Follow-up Treatment, Year 2 (30% of Year 1 costs)	1	LS	$645,000	$645,000	1	$1,009,000
Follow-up Treatment, Year 3 (10% of Year 1 costs)	1	LS	$215,000	$215,000	1	$327,500
Quarterly Monitoring (Years 1 and 2)						
Well installation, Well Rehab, Sampling, Lab Analysis, and Validation	1	LS	$380,696	$380,696	1	$595,600
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$296,696	$296,696	1	$451,900
Annual Monitoring (Years 3 through 13)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$190,000	$190,000	11	$2,796,400
Annual Monitoring (Years 14 through 30)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$167,400	$167,400	17	$2,635,300
Monitoring Report						
Annual Monitoring Report	1	Each	$60,000	$60,000	30	$2,017,900
Year Two Report - from Quarterly Monitoring Data	1	Each	$60,000	$60,000	1	$93,900
Five Year Report - CERCLA Review	1	Each	$60,000	$60,000	6	$382,400
Non Radiological Soil Remediation (Years 2 and 3)						
Above Water Table (Year 2)	7600	CY	$500	$3,800,000	1	$5,944,700
Below Water Table (Year 2)	3400	CY	$900	$3,060,000	1	$4,787,000
Above Water Table (Year 3)	0	CY	$500	$0	1	$0
Below Water Table (Year 3)	0	CY	$900	$0	1	$0
Site Closeout (Year 3)						
Abandonment of Monitoring Wells - Bedrock Wells	49	Each	$2,500	$122,500	1	$186,600
Abandonment of Monitoring Wells - Overburden Wells	34	Each	$2,500	$85,000	1	$129,500
Site Closeout (Year 30)						
Abandonment of Monitoring Wells - Bedrock Wells	24	Each	$2,500	$60,000	1	$44,500
Abandonment of Monitoring Wells - Overburden Wells	24	Each	$2,500	$60,000	1	$44,500

Lifetime O&M Costs (Present Worth)	**$21,447,000**

Notes:

1. O&M costs are totaled as a present worth cost based on a 2.7% net investment rate for the period of time noted.
2. Lifetime O&M costs include annual QA and contingency costs.
3. The O&M costs include 25% for overhead / QA costs, 20% for O&M contingency costs, and 10% for project management.

Appendix D
Table 8
Alternative 4 - Use Restrictions, Groundwater Monitoring, Groundwater Extraction with Ex Situ Treatment, Groundwater Discharge, and Non-Radiological Soil Remediation
Capital Costs and Cost Summary
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity	Units	Unit Cost	Item Cost
General Remedial Activities				
Project QA / QC Plan	1	LS	$50,000	$50,000
Project O&M Plan	1	LS	$50,000	$50,000
Groundwater Monitoring Work Plan	1	LS	$50,000	$50,000
Professional Surveying	1	LS	$20,000	$20,000
Cleanup and Demobilization	1	LS	$15,000	$15,000
Construction Reports, Completion Reports, As-Built Drawing	1	LS	$30,000	$30,000
Classification Exception Area (CEA)	1	LS	$19,400	$19,400
CEA Deed Notice	20	Each	$696	$13,900
Notification of Property Owners (registered mail)	20	Each	$116	$2,300
Non-Radiological Soil Remediation				
Above Water Table	8000	CY	$500	$4,000,000
Below Water Table	2000	CY	$900	$1,800,000
Groundwater Extraction and Treatment System				
System Design	1	LS	$115,927	$115,900
Bench-Scale Study, Health and Safety Plan, Materials List, and Procurement	1	LS	$218,407	$218,400
Site Preparation	1	LF	$29,098	$29,100
Extraction Well Installation	6	Each	$20,000	$120,000
Piping from Wells to Central Collection Line (trenching, backfill, compaction)	600	LF	$131	$78,600
Piping from Central Collection to Treatment Plant (trenching, backfill, compaction)	1,200	LF	$131	$157,200
Electric Supply Lines to Wells	1,800	LF	$29	$52,200
Electric Pumps for Extraction Wells	6	Each	$3,721	$22,300
Treatment Plant Building Construction, 30' x 30'	1	LS	$142,000	$142,000
Air stripper	1	LS	$18,637	$18,600
Initial Carbon for air stream	1	LS	$6,258	$6,300
Transfer pumps	1	LS	$2,481	$2,500
Metals Precipitation Equipment	1	LS	$148,851	$148,900
RO / Ion Exchange unit	1	LS	$155,053	$155,100
Piping inside Treatment Plant	1	LS	$18,606	$18,600
Setup and installation of equipment - labor	1	LS	$48,000	$48,000
Piping from Treatment to POTW (trenching, backfill, compaction)	2,500	LF	$47	$117,500
Permit for Discharge to POTW	1	LS	17,389	$17,400
System Startup	1	LS	18,548	$18,500
Project Management				$753,800
Remedial Action Costs Subtotal				**$8,292,000**
Additional Costs - % of Remedial Costs				
Overhead/QA Costs		30%		$2,487,600
Contingency Costs		20%		$2,155,900
Remediation Costs Subtotal				**$12,936,000**
Lifetime O&M Costs (Present Worth)	From Appendix D Table 9			**$109,266,000**
Total Present Worth for Alternative 4				**$122,202,000**

Notes:

1. Site closeout activities are presented on the accompanying O & M cost table.
2. Soil remediation includes all labor, materials, equipment, testing, and disposal costs. Excavation will occur above and below the water table. Water treatment is included for excavations below the water table.

Appendix D
Table 9
Alternative 4 - Use Restrictions, Groundwater Monitoring, Groundwater Extraction with Ex Situ Treatment, Groundwater Discharge, and Non-Radiological Soil Remediation
Operation and Maintenance Costs
Maywood GWFS
Maywood, New Jersey

Item Description	Quantity Per Year	Units	Unit Cost	Annual Cost	Number of Yearly Events	Present Worth Cost
Quarterly Monitoring (Years 1 and 2)						
Well installation, Well Rehab, Sampling, Lab Analysis, and Validation	1	LS	$380,696	$380,696	1	$595,600
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$296,696	$296,696	1	$451,900
Annual Monitoring (Years 3 through 13)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$190,000	$190,000	11	$2,796,400
Annual Monitoring (Years 14 through 30)						
Well Rehab/Replacement, Sampling, Analysis, and Validation	1	LS	$168,100	$168,100	17	$2,646,300
Groundwater Operational Costs						
Well Cleaning	1	annual	$6,956	$6,956	30	$233,900
Discharge from New Extraction Wells and Treatment System (see Note 5)	5,256,000	Gal	$0.50	$2,628,000	30	$88,384,200
Replace extraction wells with possible relocation to optimize system	1	Each	$23,185	$23,185	See Note 3	$130,600
Pump Replacement	2	Each	$3,210	$6,420	See Note 3	$36,200
Additional Piping and Trenching	300	LF	$131	$39,300	See Note 3	$221,300
Additional Redevelopment of Wells	6	Each	$3,478	$20,867	See Note 3	$117,500
Monitoring Report						
Annual Monitoring Report	1	Each	$60,000	$60,000	30	$2,017,900
Year Two Report - from Quarterly Monitoring Data	1	Each	$60,000	$60,000	1	$93,900
Five Year Report - CERCLA Review	1	Each	$60,000	$60,000	6	$382,400
Non Radiological Soil Remediation (Years 2 and 3)						
Above Water Table (Year 2)	7600	CY	$500	$3,800,000	1	$5,944,700
Below Water Table (Year 2)	3400	CY	$900	$3,060,000	1	$4,787,000
Above Water Table (Year 3)	0	CY	$500	$0	1	$0
Below Water Table (Year 3)	0	CY	$900	$0	1	$0
Site Closeout (Year 3)						
Abandonment of Monitoring Wells - Bedrock Wells	49	Each	$2,500	$122,500	1	$186,600
Abandonment of Monitoring Wells - Overburden Wells	34	Each	$2,500	$85,000	1	$129,500
Site Closeout (Year 30)						
Abandonment of Extraction Wells	11	Each	$2,500	$27,500	1	$20,400
Abandonment of Monitoring Wells - Bedrock Wells	24	Each	$2,500	$60,000	1	$44,500
Abandonment of Monitoring Wells - Overburden Wells	24	Each	$2,500	$60,000	1	$44,500

Lifetime O&M Costs (Present Worth)	**$109,266,000**

Notes:

1. O&M costs are totaled as a present worth cost based on a 2.7% net investment rate for the period of time noted.
2. Lifetime O&M costs include annual QA and contingency costs.
3. Occurs in Years 5, 10, 15, 20, and 25.
4. The O&M costs include 25% for overhead / QA costs, 20% for O&M contingency costs, and 10% for project management.
5. Includes all utility, chemical, materials, labor, analytical, POTW permit, and disposal costs associated with operating the water treatment system.