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Final Feasibility Study Report
Puchack Well Field Superfund Site
Remedial Investigation/Feasibility Study
Pennsauken Township, New Jersey
Work Assignment No.: 102-RICO-02JL

Prepared for:
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PROJECT: RAC II Contract No.: 68-W-98-210
Work Assignment No.: 102-RICO-02JL

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SUBJECT: Final Feasibility Study Report
Puchack Well Field Superfund Site

Dear Mr. Gorin:

CDM Federal Programs Corporation (CDM) is pleased to submit the Final Feasibility Study Report for the Puchack Well Field Superfund Site, Pennsauken Township, New Jersey as partial fulfillment of Subtask No. 12.2 of the Statement of Work. Both EPA and NJDEP's comments have been incorporated into this report.

Please contact me at (212) 785-9123 or Frank Tsang at (212) 785-9123 if you have questions regarding this issue.

Sincerely,

CDM FEDERAL PROGRAMS CORPORATION

Jeanne Litwin, REM
Technical Operations Manager

Enclosure (8 copies)

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Acronyms

1,1-DCE	1,1-dichloroethene
ARAR	Applicable or Relevant and Appropriate Requirements
bgs	Below ground surface
BTEX	Benzene, toluene, ethyl benzene and total xylene
CCMUA	Camden County Municipal Utilities Authority
CDM	CDM Federal Programs Corporation
CEA	Classification exemption area
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLU-IN	EPA Hazardous Waste Clean-up Information
COPC	Contaminants of Potential Concern
CT	Central Tendency
DGW	Discharge to Groundwater
EO	Executive Order
EPA	United States Environmental Protection Agency
EPA REACH IT	EPA Remediation and Characterization Innovative Technologies
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility study
ft	feet
ft^2	feet squared
gpd	gallons per day
gpm	gallons per minute
GRAs	General Response Actions
HHRA	Human Health Risk Assessment
HI	hazard index
ISRM	in situ redox manipulation
lb	Pound
LDR	land disposal restrictions
MCL	maximum contaminant levels
MCLG	maximum contaminant level goals
mgd	million gallons per day
mg/L	milligrams per Liter
MNA	monitored natural attenuation
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
ND	non detect
NJAC	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
NJPDES	New Jersey Pollutant Discharge Elimination System
NJSDWA	New Jersey State Drinking Water Act
NPL	National Priorities List
OSHA	Occupational Safety and Health Administration
OU	Operable Unit
O&M	Operation and Maintenance
PCE	tetrachloroethene

PE	preliminary evaluation
POTW	publicly owned treatment works
PRB	Permeable Reactive Barrier
PRM	Potomac-Raritan-Magothy
PRGs	preliminary remediation goals
PPE	personal protective equipment
RAGS	Risk Assessment Guidance for Superfund
RAOs	remedial action objectives
RCRA	Resource Conservation and Recovery Act
RI	remedial Investigation
RIMS	Remediation Technologies Network Remediation Information Management System
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SWMP	Stormwater Management Plan
TBC	to be considered
TCA	1,1,1-trichloroethane
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
TMV	toxicity, mobility, and volume
UCL	Upper Confidence Level
µg/L	microgram per liter
USGS	United States Geological Survey
VOC	Volatile organic compound

Executive Summary

Executive Summary

Introduction and Site History

This Groundwater Feasibility Study (FS) Report for Operable Unit 1 (OU1) was performed as part of the Remedial Investigation/Feasibility Study (RI/FS) for the groundwater contamination at the Puchack Well Field Superfund Site ("Site") located in Pennsauken Township, New Jersey. This FS was prepared by CDM Federal Programs Corporation (CDM), for the United States Environmental Protection Agency (EPA), Region II, as authorized under the option period of RAC II Contract 68-W-98-210, Work Assignment Number 102-RICO-02JL. The purpose of this OU1 FS is to develop and evaluate remedial alternatives to remediate the site-contributed hexavalent chromium plume in groundwater.

Due to the complexity of the Site, EPA divided the Site into two OUs. OU1 involves the investigation and cleanup of site-wide chromium contaminated groundwater, as well as volatile organic compounds (VOCs) present in conjunction with chromium. OU1 focuses on the clean up of the Puchack chromium plume as the primary goal. Addressing the commingled VOC contamination is a secondary goal for remediation. OU2 will address the investigation and cleanup of source areas that contributed to the Site's groundwater contamination.

The purpose of this OU1 FS is to develop and evaluate alternatives to remediate the Site's hexavalent chromium groundwater plume. The FS identifies Remedial Action Objectives (RAOs), develops General Response Actions (GRAs), identifies and screens available remedial technologies, and evaluates feasible and cost-effective remedial alternatives to address the Site's groundwater chromium plume.

The Puchack Well Field Superfund Site is located in a commercial/industrial and residential neighborhood of Pennsauken Township, Camden County, New Jersey. Several hundred single and multi-family residential buildings, commercial buildings, and industrial facilities are located within a two-mile radius of the Puchack Site. The Puchack well field consists of six municipal supply wells that are owned and were operated by the City of Camden.

Groundwater contamination, consisting of trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), tetrachlorethene (PCE), and chromium, was first detected at Puchack Well Field well 4R/6-70 in the early 1970s. Further sampling indicated the presence of hexavalent chromium (which exhibits relatively high solubility and toxicity) and trivalent chromium (which exhibits relatively low solubility and toxicity) at concentrations above the EPA maximum contaminant levels (MCL), which resulted in Puchack Well Field well 4R/6-70 being removed from service in 1975. In 1978, chromium was detected in Puchack Well Field well 5/5A. This well was removed from service sometime between 1981 and 1983. In 1982, chromium was detected in Puchack wells 2, 3/3A, and 6-75/7. In 1984, general use of the well field was terminated, however, the New Jersey Department of Environmental Protection (NJDEP) allowed the continued controlled pumping of Puchack 1 to act as a temporary plume containment measure. Groundwater extracted from Puchack 1 was

either discharged to Puchack Creek next to the Puchack Site or blended with the Camden City potable water supply. The pumping was discontinued on April 20, 1998.

In 1986, CDM investigated the chromium contamination in the well field on behalf of the State of New Jersey and documented elevated chromium, mercury and TCE concentrations (CDM 1986).

In October of 1991, NJDEP issued a directive to a number of facilities or companies in the Puchack Site vicinity that it "believed...to be responsible for the discharge of... hazardous substances" that subsequently contaminated the groundwater. Among the 22 facilities or companies identified are Advance Process Supply Company (APS); Davidson-Pacific Wood Products (Davidson-Pacific); King Arthur, Incorporated (King Arthur); Mercon Industries (Mercon); SGL Modern Hard Chrome (formerly SGL Modern Hard Chrome Service) (SGL Chrome); and Supertire Services, Incorporated (Supertire); all are suspected source areas for the Puchack Well Field Site. There are on-going investigations under State authority at some of these properties.

In 1992, CDM was tasked by NJDEP to conduct a pilot scale treatability study of the contaminated groundwater at the Puchack well field. Over a two month period, 1.7 million gallons of groundwater were treated. The pilot scale system demonstrated a substantial reduction in chromium levels in the treated water.

In March of 1996, NJDEP collected samples from the Puchack supply wells. The samples were analyzed for VOCs, total metals, and cyanide. Analytical results indicated elevated levels of chromium, mercury, and TCE in all of the supply wells.

In 1997, the United States Geological Survey (USGS), in cooperation with the NJDEP, initiated an investigation to evaluate existing groundwater quality data, groundwater usage, groundwater levels, and hydrogeology of the Pennsauken Township area. As part of this investigation, a drilling and sampling program was conducted to obtain additional information on the extent of groundwater contamination related to the Puchack Site and to enhance the understanding of the area's hydrogeologic conditions. This investigation indicated that VOC contamination was widespread, with multiple sources. VOC contamination in the underlying aquifers has commingled with the chromium plume and is larger in size.

The site was proposed for inclusion on the National Priorities List (NPL) in September of 1997 and was placed on the NPL on March 6, 1998.

Field Investigation

The nature and distribution of groundwater contamination at and near the Puchack Well Field Site is complex. The results of previous investigations, including those conducted by the USGS in cooperation with the NJDEP, have identified numerous complexities of the aquifer system stratigraphy, hydrogeology, and geochemistry at the Site, as well as the existence of multiple potential contaminant sources and changes in historical pumping.

To acquire additional data in support of OU1 of the RI/FS, the USGS, with technical support from CDM, planned and performed the field investigation at the Puchack Well Field Site. The OU1 field investigation included the completion of soil borings, subsurface soil and aquifer sediment sampling, downhole geophysical surveys, monitoring well installation and development, groundwater sampling, and synoptic and continuous water level measurements. The majority of this work was conducted from July 20, 2000 through June 8, 2001.

Hydraulic Characteristics of the Study Area

In Pennsauken Township and vicinity, permeable layers of sand and gravel of the Pennsauken Formation and Quaternary deposits cap most of the extent of the outcrops of the Cretaceous sediments that form the Potomac-Raritan-Magothy aquifer system (Owens and Denny 1979; Farlekas et. al 1976). Sands and gravels of the Pennsauken Formation are believed to have been deposited in a fluvial environment in which a series of down cutting channels were incised into the sediments below (Owens and Minard 1979). The Quaternary deposits grade from gravels and gravelly sand at Trenton to clayey silt at Philadelphia, most likely representing a change in the depositional environment. Due to the complex interaction of the individual layers, caused by the various depositional methods, discontinuities in individual units are common resulting in hydraulic connections between the units. Major confining units can contain either sand or clay lenses which serve as either local water bearing zones, or as local confining units. Additionally, major confining units are found to pinch out in some areas.

Nature and Extent of Contamination

Inorganics in the Groundwater

Hexavalent chromium groundwater contamination is the primary concern at the Puchack Site. Chromium exceeding the MCL has been detected in the Middle aquifer, Intermediate Sand and Lower aquifer. There also are scattered detections of mercury with no apparent pattern. Due to the highly soluble nature of compounds containing hexavalent chromium, their fates are dependent on their interactions with other chemicals present in the contaminated media. The concentration at a given location over time will likely be affected by both the physical processes of advection, dilution and dispersion as well as chemical interactions with the aquifer system.

Organics in the Groundwater

A variety of organic contaminants are present in the groundwater at the Puchack Site, including several chlorinated organic compounds and petroleum hydrocarbons, the most prevalent being halogenated aliphatic compounds such as PCE, TCE and 1,1,1-trichloroethane (TCA). These contaminants have been detected in the Middle aquifer, Intermediate Sand and Lower aquifer. The concentrations at a given location over time will likely be affected by both the physical processes of advection, dilution, and dispersion as well as reactions with other chemical constituents as well as microbes in the aquifer system. The commingled VOC contamination would be addressed as part of the Site remediation.

Human Health Risk Assessment (HHRA)

The HHRA identified exposure routes and human receptor groups and provided quantitative estimates of the magnitude, frequency, and duration of exposure. As residential use of groundwater can include exposure via ingestion, dermal contact, and inhalation of volatile compounds, the HHRA for the FS evaluated all complete exposure routes. The EPA recommends target values or ranges (i.e., cancer risk of 10^{-6} to 10^{-4} or hazard index [HI] of one) as threshold values for potential human health impacts. These target values aid in determining whether additional response action is necessary at the Site.

Results of the HHRA for groundwater exposures for residential use at the Site showed values that exceeded both the EPA's target risk range of 10^{-6} to 10^{-4} and the HI of 1 for both carcinogenic risks and noncarcinogenic hazards. Cancer risks associated with the Site were entirely due to the presence of VOCs in the groundwater, while noncancer hazards were primarily due to the presence of chromium and other inorganics. Results for groundwater exposures for worker ingestion indicated risks within the acceptable range for carcinogens while these limits were exceeded for noncarcinogens. Cancer risks for workers were entirely due to the presence of VOCs in the groundwater, while noncancer hazards were primarily due to the presence of chromium and other inorganics.

Remedial Action Objectives (RAOs)

RAOs are medium-specific goals for protecting human health and the environment. The process followed in developing RAOs consists of identification of chemicals of potential concern; identification of potentially applicable Federal and State regulations and other guidance; identification of applicable site-specific risk-based criteria; and the selection of the preliminary remediation goals (PRGs) based on the applicable or relevant and appropriate requirements (ARARs), guidance, or risk-based values.

The primary contaminant of concern for the Puchack Well Field Site is hexavalent chromium in the groundwater. The chemical-specific ARARs for chromium contaminated groundwater include New Jersey (NJ) Groundwater Quality Standards, which is an applicable requirements, Federal Primary Drinking Water Standards MCLs and NJ Primary Drinking Water Standards MCLs, which are relevant and appropriate requirements. The NJ Groundwater Quality Standard is set at 70 μg/L for total chromium and is selected as the preliminary remediation goals.

The groundwater at the Puchack Site is also contaminated with VOCs. The RI results show that VOC contamination is present in areas well beyond the Site's chromium plume; VOC contamination of groundwater is therefore a regional problem rather than specific to the Puchack Site. Municipal wells in the area have existing treatment facilities to remove VOCs from the extracted groundwater, and the State is directing investigations/clean ups at a number of source areas. This FS will only consider

treatment of extracted VOCs together with the chromium. VOC contamination will not be targeted for in situ treatment nor specifically extracted for treatment.

The following RAOs have been identified for the site:

- Restore the chromium contaminated groundwater aquifer for future beneficial use.
- Prevent or minimize the migration of chromium in the groundwater to existing municipal well fields, or well fields potentially impacted in the future due to increased pumping rates.
- Prevent or minimize potential future human exposures including ingestion and dermal contact with chromium contaminated groundwater.

Summary of Remedial Alternatives

Potential applicable technologies were identified and screened using effectiveness, implementability and cost as the criteria, with the most emphasis on the effectiveness of the remedial action. Those technologies that passed the initial screening were then assembled into four remedial alternatives.

Description of Remedial Action Alternatives

Alternative 1 - No Action

The No Action alternative was retained for comparison purposes as required by the National Oil and Hazardous Substance Pollution Contingency (NCP). No remedial actions would be implemented as part of the No Action alternative. This alternative does not include institutional controls.

Alternative 2 - Monitored Natural Attenuation (MNA)/In Situ Treatment (Contingency Remedy)/Institutional Controls

In this alternative, hexavalent chromium would be allowed to be reduced to trivalent chromium by the natural reducing capacity of the aquifer sediment. Hexavalent chromium is toxic, mobile (i.e., soluble in water), and highly unstable. It can easily be reduced to trivalent chromium by chemicals (e.g., ferrous iron) in soil and groundwater. Trivalent chromium is non-toxic, not mobile (precipitated out from water and fixated to soil particles), and extremely stable. The reaction is not reversible under normal environmental conditions. A bench scale study has demonstrated that there is more than adequate reduction capacity in the aquifer sediment (outside of the plume area) to reduce the hexavalent chromium in the plume. Due to the reduction and retardation properties of the sediment, it is expected that the chromium plume would only migrate slowly (up to tens of feet per year) and would not migrate far.

A compliance zone would be designated to provide a point of reference for the monitoring program. Groundwater would be sampled to monitor the contaminant concentrations and hexavalent chromium reduction over time. Additional monitoring

wells may be installed, as necessary, to allow for comprehensive monitoring of the contamination. If monitoring indicates that a certain portion of the plume has migrated past the compliance zone, an in situ treatment zone would be installed either upgradient or downgradient of the compliance zone, depending on the sub-alternative, to treat the migrating plume. Depending on the in situ treatment approach, either permeable reactive barrier (PRB) using a reducing agent such as sodium dithionite (Sub-alternative 2A), or geochemical fixation using a reducing agent such as sodium metabisulfite (Sub-alternative 2B) would be selected. Institutional controls such as groundwater classification exemption area (CEA) and restriction on new well installation would be implemented to prevent exposure to contaminated groundwater.

Present worth:
Sub-alternative 2A (MNA only) $1.2 million
Sub-alternative 2A (MNA with PRB) $10.5 million
Sub-alternative 2B (MNA only) $1.2 million
Sub-alternative 2B (MNA with in situ geochemical fixation) $7.8 million

Alternative 3 - In Situ Treatment/MNA/Institutional Controls

In this alternative, an in situ treatment zone would be installed in selected areas either downgradient of or within the plume area to reduce hexavalent chromium to trivalent chromium in the Middle aquifer, Intermediate Sand and Lower aquifer. Depending on the in situ treatment approach either PRB using a reducing agent such as sodium dithionite (Sub-alternative 3A), or geochemical fixation using a reducing agent such as sodium metabisulfite (Sub-alternative 3B and 3C) would be selected. Sub-alternatives 3A and 3B would target the chromium plume greater than 1,000 mircograms/liter (µg/L), while Sub-alternative 3C would treat the entire plume above the 70 µg/L chromium PRG. The target value of 1,000 ug/L was selected because it is sufficiently higher than the PRG and, yet, about half the plume exceeds this value. This target value will allow for roughly half the plume to be treated in situ, to 1,000 ug/L. In areas that do not have an in situ treatment zone, hexavalent chromium would be allowed to be reduced to trivalent chromium by the natural reducing capacity of the aquifer sediment. Groundwater monitoring would be performed to determine if a treatment zone is required. Institutional controls would be implemented to prevent exposure to contaminated groundwater.

Present worth:
Sub-alternative 3A (PRB>1000 ug/L) $14.5 million
Sub-alternative 3B (in situ geochemical fixation>1000 µg/L) $12.0 million
Sub-alternative 3C (in situ geochemical fixation>70 µg/L) $17.6 million

Alternative 4 - Groundwater Extraction/Treatment/Off-Site Disposal/Long-Term Groundwater Monitoring/ Institutional Controls

In this alternative, contaminated groundwater would be extracted and treated ex situ. Treatment of extracted groundwater would include inorganic removal using chemical reduction and precipitation with ferrous iron as a reducing agent, and VOC removal

using air stripping. Treated water would be re-injected through injection wells. Any excess groundwater would be discharged to off-site surface water. Groundwater monitoring would be performed to evaluate changes in contaminant concentrations and distributions over time. Institutional controls would be implemented to prevent exposure to contaminated groundwater during remediation.

Present Worth: $32.1 million

Evaluation of Remedial Alternatives

The groundwater alternatives were evaluated according to the following criteria.

Overall Protection of Human Health and the Environment

Alternative 1 would not provide protection of human health, since contamination would persist in groundwater, and potential exposure to contaminated groundwater would not be restricted. There is no mechanism to monitor the migration of the contaminant. Alternatives 2 through 4 are equally protective of human health by implementation of institutional controls restricting the future use of contaminated groundwater. Alternative 2 would utilize natural reductive capacity of the aquifer sediment to reduce and fixate the hexavalent chromium. A limited number of groundwater samples has shown that hexavalent chromium concentrations have been attenuated by more than 50 percent between 1998 and 2000. A bench scale study has shown that the aquifer sediment has more than adequate reductive capacity to reduce the hexavalent chromium plume. Alternative 2 also include in situ treatment as a contingency remedy should any part of the chromium plume migrate pass a compliance zone. Alternatives 3 and 4 would utilize active treatment processes to reduce the toxicity, mobility and volume of the contaminants.

Alternative 1 would not be protective of the environment. Alternatives 2 through 4 would provide protection of the environment as the contaminant migration would be restricted by natural attenuation or active treatment, and would not migrate to other media.

Compliance with ARARs

Alternative 1 would not comply with chemical-specific ARARs, while Alternative 2 through 4 would comply with chemical-specific ARARs and achieve PRGs in the long-term. Long-term groundwater monitoring is a component of Alternatives 2 through 4 to assess the degree of compliance achieved over time. All alternatives would comply with location- and action-specific ARARs.

Long-Term Effectiveness and Permanence

Alternative 1 would not be effective or permanent, since the contaminants would not be monitored and there would be no mechanism to prevent future exposure to contaminated groundwater. Alternatives 2 through 4 would be effective when combined with institutional controls. Alternative 2 would rely on natural mechanisms to reduce contaminant levels. The results from both the groundwater

samples and bench scale study have demonstrated this would be a viable approach. Alternative 2 also includes in situ treatment as a contingency remedy should the chromium plume migrate pass the compliance zone. Alternatives 3 and 4 would actively removed and treated contaminants. The effectiveness of these alternatives would be assessed through periodic groundwater monitoring and five-year reviews. The relative degrees of effectiveness and permanence associated with Alternatives 2, 3, and 4 are generally comparable.

The in situ treatment technologies under Alternatives 2 and 3 have been implemented at other Superfund sites but are still considered innovative technologies. Both bench and pilot scale treatability studies would be required to demonstrate their effectiveness and develop the design parameters.

Reduction of Toxicity, Mobility, or Volume Through Treatment

Alternative 1 would not reduce the toxicity, mobility, and volume (TMV) through treatment as no active treatment of contaminated groundwater occurs. The toxicity and volume would eventually be reduced for Alternatives 1 and 2 by the natural reduction capacity of the aquifer sediment. Alternative 2 would reduce the TMV through treatment if in situ treatment were implemented. Alternatives 3 and 4 would significantly reduce the TMV of the contaminated groundwater through treatment. These alternatives involve reduction and immobilization of contaminants in the groundwater, thereby reducing toxicity. It is anticipated that Alternative 3 would achieve the most reduction in TMV in the shortest duration. Alternatives 2 and 4 would achieve reduction of toxicity and volume in the long-term.

Short-Term Effectiveness

For Alternative 1, protection of the community and workers during remedial activities would not be applicable as no remedial action is occurring. Air monitoring, engineering controls and appropriate worker personal protective equipment (PPE) would be used to protect the community and workers for Alternatives 2 through 4.

There are no potential adverse impacts associated with construction and implementation of Alternative 1. Construction of the injection wells under Alternative 2 (if required as a contingency remedy) would have temporary negative impacts on the commercial business and the residences located near the proposed installation location. Alternative 3 would also have temporary impact to the commercial business and residences due to installation and operation of injection wells.

Alternative 4 would have the greatest impact to the community. The pump and treat system would be operated for approximately 30 years in the commercial business and residential areas.

Sub-alternative 3C - In Situ Geochemical Fixation would achieve the PRGs in the shortest duration, expected to be in the five- to ten-year range. It is not known if the PRGs would be attained within the 30-year time frame for Alternatives 2 and 4, and

sub-alternatives 3B and 3C. Additional monitoring would provide the needed information to better predict the time to attain the PRGs for Alternative 2 and Sub-alternatives 3B and 3C.

Implementability

Alternative 1 would be easiest both technically and administratively to implement. Alternatives 2 and 3 would be moderately difficult to implement. Alternative 4 is the most difficult to implement as there is very limited space available to lay the piping and build the treatment facility. Alternatives 2, 3 and 4 would require access agreements from the neighboring properties. Alternative 4 would also require the government to lease or purchase properties for the treatment facility.

Cost

Alternative 1 incurs no cost but also provides no protection to human health or the environment. Alternative 2 costs are low unless the in situ treatment contingency remedy is required. Alternative 3 costs are higher than Alternative 2, and Alternative 4 is the most expensive.

The cost estimates for the in situ treatment technologies under Alternatives 2 and 3 are highly dependent on the effective radius of treatment. The cost estimates could vary significantly should the site conditions differ from the cost assumptions. Cost sensitivity analyses were performed for Sub-alternatives 3A, 3B, and 3C. Cost increases up to 71 percent were experienced if the injection point spacing was reduced by half. Other factors that could have significant effect on the cost estimates may include the injection duration at each location and the number of injection events.

1 Section One

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Section 1
Introduction

1.1 Purpose and Report Organization

This Groundwater Feasibility Study (FS) Report for Operable Unit 1 (OU1) was performed as part of the Remedial Investigation/Feasibility Study (RI/FS) for the groundwater contamination at the Puchack Well Field Superfund Site ("Site") located in Pennsauken Township, New Jersey. This FS was prepared by CDM Federal Programs Corporation (CDM), for the United States Environmental Protection Agency (EPA), Region II, as authorized under the option period RAC II Contract 68-W-98-210, Work Assignment Number 102-RICO-02JL.

Due to the complexity of the Site, EPA divided the Site into two Operable Units (OUs). OU1 involves the investigation and cleanup of site-wide chromium contaminated groundwater, as well as volatile organic compounds (VOCs) present in conjunction with chromium. OU1 focuses on the clean up of the Puchack chromium plume as the primary goal. Addressing the commingled VOC contamination is a secondary goal for remediation. OU2 will address the investigation and cleanup of source areas that contributed to the Site's groundwater contamination.

Information concerning contamination for this FS was obtained from the Final OU1 Remedial Investigation Report, Puchack Well Field Superfund Site, dated June 22, 2005 (CDM 2005), and the Final OU1 Human Health Risk Assessment, dated March 28, 2003 (CDM 2003).

The purpose of this OU1 FS is to develop and evaluate alternatives to remediate the Site's hexavalent chromium groundwater plume. The FS identifies Remedial Action Objectives (RAOs), develops General Response Actions (GRAs), identifies and screens available remedial technologies, and evaluates feasible and cost-effective remedial alternatives to address the Site's groundwater chromium plume .

A Preliminary Evaluation (PE) report (CDM 2001) was prepared prior to this full FS to assist the EPA and New Jersey Department of Environmental Protection (NJDEP) to focus the bulk of the FS effort on the most promising remedial options. The PE developed and evaluated a number of remedial options and identified key components for the purpose of focusing this groundwater FS. The PE also presented an initial evaluation of remedial options for groundwater contamination at the Site. The PE evaluated various groundwater pumping, treatment, and discharge options, as well as in situ treatment options. The FS builds on the results of the PE, as well as incorporating the results of the recently completed treatability study, as discussed in detail in Section 2.0.

This FS report is divided into five sections:

Section 1	Introduction: summarizes the Site history, provides a description of the Site features, and summarizes the results of the field investigation and human health risk assessment.
Section 2	Identification and Screening of Technologies: provides the rationale for the remedial action objectives, describes general response actions, and identifies technology types and process options.
Section 3	Development and Screening of Remedial Action Alternatives: provides a brief description and screens remedial technologies that are applicable to the Site.
Section 4	Detailed Analysis of Remedial Action Alternatives: evaluates and compares the remedial alternatives in detail using the nine EPA evaluation criteria.
Section 5	References: presents the list of reports, documents, and publications used to prepare this FS.

1.2 Background Information

1.2.1 Site Description

1.2.1.1 Puchack Well Field Superfund Site

The Puchack Well Field Superfund Site is located in a commercial/industrial and residential neighborhood of Pennsauken Township, Camden County, New Jersey (Figure 1-1). OU1 at the Puchack Site is defined by the location of the chromium contamination in groundwater, which is defined by the 70 micrograms per liter (µg/L) chromium isoconcentration line. The 70 µg/L chromium isoconcentration line was chosen because this is the New Jersey Department of Environmental Protection (NJDEP) groundwater quality standard for chromium. Groundwater sampling data obtained in 1999-2001 were used to draw a 70 µg/L isoconcentration line, which shows that the chromium contaminated groundwater is situated in an area roughly bounded to the north by Route 90, to the east by Westfield Avenue, to the south by Cove Road, and to the west by the Conrail railroad track (Figure 1-2).

The area within and surrounding the site is used for residential, commercial, and industrial purposes. Several hundred single and multi-family residential buildings, commercial buildings, and industrial facilities are located within a two-mile radius of the Puchack Site. One section of the Pennsauken Industrial Park is located approximately one-half mile to the northeast of the Puchack site while another section of the industrial park is located approximately several hundred feet to the southwest. A Conrail railroad track runs through the site and the tollgate for the Betsy Ross Bridge (Route 90) is located east of the site.

1.2.1.2 Puchack Well Field

The Puchack well field consists of six municipal supply wells that are owned and were operated by the City of Camden. The six public supply wells are referred to as Puchack 1, 2, 3 (also referred to as 3A), 5 (also referred to as 5A), 4R/6-70, and 6-75/7. All six wells are located within the area bounded by Route 90 (Betsy Ross Bridge) to the northeast, Forrest Avenue to the southeast, Derousse Avenue to the southwest, and River Road to the northwest. Three of the wells are located in the vicinity of Sculley Park. The other three wells are located within residential areas. Figure 1-2 shows the location of the well field. According to construction logs, the well depths range from 141 feet (Puchack1) to 220 feet (Puchack 4R/6-70) below ground surface (bgs). During operation, the six wells had a combined capacity of six million gallons per day (mgd). A seventh Puchack supply well, No. 4/SEALED, was reportedly destroyed during the construction of the adjacent Betsy Ross Bridge that spans the Delaware River and connects New Jersey and Pennsylvania.

1.2.2 Site History

Groundwater contamination, consisting of trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), tetrachloroethene (PCE), and chromium, was first detected at Puchack 4R/6-70 in the early 1970s. Further sampling indicated the presence of hexavalent chromium (which exhibits relatively high solubility and toxicity) and trivalent chromium (which exhibits relatively low solubility and toxicity) at concentrations above the EPA maximum contaminant level (MCL), which resulted in Puchack 4R/6-70 being removed from service in 1975. This was a significant loss to the supply system since this well was one of the city's most productive wells, with a capacity of up to 3.2 mgd. In 1978, chromium was detected in Puchack 5/5A. This well was removed from service sometime between 1981 and 1983. In 1982, chromium was detected in Puchack 2, 3/3A, and 6-75/7. Historical chromium concentrations ranged from 1,500 to 3,000 µg/L (Weston 1997). In 1984, general use of the well field was terminated; however, NJDEP allowed the continued controlled pumping of Puchack 1 to act as a temporary plume containment measure. Groundwater extracted from Puchack 1 was either discharged to Puchack Creek next to the Puchack Site or blended with the Camden City potable water supply. The pumping was discontinued on April 20, 1998.

In 1986, CDM investigated the chromium contamination in the well field on behalf of the State of New Jersey. The CDM investigation documented chromium concentrations up to 1,000 µg/L, mercury concentrations up to 5.8 µg/L, and TCE concentrations up to 70 µg/L in the well field (CDM 1986).

In October of 1991, NJDEP issued a directive to a number of facilities or companies in the Puchack Site vicinity that it "believed...to be responsible for the discharge of... hazardous substances" that subsequently contaminated the groundwater. NJDEP determined what facilities would receive the directives "based upon a review of the hydrogeologic conditions that exist at the well field" and existing documentation of facility operations and discharges (Weston 1997). Among the 22 facilities or companies identified are Advance Process Supply Company (APS); Davidson-Pacific

Wood Products (Davidson-Pacific); King Arthur, Incorporated (King Arthur); Mercon Industries (Mercon); SGL Modern Hard Chrome (formerly SGL Modern Hard Chrome Service) (SGL Chrome); and Supertire Services, Incorporated (Supertire); all are suspected source areas for the Puchack Well Field Site. There are on-going investigations under State authority at some of these properties. To date, the specific source or sources of the contaminants detected in the Puchack wells may not have all been identified.

In 1992, CDM was tasked by NJDEP to conduct a pilot scale treatability study of the contaminated groundwater at Puchack well field, which had an average hexavalent chromium concentration of 2,500 µg/L. Over a two month period, 1.7 million gallons of groundwater were treated. The pilot scale system demonstrated a substantial reduction in chromium levels in the treated water. The nearby Morris well field water, which contained 30 to 45 milligram per liter (mg/L) of iron, was considered as a potential source of ferrous iron.

In March of 1996, NJDEP collected samples from the Puchack supply wells. The samples were analyzed for VOCs, total metals, and cyanide. Analytical results indicated elevated levels of chromium, mercury, and TCE in all of the supply wells. Detected chromium concentrations ranged from 46.6 µg/L in Puchack 1 to 1,410 µg/L in Puchack 6-75/7. Mercury concentrations ranged from 0.15 µg/L in Puchack 4R/6-70 to 0.77 µg/L in Puchack 2. TCE concentrations ranged from 0.3 µg/L in Puchack 5/5AA to 20 µg/L in Puchack 2 (Weston 1997).

In 1997, the United States Geological Survey (USGS), in cooperation with NJDEP, initiated an investigation to evaluate existing groundwater quality data, groundwater usage, groundwater levels, and hydrogeology of the Pennsauken Township area. As part of this investigation, a drilling and sampling program was conducted to obtain additional information on the extent of groundwater contamination related to the Puchack Site and to enhance the understanding of the area's hydrogeologic conditions. This investigation included the following tasks:

- Twenty-six wells, in 12 clusters, were installed and subsequently sampled.
- Geophysical logs were run in each of the 12 well cluster locations.
- Twenty-nine additional existing wells were sampled.
- Water level measurements were collected from 128 monitoring and water supply wells located at facilities throughout the study area to better define hydraulic gradients and groundwater flow directions in the Middle and Lower Potomac-Raritan-Magothy (PRM) aquifers.
- USGS initiated the development of a groundwater flow model for the Pennsauken Township area.

The draft USGS report (Walker and Jacobsen in press) summarizes the results of the 1997-1998 USGS/NJDEP field investigation. Groundwater contaminated with chromium was found in the Middle aquifer in two isolated areas: one located at the SGL Chrome property and one located near the Pennsauken Landfill north of the

Puchack Site. (Groundwater contamination at the Pennsauken Landfill is not related to the Puchack Site.) The SGL Chrome site is also the location of the highest hexavalent chromium groundwater contamination in the Middle aquifer at 11,540 µg/L. Based on sampling results from the 1997-1998 USGS investigation, total chromium levels in the Middle aquifer, Intermediate Sand, and Lower aquifer generally ranged from non-detect to 10,250 µg/L, 2 to 9,070 µg/L, and from non-detect to 3,454 µg/L, respectively.

The findings of the 1997-1998 USGS sampling indicated that VOC contamination was more widespread, with multiple sources, and was present in pockets near contaminant source areas. VOC contamination in the three aquifers has commingled with the chromium plume and is generally larger in size. TCE, with estimated concentrations up to 140 µg/L, was the most frequently detected VOC. Other frequently detected VOCs included 1,1,1-trichloroethane (1,1,1-TCA) with estimated concentrations up to 12,500 µg/L, 1,1-DCE with estimated concentrations up to 3,580 µg/L, PCE with estimated concentrations up to 280 µg/L, and benzene with estimated concentrations up to 1,200 µg/L.

The site was proposed for inclusion on the National Priorities List (NPL) in September of 1997 and was placed on the NPL on March 6, 1998.

1.2.2.1 Study Area Investigations

The nature and distribution of groundwater contamination at and near the Puchack Well Field Site is complex. The results of previous investigations, including those conducted by the USGS in cooperation with the NJDEP, have identified numerous complexities of the aquifer system stratigraphy, hydrogeology, and geochemistry at the Site, as well as the existence of multiple potential contaminant sources and changes in historical pumping.

The USGS planned and implemented the field investigation, with technical support from CDM, at the Puchack Well Field Site to acquire data for the OU1 RI. The OU1 field investigation included the completion of soil borings, subsurface soil and aquifer sediment sampling, downhole geophysical surveys, monitoring well installation and development, groundwater sampling, and synoptic and continuous water level measurements. The majority of this work was conducted from July 20, 2000 through June 8, 2001.

The USGS was responsible for the planning and protocols required for the OU 1 RI field activities. All locations, procedures, and protocols for the installation of the monitoring wells were provided by the USGS. CDM provided technical support and subcontracted services for drilling, well installation, surveying, waste management, and chemical analyses.

The following activities were completed:

- A total of 16 borings were advanced using hollow stem auger methods at selected potential source areas. A total of 60 soil and geologic sediment samples were collected for chemical analyses.
- A total of 28 borings were advanced using mud rotary drilling methods.
- A total of 47 subsurface soil and geologic sediment samples (and 6 duplicate samples) were collected from 43 monitoring well borings for chemical analysis.
- Downhole geophysical logging was conducted by the USGS at 27 locations.
- A total of 64 monitoring wells were installed and developed at 27 clusters during the RI field investigation.
- Thirteen groundwater samples from 13 monitoring and water supply wells were collected for chemical analyses from October 1999 to December 1999.
- 135 groundwater samples from 88 monitoring wells were collected for chemical analyses from August 2000 to April 2001.

Groundwater quality in the PRM aquifer system in Pennsauken Township has been affected by both inorganic and organic contaminants. Stratigraphic and hydrologic data gathered at newly installed monitoring wells has led to refined interpretations of local hydrostratigraphy, groundwater flow directions, and hydraulic gradients. Thus, the distribution of contaminants in the aquifer system can be better understood in light of these interpretations, as described in the following sections.

1.2.2.2 Site Hydrogeology

In Pennsauken Township and vicinity, permeable layers of sand and gravel (Figures 1-3 and 1-4) of the Pennsauken Formation and Quaternary deposits cap most of the extent of the outcrops of the Cretaceous sediments that form the Potomac-Raritan-Magothy aquifer system (Owens and Denny 1979; Farlekas et. al 1976). Sands and gravels of the Pennsauken Formation are believed to have been deposited in a fluvial environment in which a series of down cutting channels were incised into the sediments below (Owens and Minard 1979). The Quaternary deposits grade from gravels and gravelly sand at Trenton to clayey silt at Philadelphia, most likely representing a change in the depositional environment. Due to the complex interaction of the individual layers, caused by the various depositional methods, discontinuities in individual units are common resulting in hydraulic connections between the units. Major confining units can contain either sand or clay lenses which serve as either local water bearing zones, or as local confining units. Additionally, major confining units are found to pinch out in some areas.

The following information provides a summary of the hydrogeologic features at the Site:

- There are four water-bearing units in the Potomac-Raritan-Magothy aquifer system: the Upper aquifer (mostly unsaturated in the study area), the Middle aquifer, the Intermediate Sand, and the Lower aquifer, all separated by leaky confining units.
- A detailed delineation of the hydrostratigraphic framework in the study area indicates that there are areas of cut-and-fill in the confining units. These create

permeable zones that apparently do not prevent passage of water through the confining units.

- There are downward head gradients between the Middle aquifer and Intermediate Sand that promote movement of contaminated water between these two water-bearing units.
- Although hydraulic heads between the Intermediate Sand and the Lower aquifer are now similar, it is likely that during full-scale pumping at the Puchack Well Field, a greater downward head gradient between these two units existed. These conditions probably contributed to the movement of chromium contamination from the Intermediate Sand into the Lower aquifer and to the Puchack wells.
- During full-scale pumping at the Puchack Well Field, groundwater flow directions, locally, were probably toward the northeast, but now have shifted to the southeast. Figures 1-5 and 1-6 identify the potentiometric surface and groundwater flow direction in the Middle aquifer and Lower aquifer (including the Intermediate Sand).
- A general increase in water level elevations of over two feet in all aquifers from 1998 to 2000 was observed.
- The current groundwater velocity is estimated to be 310 feet/year (ft/yr) (0.85 ft/day), based on a $V = K * I / n$, where:

  V = average linear velocity (ft/day)
  K = hydraulic conductivity (150 ft/day)
  I = hydraulic gradient (0.0017 ft/ft)
  n = effective porosity (0.3)

1.2.3 Nature and Extent of Contamination

1.2.3.1 Inorganic Contamination in Groundwater

Hexavalent chromium groundwater contamination is the primary concern at the Puchack Site. There also are scattered detections of mercury with no apparent pattern. The areal extent and concentration of metals exceeding MCLs detected during RI field investigations from 1999 to 2001 are depicted in Figure 1-7. The areal extent of the chromium plume above the 70 µg/L groundwater quality standard in the Middle aquifer, Intermediate Sand and Lower aquifer is presented in Figures 1-8, 1-9, and 1-10, respectively. Major findings of chromium groundwater contamination include:

- Chromium-contaminated groundwater forms plumes in each of three water-bearing zones: the Middle aquifer, the Intermediate Sand, and the Lower aquifer.
- Chromium was detected in the Middle aquifer above the 70 µg/L groundwater quality standard in two samples, one located at former SGL Chrome and one at the Pennsauken Landfill. The chromium detected at SGL Chrome was not detected above the groundwater quality standard either downgradient of this location in the Middle aquifer or directly below this location in the Intermediate Sand or Lower aquifer.

- The position and orientation of chromium detected in the Middle aquifer indicate the SGL chromium contaminant source area is related to the Site. The Pennsauken Landfill located to the north appears to be unrelated to the Site.
- Chromium-contaminated groundwater has moved through more permeable lenses in confining units between the water-bearing zones in response to downward vertical head gradients, resulting in contamination reaching deeper water bearing units.
- The plumes in the Intermediate Sand and Lower aquifer are moving to the southeast, an apparent shift in direction since shut down of the Puchack Well Field.
- Chromium concentrations in the groundwater plumes have generally decreased from 1997-1998 to 2000-2001, as shown in Table 1-1. One exception to this trend was observed in MW-14 (Intermediate Sand) where chromium levels have increased, presumably due to the shift in groundwater flow direction after the Puchack Well Field was shut down.
- It is not clear whether the decreases in chromium concentrations are the result of reduction of hexavalent chromium and precipitation of the resulting trivalent chromium, whether hexavalent chromium is adsorbing to aquifer materials, or whether physical movement (advection and dispersion) of the plumes has led to decreases in concentration at a given well. Based on existing data, it is likely that all three processes have affected chromium concentrations.

1.2.3.2 Organic Contamination in Groundwater

A variety of organic contaminants are present in the groundwater at the Puchack Site, including several chlorinated organic compounds and petroleum hydrocarbons. The areal extent and concentration of VOCs exceeding MCLs are depicted in Figure 1-11. The areal extent of the VOCs in the Middle aquifer, Intermediate Sand and Lower aquifer is presented in Figures 1-12, 1-13, and 1-14, respectively. Major findings of VOC contamination include:

- The most frequently detected VOC is TCE; others (including PCE, 1,1,1-TCA, and benzene, toluene, ethyl benzene, and total xylene [BTEX]) are detected less frequently.
- VOC contamination is more widespread in all water-bearing units than chromium contamination. Coherent VOC plumes have not been identified.
- Based on the variety of compounds and widespread distribution, multiple sources of VOCs are likely.
- At several locations, VOC concentrations have declined and there is evidence of degradation of the VOCs, particularly the chlorinated compounds, as *cis*-1,2-dichloroethene and vinyl chloride are detected, and their frequency and concentrations increase with depth in the aquifer system (Table 1-2).
- As with the chromium plume, there is evidence of movement of VOC contamination.

The commingled VOC contamination would be addressed as part of the Site remediation. However, EPA intends to include treatment of VOCs that are encountered during Puchack chromium plume capture. VOC contamination that is

not captured within the chromium plume will be considered separately from the Puchack remediation.

1.2.3.3 Potential Contamination Sources

Limited investigations were conducted at five potential source areas. These properties include Advanced Process Supply Company (APS); King Arthur, Incorporated (King Arthur); Mercon Industries (Mercon); SGL Modern Hard Chrome Service (SGL Chrome); and Supertire Services, Incorporated (Supertire). The major findings from the EPA investigation include:

- SGL Chrome property appears to be a source of chromium contamination, based on the high concentrations of chromium detected in soil and groundwater samples.
- Only sporadic chromium contamination, mostly at levels below background concentrations, were detected in samples from the four other properties investigated.
- Organic contamination was found in all five properties. The major contaminants included TCE, 1,1,1-TCA, and PCE.
- High concentrations of 1,1,1-TCA were detected in soil gas and soil samples from the Supertire property.

The Mercon Industries facility is considered a potential source area and limited investigation was performed in the vicinity of the facility during the RI. Two groundwater samples were collected from monitoring wells adjacent to the Mercon lagoon in the middle aquifer (MW-24M) and the Intermediate Sand aquifer (MW-24I). Chromium was detected in these samples at 1.1 ug/L and 3.3 ug/L, respectively. Since these sample results are significantly below the 70 ug/L groundwater quality standard, quantifiable evidence is not available to consider the Mercon facility as a known source area.

1.2.4 Contaminant Fate and Transport

1.2.4.1 Cr(VI): Fate in the Aquifer

The primary inorganic contaminant of concern in the groundwater at the Puchack Site is chromium in the hexavalent form. Because species containing Cr(VI) tend to be highly soluble and therefore mobile, their fates are dependent on their interactions with other chemicals present in the contaminated media.

The concentration at a given location over time can be affected by several mechanisms. Advection reduces the concentration through the physical replacement of contaminated groundwater with less contaminated groundwater from an upgradient source. Dilution occurs as uncontaminated groundwater, in this case primarily from infiltration and lateral flow from the Delaware River, flows into the plume area. Dispersion is a function of different hydraulic conductivities along the path of flow spreading the contamination longitudinally ahead of the average flow, as well as laterally. All three of these physical mechanisms are enhanced during periods in which the Puchack wells were pumping.

Several chemical processes can contribute to the decrease in concentration of aqueous chromium. Under the moderately acidic conditions that prevail in much of the aquifer system, some Cr(VI) may adsorb to the sediment. Because the adsorption process is a reversible equilibrium process affected by changes in competing anions and pH, the chromium is not permanently bound to the sediments. The reduction of Cr(VI) and precipitation of Cr(III) is another likely mechanism for the removal of hexavalent chromium from the aqueous phase.

Based on existing data, it is likely that the above mentioned processes have all affected chromium concentrations.

1.2.4.2 Cr(VI): Transport in the Aquifer

During the periods of active discharge chromium initially moved down through the soil column and into the Middle aquifer layer. Cr(VI) would initially interact with constituents in the soils where, depending on the soil characteristics, it would either adsorb onto the soil particles or be reduced to Cr(III). Once the soils adsorption/reduction capacity was reached, Cr(VI) would continue to migrate horizontally and vertically until its downward migration was impeded locally by a confining unit. Chromium migrated eastward until reaching discontinuities in the confining layer and was able to move into the Intermediate Sand layer. Historically, during periods of active dumping, the Cr(VI) was estimated to move several hundred to a thousand feet per year as a result of a combination of factors. Higher groundwater velocity, depletion of adsorptive and reductive capacities of the soil, increased hydraulic gradient, preferential pathways and the presence of sulfate, which increases the mobility of Cr(VI) all contributed to this increased migration rate.
An estimate can be made of the rate that hexavalent chromium would migrate from the leading edge of the plume under current conditions. Given the groundwater velocity of 310 ft/yr and the retardation factor (calculated in Appendix A) of 26 to 65 (hexavalent chromium near the downgradient plume boundary), this would yield a hexavalent chromium velocity in the groundwater of only between 5 and 12 ft/yr. This estimate does not take into account the reduction of hexavalent chromium to trivalent chromium and binding to the aquifer solids due to the natural reductive capacity of the aquifer. Due to the high retardation factor, the Cr(III) would hardly move.

A downward vertical gradient provided by pumping from the Puchack well field and other nearby well fields drawing from the Lower aquifer provided the driving force for contaminant migration from the Middle aquifer to the Intermediate Sand, and subsequently Lower aquifer (Figure 1-15). The Intermediate Sand also is connected hydraulically to the Lower aquifer (Walker and Jacobsen, in press) and thus this condition has, in the past, facilitated the movement of contaminated water downward into the more regionally extensive Lower aquifer. The hydraulic gradient between the Intermediate Sand and the Lower aquifer probably has decreased since cessation of full-scale pumping at the Puchack well field, to the point where, since 1998, heads in both units are nearly the same. The similar heads illustrate the effective hydraulic connection between these two water-bearing zones. Thus, there is currently little

impetus for contamination to continue to move downward, out of the Intermediate Sand. This could change if local pumping patterns in the Lower aquifer change.

1.2.4.3 VOCs: Fate in the Aquifer

A wide variety of VOCs are found in groundwater in the study area: the most prevalent being halogenated aliphatic compounds such as PCE, TCE and 1,1,1-TCA with significantly lower levels of aromatic compounds also being present.

The fate of organic contaminants depends on not only their reactions with other chemical constituents, but also with microbes in the aquifer. Decreases in concentration at a specific location over time can be the result of biogeochemical interactions or the migration of the plume away from the specific location. Chlorinated solvents and aromatic hydrocarbons can adsorb onto soil particles, but as this is a reversible process the aquifer may not permanently sequester compounds. Increases in concentration over time are likely due to plume movement.

Changes in concentration indicate that both plume movement and degradation are likely occurring. The presence or increase in daughter products as well as changes in concentration of other constituents and anomalies in redox potential may also indicate degradation.

1.2.4.4 VOCs: Transport in the Aquifer

VOC contaminated water appears to have moved from the Middle aquifer, through more permeable lenses in confining units, into the Intermediate Sand and Lower aquifer over a wider area than has chromium-contaminated water. VOCs generally do not appear to have reached the Lower aquifer in the western part of the study area, but they appear with greater frequency, at increasingly deeper depths, and in higher concentrations in more easterly parts of the aquifer system. Plume movement is generally in the southeasterly direction at a rate of approximately 44 ft/yr for m-xylene and p-xylene and 155 ft/yr for benzene.

1.2.4.5 Contaminant Interactions

In the Intermediate Sand, Lower aquifer and to a lesser extent the Middle aquifer the VOC-contaminated groundwater overlaps the chromium-contaminated groundwater. This has the potential for interactions between contaminants or competition between contaminants.

1.2.5 Baseline Risk Assessment

CDM prepared a Final Human Health Risk Assessment (HHRA) using the RI groundwater data to evaluate the potential health threats to residents via ingestion, dermal contact and inhalation pathways. The Final HHRA was submitted to EPA on March 28, 2003. The risks associated with the Middle and Lower aquifers (including the Intermediate Sand) were identified. The estimates of cancer risk and noncancer health hazard and the greatest chemical contributors to these estimates were presented and discussed.

1.2.5.1 Summary of HHRA Approach

Contaminants of potential concern (COPCs) were selected for evaluation in the risk assessment based on criteria outlined in EPA's *Risk Assessment Guidance for Superfund* (RAGS) (EPA 1989). The COPCs included VOCs and inorganics.

The HHRA identified exposure routes and human receptor groups and provided quantitative estimates of the magnitude, frequency, and duration of exposure. As residential use of groundwater can include exposure via ingestion, dermal contact, and inhalation of volatile compounds, the HHRA for the FS evaluated all complete exposure routes. In this assessment, exposure point concentrations were estimated using the minimum of the 95 percent upper confidence level (UCL) and the maximum concentration. Chronic daily intakes were calculated based on the reasonable maximum exposure (RME), which is the highest exposure reasonably expected to occur at a site. The RME is intended to estimate a conservative exposure case that is still within the range of possible exposures. Central tendency (CT) exposure assumptions were also developed.

In the toxicity assessment, current toxicological human health data (i.e., reference doses and slope factors) were obtained from various sources and were utilized in the order as specified by RAGS (EPA 1989).
Risk characterization involved integrating the exposure and toxicity assessments into quantitative expressions of risks/health effects. Specifically, chronic daily intakes were compared with concentrations known or suspected to present health risks or hazards.

In accordance with the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) Section 300.430 (e)(2) for known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper-bound lifetime cancer risk to an individual of between 10^{-6} and 10^{-4}. Per *RAGS Part B: Development of Risk-Based Preliminary Remediation Goals* (EPA 1991), for noncarcinogenic effects, the NCP does not specify a range, but it is generally appropriate to assume a hazard index (HI) equal to 1.

In general, the EPA recommends target values or ranges (i.e., cancer risk of 10^{-6} to 10^{-4} or hazard index of one) as threshold values for potential human health impacts (EPA 1989). These target values aid in determining whether additional response action is necessary at the Site. In cases where remedial action is warranted, the values also provide a basis for determining residual chemical levels that are adequately protective of human health, as well as a basis for comparing potential health impacts of various remedial alternatives.

1.2.5.2 Summary of Risks

A review of the carcinogenic risks and noncarcinogenic hazards for groundwater exposures at the Site showed values that exceeded both the EPA's target risk range of 10^{-6} to 10^{-4} and HI of 1. Cancer risks associated with the Site were entirely due to the

presence of VOCs in the groundwater, while noncancer hazards were primarily due to the presence of chromium and other inorganics.

1.2.5.2.1 Summary of Risks Associated with the Middle Aquifer

Total excess lifetime cancer risk from residential use of Middle aquifer groundwater assuming exposure from ages 0 to 30 years was 2.1×10^{-2} (two in one hundred) for the RME scenario. The cancer risk for that population decreased about 8-fold to 2.6×10^{-3} (almost three in one thousand) when CT exposure assumptions were used. Thus, both RME and CT exposures for residents would result in excess lifetime cancer risks that exceed EPA's target risk range of 10^{-6} to 10^{-4}. The chemicals that contributed most significantly to residential cancer risk estimates for the Middle aquifer include TCE, benzene, PCE, and 1,1-DCE.

For the Middle aquifer, the total RME hazard index for adult residents was 120, for child residents was 420, and for the combined adult and child resident was 180, all of which are well above the threshold of 1 for noncancer effects. The total CT HI for adult residents was 75, for child residents was 120, and for the combined adult and child resident was 47, all of which were well above the threshold of 1 for noncancer effects. Based on these hazard indices there is a potential for noncancer health effects to occur from residential use of groundwater from the Middle aquifer at the Site under either the RME or CT exposure scenarios. The chemicals that contributed most significantly to residential hazard index estimates for the Middle aquifer are chromium, TCE, benzene, and manganese.

Total excess lifetime cancer risk from worker ingestion of Middle aquifer groundwater was 6.2×10^{-5} (six in one hundred thousand) for the RME scenario. The cancer risk for that population decreased almost 4-fold to 1.6×10^{-5} (one in one hundred thousand) when CT exposure assumptions were used. Thus, both RME and CT exposures for workers would result in cancer risks that are within EPA's target risk range of 10^{-6} to 10^{-4}. The chemicals that contributed most significantly to worker cancer risk estimates for the Middle aquifer were the same as those that contributed most significantly to the residential risks (i.e., TCE, benzene, 1,1-DCE, and PCE).

The total RME hazard index from worker ingestion of Middle aquifer groundwater was 35 for the RME scenario and 31 for the CT exposure scenario. Thus, both RME and CT exposures for workers would result in noncancer hazard indices that are above the threshold of 1 for noncancer effects. The chemicals that contributed most significantly to worker HI estimates for the Middle aquifer were chromium, TCE, and manganese.

1.2.5.2.2 Summary of Risks Associated with the Lower Aquifer

Total excess lifetime cancer risk from residential use of Lower aquifer (including the Intermediate Sand) groundwater assuming exposure from ages 0 to 30 years was 2.3×10^{-3} (about two in one thousand) for the RME scenario. The cancer risk for that population decreased almost 8-fold to 2.9×10^{-4} (almost three in ten thousand) when CT exposure assumptions were used. Thus both RME and CT exposures for residents using Lower aquifer water would result in excess lifetime cancer risks exceeding

EPA's target risk range of 10^{-6} to 10^{-4}. The chemical that contributed most significantly to residential cancer risk estimates for the Lower aquifer was TCE. Other chemicals that contributed to residential cancer risk estimates included 1,1-DCE, benzene, and PCE.

For the Lower aquifer, the total RME HI for adult residents, child residents and combined adult and child residents were 42, 120 and 60 respectively; all of which were above the threshold of 1 for noncancer effects. The total CT hazard index for adult residents, child residents and combined adult and child residents were 26, 40 and 16 respectively; all of which were above the threshold of 1 for noncancer effects. Based on these hazard indices there is a potential for noncancer health effects to occur from residential use of groundwater from the Lower aquifer at the Site under either the RME or CT exposure scenarios. The chemicals that contributed most significantly to residential hazard index estimates for the Lower aquifer were chromium, TCE, manganese, and chloroform.

Total excess lifetime cancer risk from worker ingestion of Lower aquifer groundwater was 7.1×10^{-6} for the RME scenario. The cancer risk for that population decreased almost 4-fold to 1.8×10^{-6} when CT exposure assumptions were used. Thus, both RME and CT exposures for workers would result in cancer risks that are within EPA's target risk range of 10^{-6} to 10^{-4}. The chemicals that contributed most significantly to worker cancer risk estimates for the Lower aquifer were 1,1-DCE and TCE.

The total RME HI from worker ingestion of Lower aquifer groundwater was 12 for the RME scenario and 11 for the CT exposure scenario. Thus, both RME and CT exposures for workers would result in noncancer hazard indices that are above the threshold of 1 for noncancer effects. The chemicals that contributed most significantly to worker HI estimates for the Lower aquifer were chromium, TCE, and manganese.

Table 1-1
Changes in Chromium Concentrations in Selected Wells Sampled in 1998-1999, 2000 and 2001[4]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Well Name [1]	Date Sampled	Total Chromium Conc. [2] [3] (µg/L)	Date Sampled	Total Chromium Conc. [2] (µg/L)	Change In Chromium Conc. (µg/L)	Percent Change in Chromium Conc.
Middle Aquifer Wells						
Landfill 4	03/02/98	341	12/01/99	290	-51	-15
MW-1S	05/07/98	9,720	02/14/01	8,010	-1,710	-18
Intermediate Sand Wells						
CCMW-1A	02/25/98	4,130	12/11/00	1,730	-2,400	-58
CCMW-2A	02/26/98	9,070	10/30/00	3,570	-5,500	-61
MW-5I	05/06/98	8,100	09/06/00	3,010	-5,090	-63
MW-14	03/25/98	<1	01/11/01	1,720	+1,720	NM
Lower Aquifer Wells						
MW-5D	04/30/98	904	09/07/00	384 [3]	-520	-58
MW-6D	04/22/98	3,320	11/02/00	1,450	-1,870	-56

Notes:
(1) Only wells with total chromium concentrations above MCL in one of the sample rounds were shown here.
(2) In all cases but MW-6D, hexavalent chromium concentrations are similar to, or larger than, total chromium concentrations. Therefore, in all but the later sample from MW-6D, all chromium measured is in the hexavalent form.
(3) Filtered sample results
(4) This table includes data collected in 1998 (Walker, R.L., and Jacobsen, Eric. In press) and 1999 under the NJDEP contract and during the OU1 RI, 2000-2001
Conc. = Concentration
NM = No Meaning
µg/L = microgram per liter

400037

Table 1-2
Changes in VOCs Over Time in Selected Groundwater Samples[1]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

VOC	Well Name	Date Sampled	VOC Concentration (mg/L)	Date Sampled	VOC Concentration (mg/L)	Change in VOC Concentration (mg/L)	Percent Change in VOC Concentration
TCE	CCMW-1A	02/25/98	16	12/11/00	8.4	-7.6	-48
TCE	CCMW-1B	02/03/98	E35	11/30/00	220	185	529
TCE	CCMW-2A	02/26/98	E51	10/30/00	43	-8	-16
TCE	CCMW-4A	03/30/98	12	01/09/01	12	0	0
TCE	MW-10M	04/29/98	E24	03/07/01	E3.5	-20.5	-85
TCE	MW-12M	04/13/98	16	12/07/99	36	20	125
TCE	MW-14	03/25/98	E93	01/11/01	53	-40	-43
TCE	MW-1S	05/07/98	E76	02/14/01	110	34	45
TCE	MW-3D	04/14/98	3	01/30/01	3.4	0.4	13
TCE	MW-3M	04/14/98	1.3	01/03/01	0.22	-1.08	-83
TCE	MW-4D	04/07/98	18	08/29/00	9	-9	-50
TCE	MW-4I	04/07/98	E140	08/29/00	52	-88	-63
TCE	MW-4M	04/07/98	0.5	08/28/00	<1	--	0
TCE	MW-5D	04/30/98	0.91	09/07/00	1.3	0.39	43
TCE	MW-5I	05/06/98	E48	09/06/00	24	-24	-50
TCE	MW-6D	04/22/98	17	11/02/00	9.3	-7.7	-45
TCE	MW-9D	04/21/98	E130	12/14/99	46	-84	-65
PCE	CCMW-1A	02/25/98	2	12/11/00	0.47	-1.53	-77
PCE	CCMW-2A	02/03/98	5	11/30/00	3	-2	-40
PCE	Landfill-4	03/02/98	4	12/01/99	2.1	-1.9	-48
PCE	MW-12M	04/13/98	E0.28	12/07/99	1.1	0.82	293
PCE	MW-14	03/25/98	4	01/11/01	7.5	3.5	88
PCE	MW-1S	05/07/98	E280	02/14/01	230	-50	-18
PCE	MW-4D	04/07/98	1	08/29/00	E0.78	-0.22	-22
PCE	MW-4I	04/07/98	<0.5	08/29/00	E0.87	>-0.37	NM
PCE	MW-5I	05/06/98	3	09/06/00	E0.49	-2.51	-84
PCE	MW-6D	04/22/98	1	11/02/00	<1	--	NM
PCE	MW-9D	04/21/98	11	12/14/99	11	0	0

Table 1-2
Changes in VOCs Over Time in Selected Groundwater Samples[1]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

VOC	Well Name	Date Sampled	VOC Concentration (mg/L)	Date Sampled	VOC Concentration (mg/L)	Change in VOC Concentration (mg/L)	Percent Change in VOC Concentration
cis-1,2-DCE	CCMW-2A	02/03/98	2	11/30/00	1.4	-0.6	-30
cis-1,2-DCE	CCMW-4A	03/30/98	<0.1	01/09/01	1.7	>+ 1.6	NM
cis-1,2-DCE	MW-10M	04/29/98	E22	03/07/01	<100	--	NM
cis-1,2-DCE	MW-12M	04/13/98	<0.1	12/07/99	E0.2	>+0.1	NM
cis-1,2-DCE	MW-14	03/25/98	0.9	01/11/01	2	1.1	122
cis-1,2-DCE	MW-1S	05/07/98	8	02/14/01	E8.6	0.6	8
cis-1,2-DCE	MW-4D	04/07/98	E0.3	08/29/00	<1	--	NM
cis-1,2-DCE	MW-4I	04/07/98	4	08/29/00	<1	>-3	-75
cis-1,2-DCE	MW-5D	04/30/98	<0.1	09/07/00	E0.28	>+0.18	NM
cis-1,2-DCE	MW-5I	05/06/98	5	09/06/00	4.7	-0.3	-6
cis-1,2-DCE	MW-6D	04/22/98	<0.4	11/02/00	1.6	>+1.2	NM
cis-1,2-DCE	MW-9D	04/21/98	19	12/14/99	36	17	89

Table 1-2
Changes in VOCs Over Time in Selected Groundwater Samples[1]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

VOC	Well Name	Date Sampled	VOC Concentration (mg/L)	Date Sampled	VOC Concentration (mg/L)	Change in VOC Concentration (mg/L)	Percent Change in VOC Concentration
1,1-DCE	CCMW-1A	02/25/98	2	12/11/00	0.9	-1.1	-55
1,1-DCE	CCMW-2A	02/03/98	5	11/30/00	4.1	-0.9	-18
1,1-DCE	MW-12M	04/13/98	<0.12	12/07/99	2.3	>+2.18	NM
1,1-DCE	MW-14	03/25/98	E10	01/11/01	5.8	-4.2	-42
1,1-DCE	MW-1S	05/07/98	9	02/14/01	E6.8	-2.2	-24
1,1-DCE	MW-4D	04/07/98	1	08/29/00	E0.46	-0.54	-54
1,1-DCE	MW-4I	04/07/98	<0.4	08/29/00	E0.56	>-0.16	NM
1,1-DCE	MW-5I	05/06/98	10	09/06/00	2.7	-7.3	-73
1,1-DCE	MW-6D	04/22/98	3	11/02/00	E0.78	-2.22	-74
1,1-DCE	MW-9D	04/21/98	2	12/14/99	3.2	1.2	60
1,2-DCA	MW-14	03/25/98	0.5	01/11/01	<1	--	NM
1,2-DCA	MW-4D	04/07/98	0.4	08/29/00	<1	--	NM
1,2-DCA	MW-6D	04/22/98	0.3	11/02/00	<1	--	NM
1,2-DCA	MW-9D	04/21/98	2	12/14/99	2	0	0
1,2-DCA	MW-5I	05/06/98	0.4	09/06/00	<1	--	NM
1,1-DCA	CCMW-1A	02/25/98	2	12/11/00	2.4	0.4	20
1,1-DCA	CCMW-2A	02/03/98	1	11/30/00	1.1	0.1	10
1,1-DCA	CCMW-4A	03/30/98	2.6	01/09/01	1.5	-1.1	-42
1,1-DCA	Landfill-4	03/02/98	E0.07	12/01/99	<1	--	NM
1,1-DCA	MW-14	03/25/98	0.5	01/11/01	1.7	1.2	240
1,1-DCA	MW-4D	04/07/98	E0.3	08/29/00	E0.2	-0.2	NM
1,1-DCA	MW-5D	04/30/98	<0.09	09/07/00	E0.21	>+0.12	NM
1,1 DCA	MW-5I	05/06/98	3	09/06/00	3.8	0.8	27
1,1-DCA	MW-6D	04/22/98	0.9	11/02/00	1	0.1	11
1,1-DCA	MW-9D	04/21/98	6	12/14/99	5.5	-0.5	-8
1,1,2-TCA	MW-5I	05/06/98	0.2	09/06/00	<1	--	NM

Table 1-2
Changes in VOCs Over Time in Selected Groundwater Samples[1]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

VOC	Well Name	Date Sampled	VOC Concentration (mg/L)	Date Sampled	VOC Concentration (mg/L)	Change in VOC Concentration (mg/L)	Percent Change in VOC Concentration
1,1,1-TCA	CCMW-1A	02/25/98	6	12/11/00	3.3	-2.7	-45
1,1,1-TCA	CCMW-2A	02/03/98	8	11/30/00	3.7	-4.3	-54
1,1,1-TCA	CCMW-4A	03/30/98	13	01/09/01	1.1	-11.9	-92
1,1,1-TCA	MW-12M	04/13/98	0.76	12/07/99	2.8	2.04	268
1,1,1-TCA	MW-14	03/25/98	9	01/11/01	4.9	-4.1	-46
1,1,1-TCA	MW-1S	05/07/98	6	02/14/01	E5.2	-0.8	-13
1,1,1-TCA	MW-3M	04/14/98	2.4	01/03/01	E0.38	-2.02	-84
1,1,1-TCA	MW-4D	04/07/98	1	08/29/00	E0.56	-0.44	-44
1,1,1-TCA	MW-4I	04/07/98	E0.4	08/29/00	E0.68	0.28	NM
1,1,1-TCA	MW-5I	05/06/98	11	09/06/00	5	-6	-55
1,1,1-TCA	MW-6D	04/22/98	3	11/02/00	1.4	-1.6	-53
1,1,1-TCA	MW-9D	04/21/98	0.7	12/14/99	2.6	1.9	271

Table 1-2
Changes in VOCs Over Time in Selected Groundwater Samples[1]
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

VOC	Well Name	Date Sampled	VOC Concentration (mg/L)	Date Sampled	VOC Concentration (mg/L)	Change in VOC Concentration (mg/L)	Percent Change in VOC Concentration
Ethylbenzene	MW-10M	04/29/98	E1000	03/07/01	190	-810	-81
Benzene	MW-10M	04/29/98	E1200	03/07/01	170	-1030	-86

"--" = change in concentration cannot be determined
DCA = dichloroethane
DCE = dichloroethylene
TCA = trichloroethane
TCE = trichloroethylene
PCE = tetrachloroethylene
VOC = volatile organic compound
mg/L = microgram per liter
NM = No meaning
"E" = estimated value
1. This table includes data collected in 1998 (Walker, R.L., and Jacobsen, Eric. In press) and 1999 under the NJDEP contract and during the OU1 RI, 2000-2001

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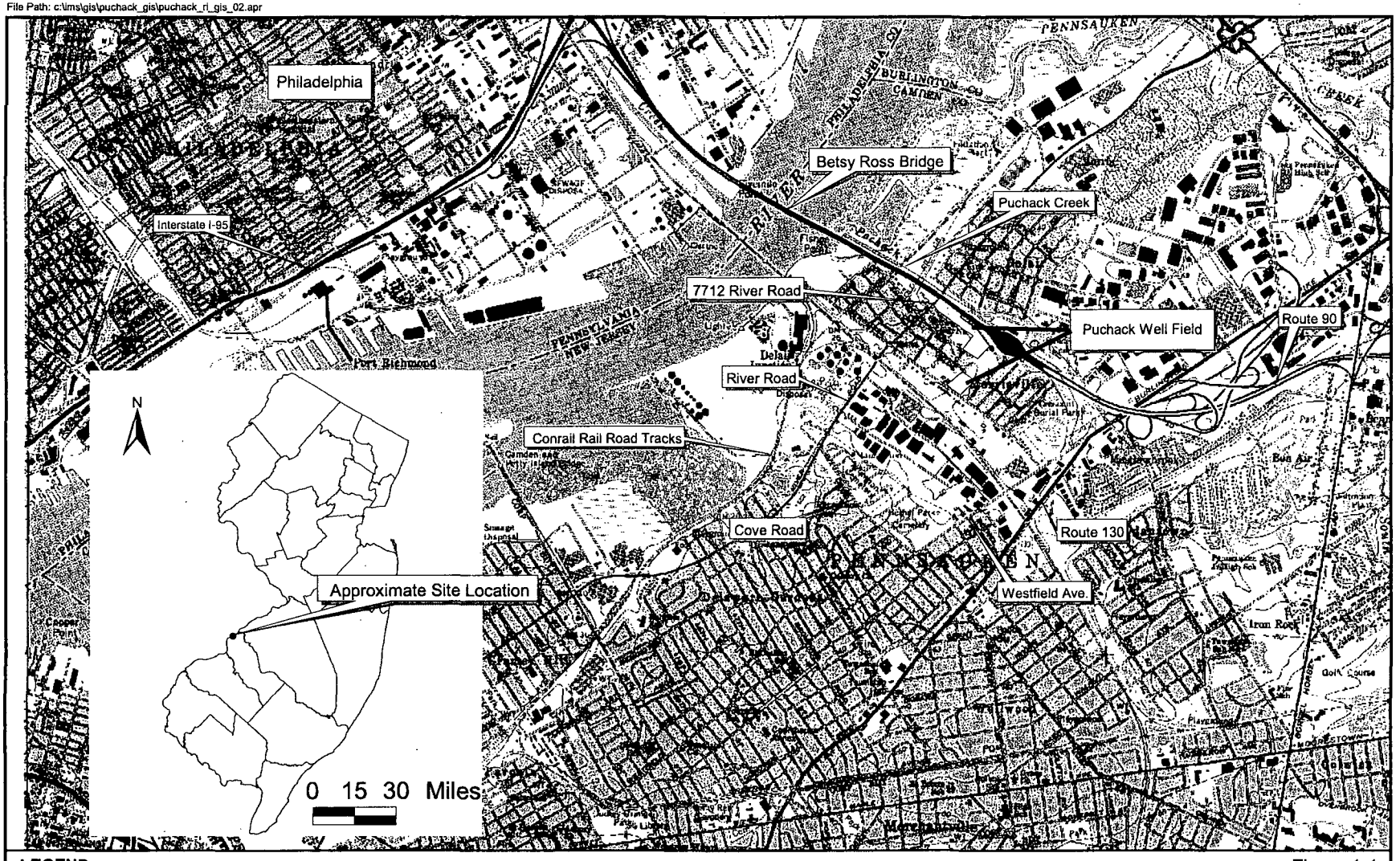


LEGEND

Puchack Well Field

Topographic Map: Camden, NJ 7.5 Minute Quadrangle

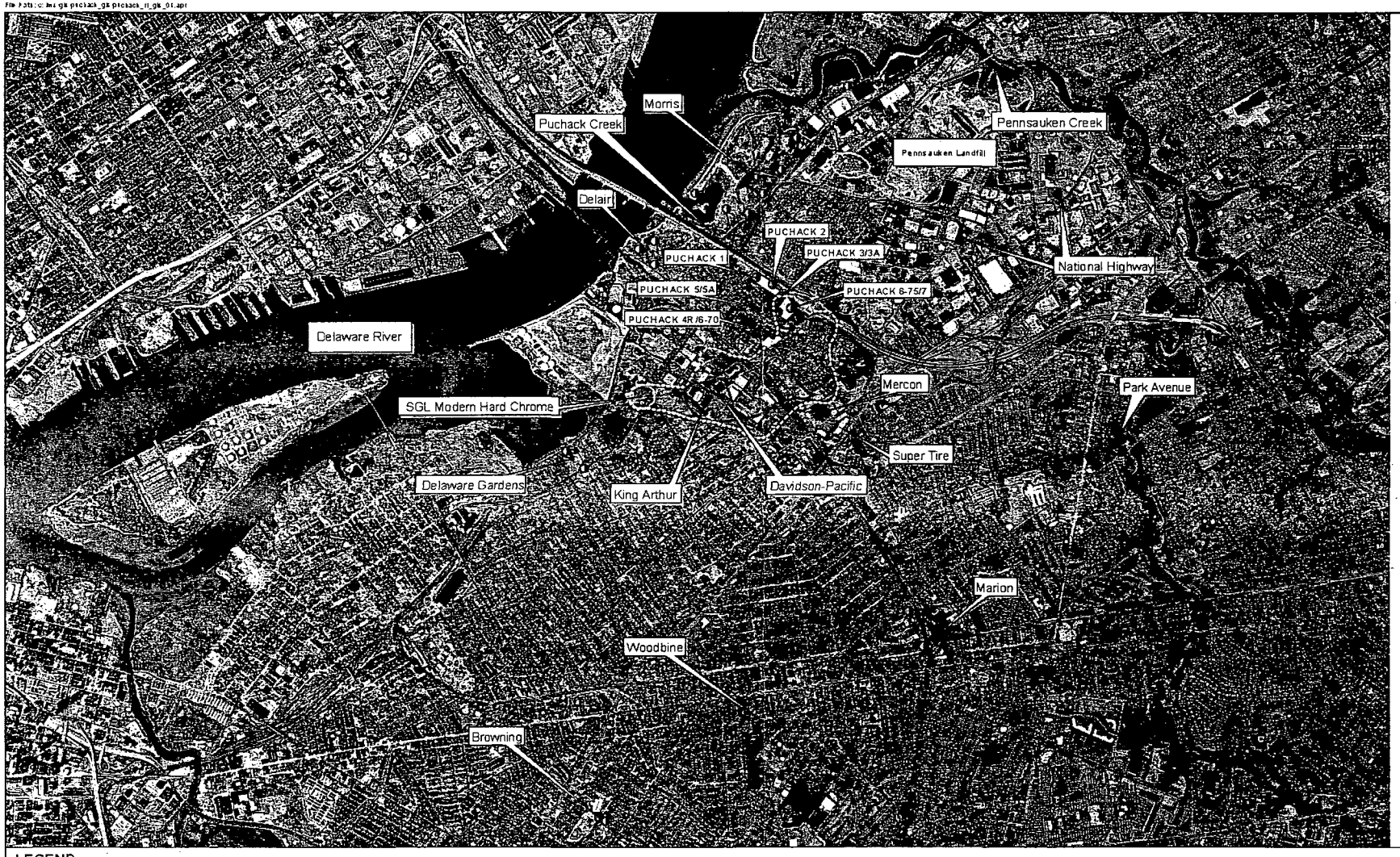
N

0 2000 4000 Feet

1:36,000

Figure 1-1
Puchack Well Field Location
Remedial Investigation/Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

CDM



LEGEND

- OU1 Boundary
- Middle Sand: 70 ug/L Chromium Isoconcentration Contour, 1999-2001 Data
- Intermediate Sand: 70 ug/L Chromium Isoconcentration Contour, 1999-2001 Data
- Lower Sand: 70 ug/L Chromium Isoconcentration Contour, 1999-2001 Data
- Puchack Well Field

WELL FIELDS

- Browning
- Delaware Gardens
- Delair
- Marion
- Morris
- National Highway
- Park Avenue
- Woodbine
- Puchack

N

0 2000 4000 Feet

Figure 1-2
OU1 Boundary and Chromium
Groundwater Quality Data
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

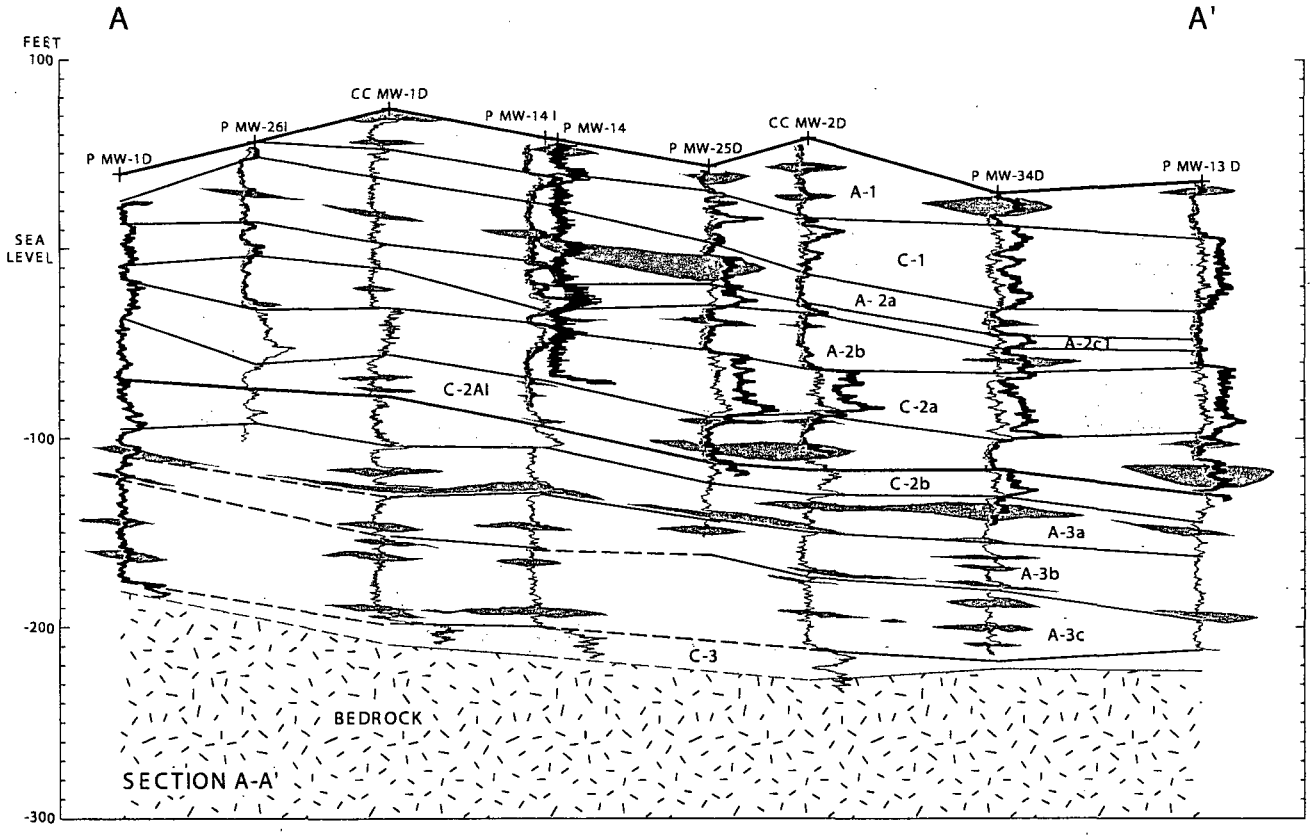
CDM

400044

POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM

PREVIOUSLY DESCRIBED FRAMEWORK	FRAMEWORK USED IN THIS STUDY
UPPER AQUIFER	AQUIFER (A-1)
UPPER/MIDDLE CONFINING UNIT	CONFINING UNIT (C-1)
MIDDLE AQUIFER	UPPER SAND (A-2a)
	INTERBEDDED CONFINING UNIT (A-2C1)
	LOWER SAND (A-2b)
MIDDLE/LOWER CONFINING UNIT	UPPER CONFINING UNIT (C-2a)
	INTERMEDIATE SAND (C-2AI)
	LOWER CONFINING UNIT (C-2b)
LOWER AQUIFER	UPPER ZONE (A-3a)
	MIDDLE ZONE (A-3b)
	LOWER ZONE (A-3c)
LOWER CONFINING UNIT	CLAY OR BEDROCK BASAL CONFINING UNIT (C-3)

Figure 1-3 Five-layer and Subdivided Interpretations of the Hydrostratigraphic Framework of the Potomac-Raritan-Magothy Aquifer System, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



EXPLANATION

Predominantly sands and gravels

Predominantly clays and silts

P MW-1D + Well and well number shown in hydrostratigraphic section

P Puchack

CC Camden City

0 200 400 600 800 1,000 2,000 FEET

0 100 200 METERS

HYDROSTRATIGRAPHY OF THE POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM IN THE PENNSAUKEN TOWNSHIP AND VICINITY

Layer	Unit
A-1	Upper aquifer
C-1	Upper/Middle confining unit
A-2a	Middle aquifer, upper sand
A-2C1	Middle aquifer, interbedded confining unit
A-2b	Middle aquifer, lower sand
C-2a	Middle/Lower confining unit, upper confining unit
C-2AI	Middle/Lower confining unit, intermediate sand
C-2b	Middle/Lower confining unit, lower confining unit
A-3a	Lower aquifer, upper zone
A-3b	Lower aquifer, middle zone
A-3c	Lower aquifer, lower zone
C-3	Basal confining unit

GAMMA LOG
Increasing radiation

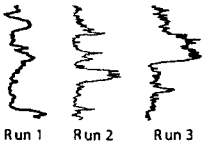
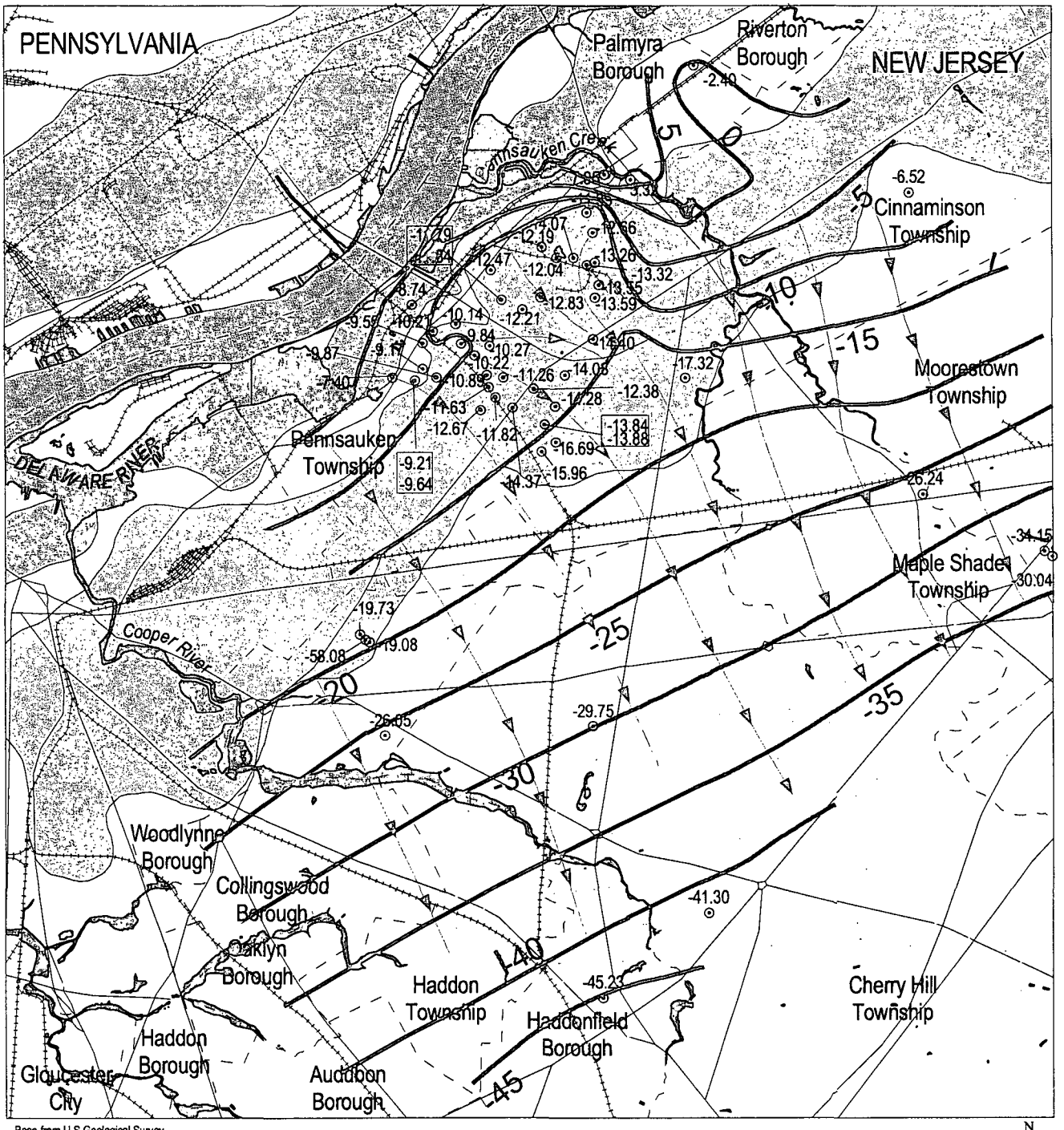


Figure 1-4 . Estimated Lateral Extent of Minor Sand and Clay Units Within the Potomac-Raritan-Magothy Aquifer System, Section A-A', Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Line of section shown on plate 2.) (Figure prepared by the USGS)



Base from U.S.Geological Survey digital line files, 1:24000

1 0 1 2 Miles

N

EXPLANATION

-10.27 ⊙ Location of well and water level. Pumping affected water level indicated in blue.

Direction of Flow

-30 WATER LEVEL CONTOUR--Shows altitude of the water level in screened wells. Contour interval 5 feet. Datum is sea level.

Township boundaries

Major roads

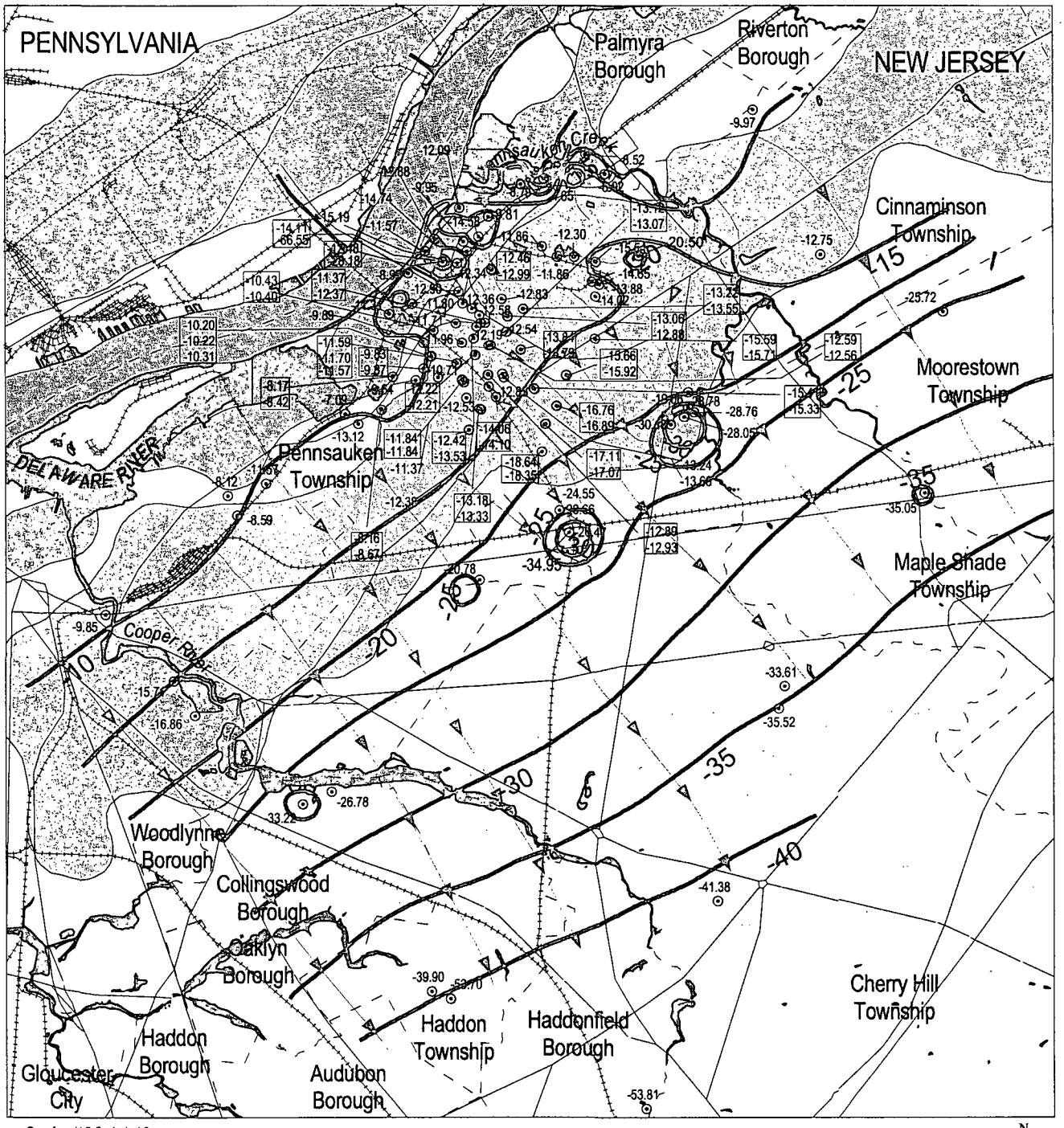
Railroads

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system. Modified from Navoy and Carleton, 1995.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system. Modifed from Navoy and Carleton, 1995.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system. From Navoy and Carleton, 1995

Figure 1-5. Potentiometric Surface of the Middle Aquifer, Potomac-Raritan-Magothy Aquifer System, April 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S.Geological Survey digital line files, 1:24000

1 0 1 2 Miles

N

EXPLANATION

-12.53 Location of well and water level. Pumping affected water level indicated in blue.

Direction of Flow

-30 WATER LEVEL CONTOUR–Shows altitude of the water level in screened wells. Contour interval 5 feet. Datum is sea level.

Township boundaries

Major roads

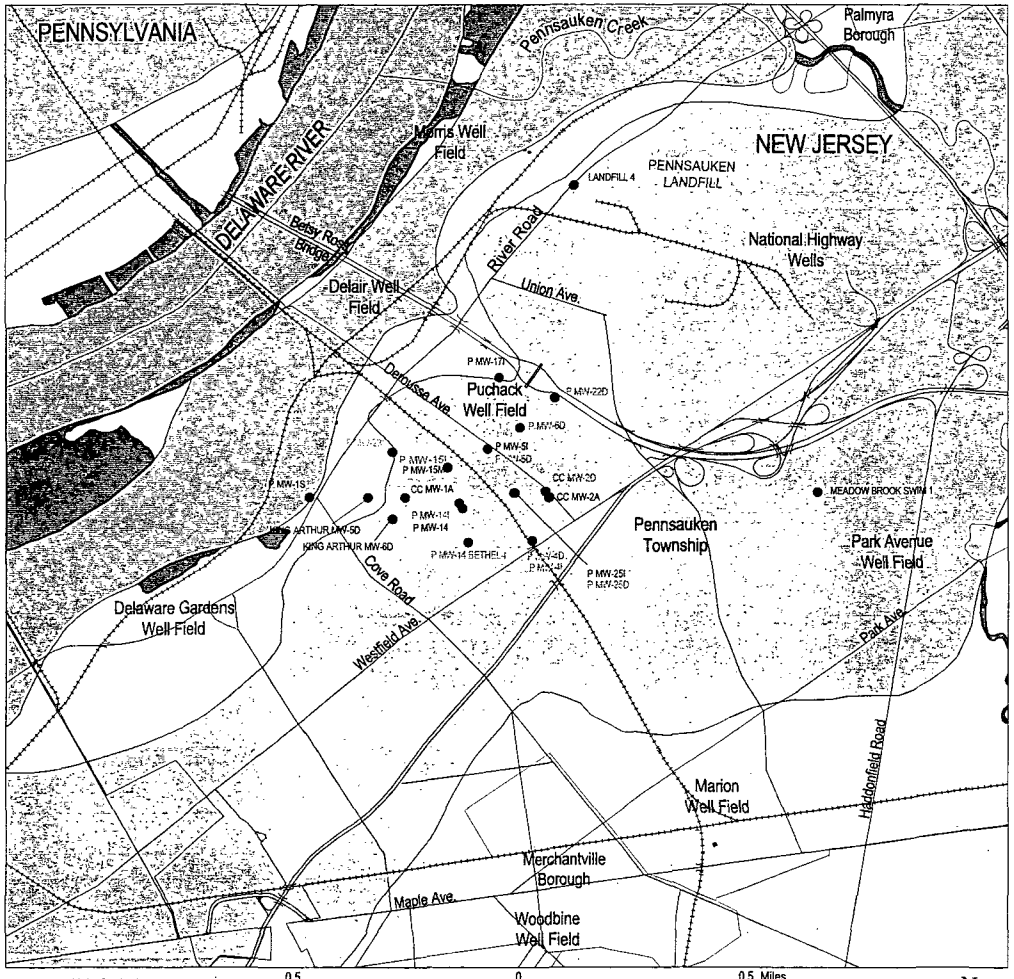
Railroads

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system. Modified from Navoy and Carleton, 1995.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system. Modifed from Navoy and Carleton, 1995.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system. From Navoy and Carleton, 1995

Figure 1-6. Potentiometric Surface of the Lower Aquifer, Including the Intermediate Sand, Potomac-Raritan-Magothy Aquifer System, April 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

EXPLANATION

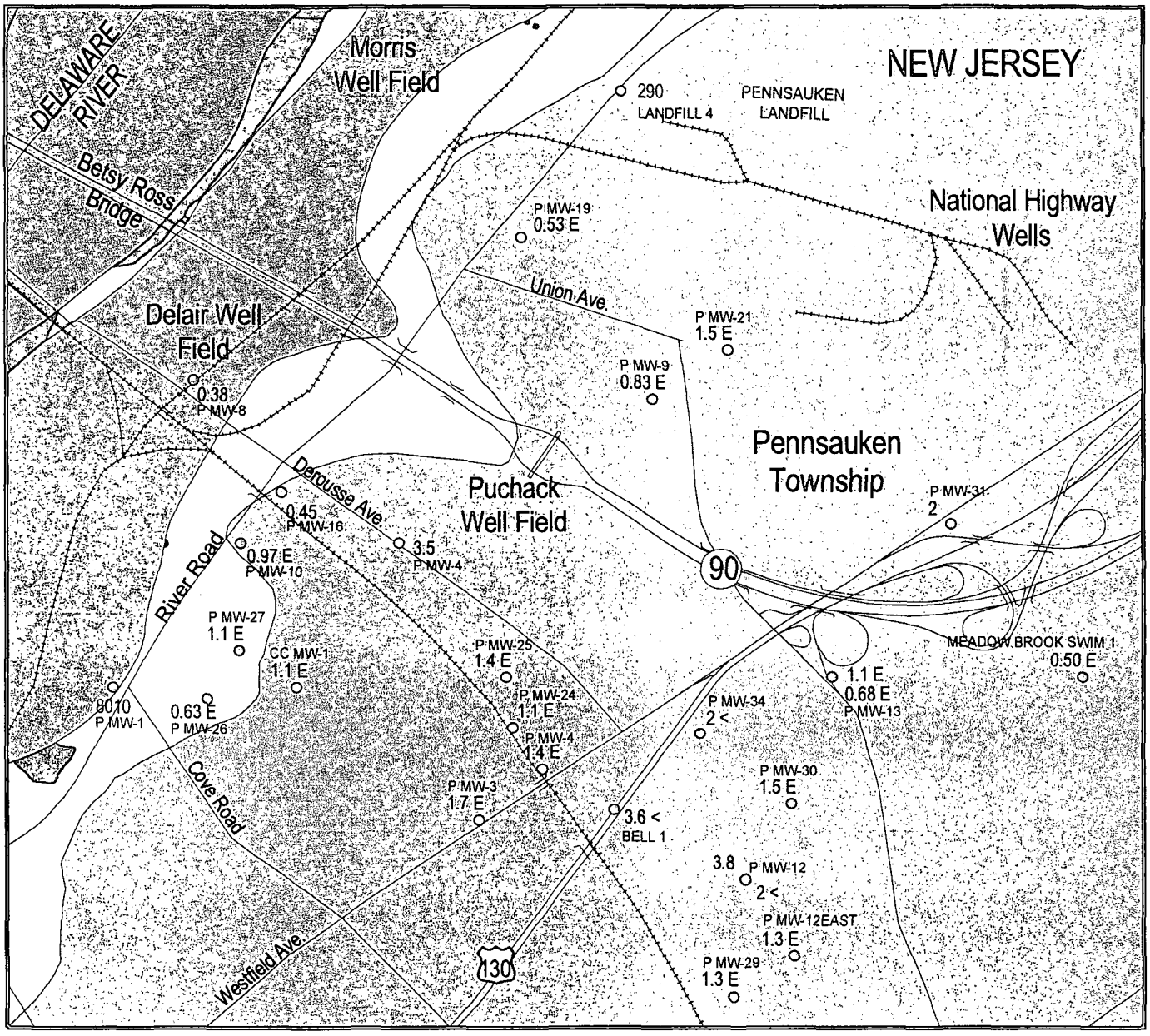
- Location of well with site name. Labels color coded per layer; orange-lower, red-intermediate sand, and green-middle.
- Railroads
- Township boundaries
- Major Roads
- Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.
- Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.
- Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Well name	Aquifer-Layer Description	Layer Code	Sample Date	Total Chromium (µg/L)	Mercury (µg/L)	Lead (µg/L)
MEADOW BROOK SWIM 1	Middle-Upper Sand	a2a	8/31/2000	--	--	29.2
P MW-1S	Middle-Lower Sand	a2b	2/14/2001	8010	--	--
LANDFILL 4	Middle-Lower Sand	a2b	12/1/1999	290*	--	--
P MW-15M	Intermediate Sand	c2ai	2/21/2001	766	--	--
P MW-17I	Intermediate Sand	c2ai	11/28/2000	100	--	--
P MW-25I	Intermediate Sand	c2ai	11/1/2000	6310	--	--
KING ARTHUR MW-5D	Intermediate Sand	c2ai	12/15/1999	910*	--	--
KING ARTHUR MW-6D	Intermediate Sand	c2ai	12/16/1999	320*	--	--
P MW-14	Intermediate Sand	c2ai	1/11/2001	1720	3.3	--
P MW-5I	Intermediate Sand	c2ai	9/6/2000	3010	--	--
CC MW-2A	Intermediate Sand	c2ai	10/30/2000	3570	--	--
CC MW-1A	Intermediate Sand	c2ai	12/11/2000	1730	--	--
P MW-23I	Lower-Upper Zone	a3a	12/12/2001	129	--	--
P MW-15I	Lower-Upper Zone	a3a	3/8/2001	2230	--	--
P MW-14I	Lower-Upper Zone	a3a	11/16/2001	4810	--	--
P MW-14 BETHEL-I	Lower-Upper Zone	a3a	2/26/2001	1460	--	--
P MW-4I	Lower-Upper Zone	a3a	12/13/1999	--	2.95*	--
P MW-4I	Lower-Upper Zone	a3a	8/29/2000	--	3.7	--
P MW-6D	Lower-Middle Zone	a3b	11/2/2000	1450	--	--
P MW-5D	Lower-Middle Zone	a3b	9/7/2000	427	--	--
P MW-4D	Lower-Middle Zone	a3b	8/29/2000	--	3.6	--
P MW-22D	Lower-Lower Zone	a3c	11/9/2000	185	2.6	--
P MW-25D	Lower-Lower Zone	a3c	10/31/2000	237	--	--
CC MW-2D	Lower-Lower Zone	a3c	10/26/2000	543	2.4	--

Note:
CC - Camden City
P - Puchack
USGS - US Geological Survey
* - filtered sample
-- - data below NJ Groundwater Quality Standards (GWQS)

GWQS for Total Chromium is 70 µg/L
GWQS for Mercury is 2 µg/L
GWQS for Lead is 5 µg/L

Figure 1-7
Aerial Extent of Metals Exceeding Maximum Contaminant Levels and Action Levels in Groundwater from the Potomac-Raritan-Magothy Aquifer System, 1999-2001
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey
(Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

2 Location of well. Number is Total Chromium, unfiltered (μ g/L). Number in blue is Total Chromium, filtered (μ g/L). E= estimated, <= less than.

Railroads

Township boundaries

Major Roads

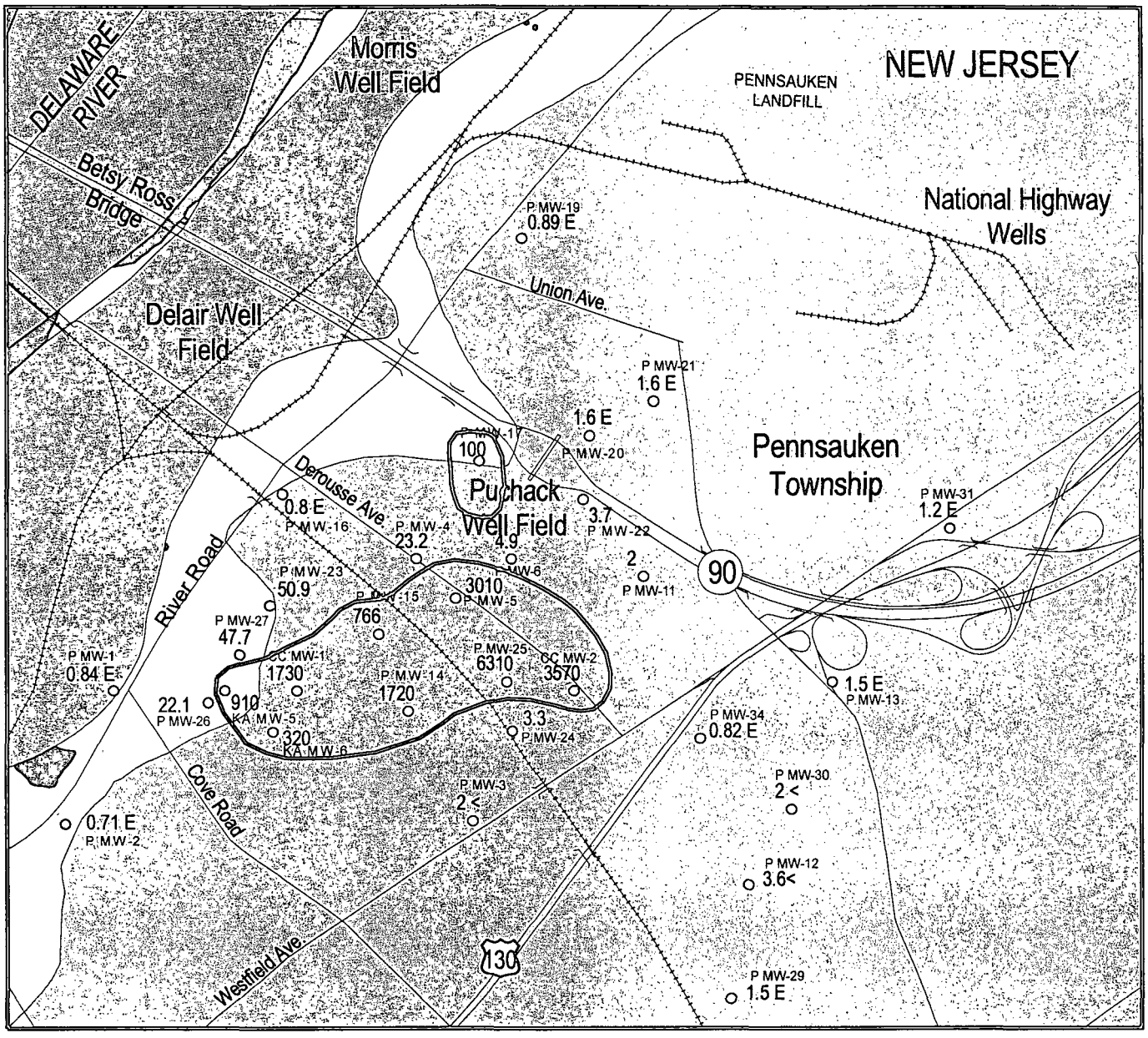
290 Total Chromium Concentrations exceeding 70 μg/L.

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-8. Aerial extent of chromium contaminated groundwater in the Middle aquifer, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

2 Location of well. Number is Total Chromium, unfiltered (μ g/L). Number in blue is Total Chromium, filtered (μ g/L). E= estimated, <= less than.

Railroads

Township boundaries

Major Roads

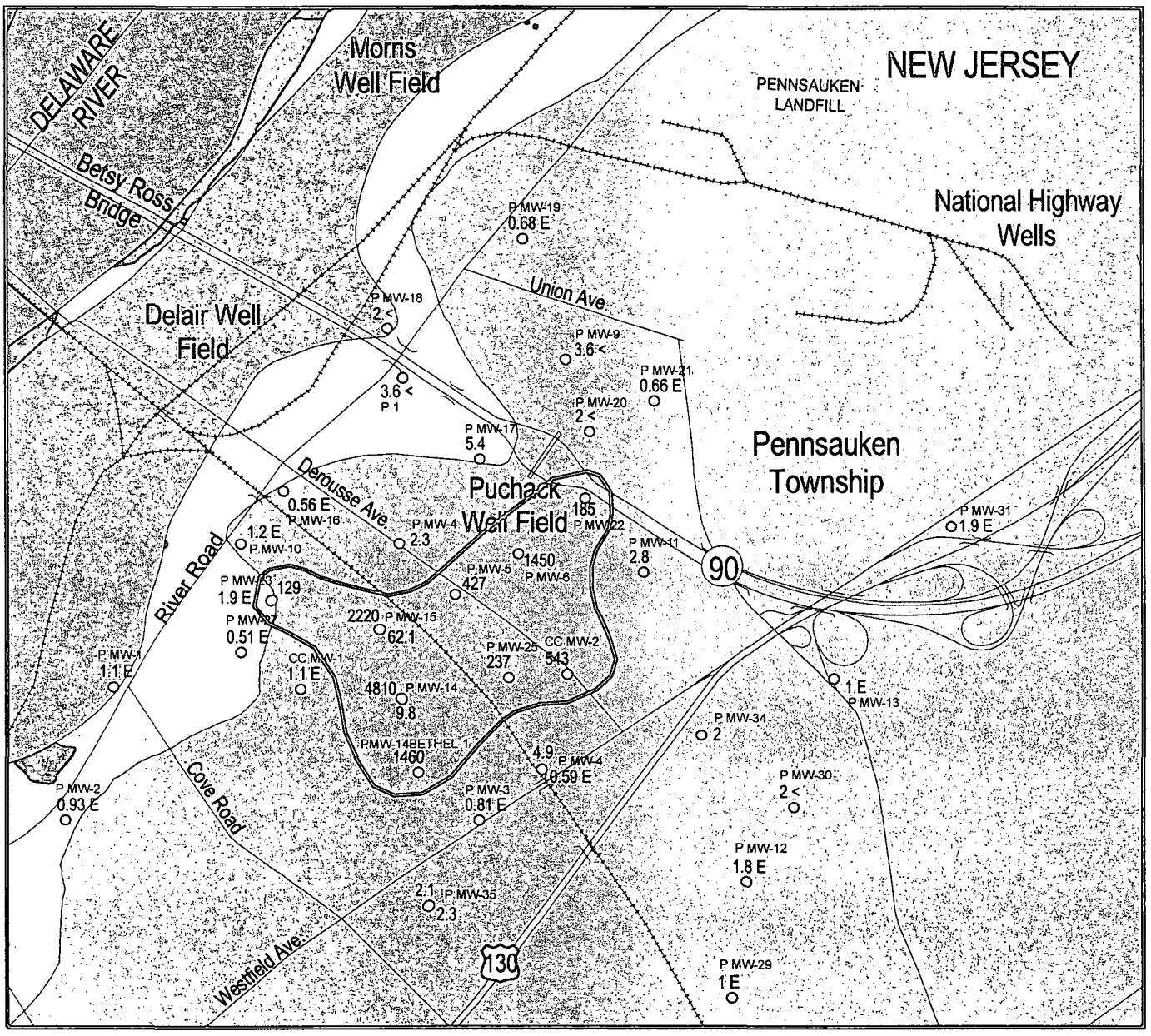
Approximate area of Total Chromium exceeding 70 μg/L.

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-9. Aerial Extent of Chromium Contaminated Groundwater in the Intermediate Sand, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

2 Location of well. Number is Total Chromium, unfiltered (μ g/L). Number in blue is Total Chromium, filtered (μ g/L). E= estimated, <= less than.

Railroads

Township boundaries

Major Roads

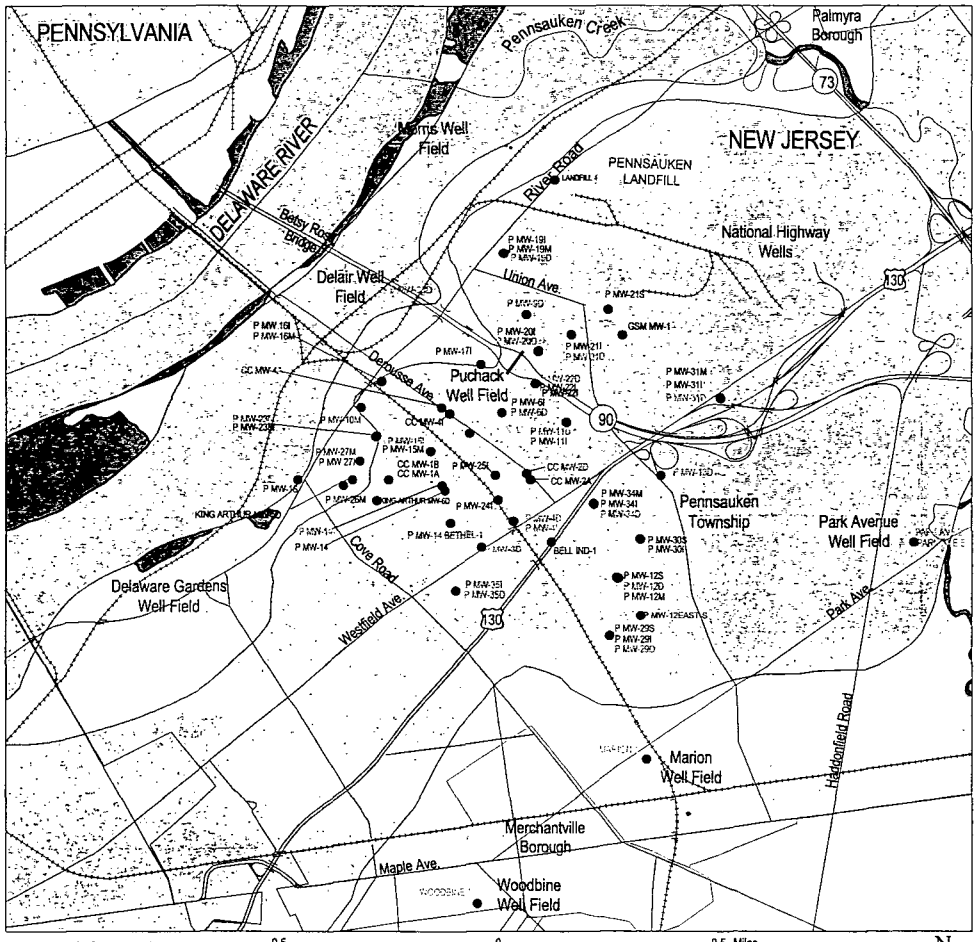
Approximate area of Total Chromium exceeding 70 μg/L.

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-10. Aerial extent of chromium contaminated groundwater in the Lower aquifer, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

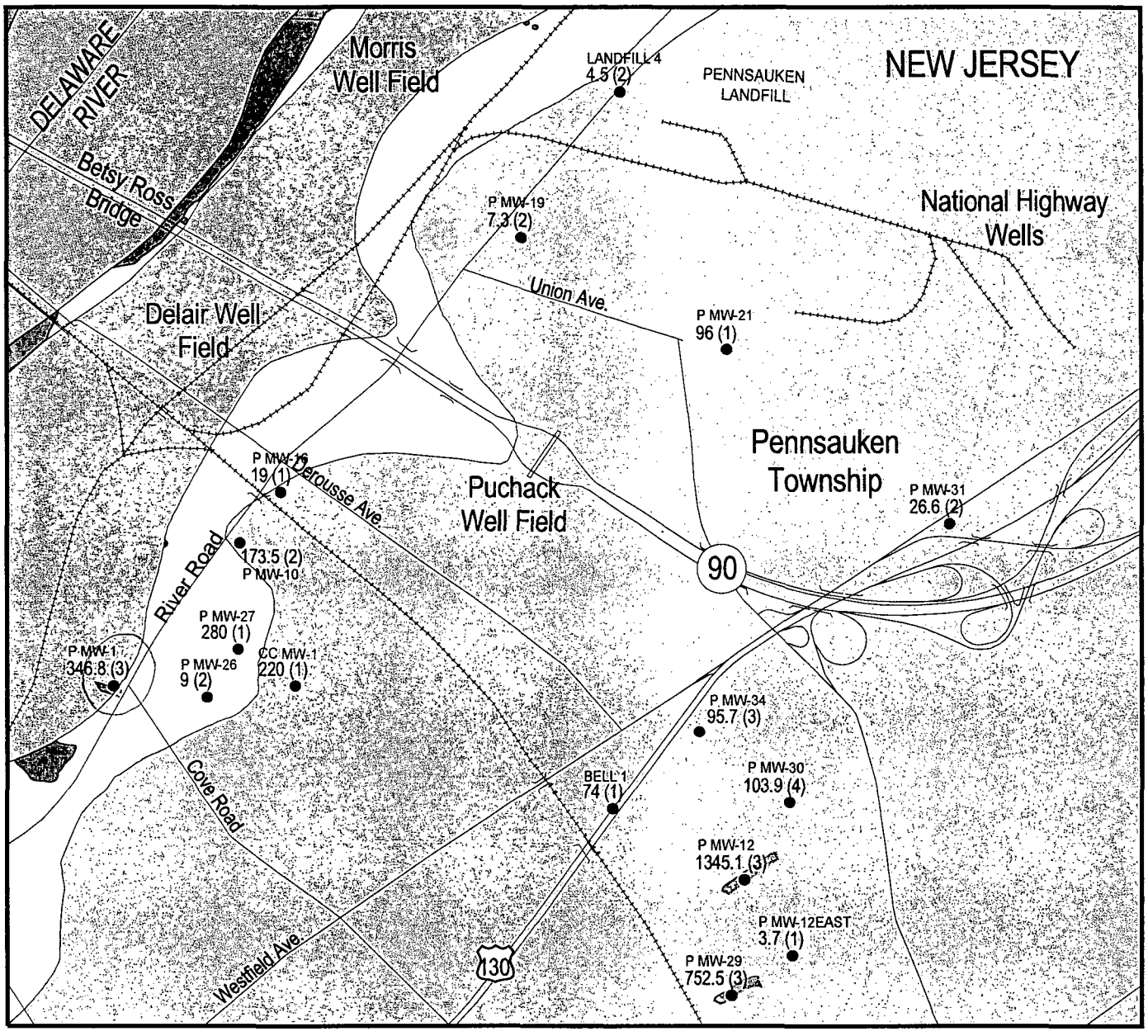
EXPLANATION

- Location of well with site name. Labels color coded per layer; orange-lower, red-intermediate sand, green-middle and black-upper.
- Railroads
- Township boundaries
- Major Roads
- Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.
- Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.
- Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Well Name	Aquifer-Layer Description	Layer	Sample Date	Benzene (µg/L)	Carbon Tetrachloride (µg/L)	1,1-DCE (µg/L)	cis-1,2-DCE (µg/L)	PCE (µg/L)	1,1,1-TCA (µg/L)	TCE (µg/L)	Vinyl Chloride (µg/L)
GSM MW-1	Upper	a1	08/31/00	--	--	E14	450	--	55	990	--
BELL IND-1	Middle-Upper Sand	a2a	11/17/99	--	--	--	--	--	--	74	--
P MW-21S	Middle-Upper Sand	a2a	03/08/01	--	--	--	--	--	--	96	--
P MW-31M	Middle-Upper Sand	a2a	02/28/01	--	--	19	--	--	--	7.6	--
P MW-34M	Middle-Upper Sand	a2a	03/13/01	--	--	58	--	E1.7	36	--	--
CC MW-1B	Middle-Lower Sand	a2b	11/30/00	--	--	--	--	--	--	220	--
LANDFILL 4	Middle-Lower Sand	a2b	12/01/99	--	--	--	--	2.4	--	--	--
P MW-10M	Middle-Lower Sand	a2b	03/07/01	170	--	--	--	--	--	E3.5	--
P MW-12EAST-S	Middle-Lower Sand	a2b	02/15/01	--	--	3.7	--	--	--	--	--
P MW-12S	Middle-Lower Sand	a2b	10/18/00	--	--	400	--	--	940	E5.1	--
P MW-16M	Middle-Lower Sand	a2b	12/19/00	19	--	--	--	--	--	--	--
P MW-19M	Middle-Lower Sand	a2b	12/14/00	--	--	--	--	4.5	--	2.8	--
P MW-1S	Middle-Lower Sand	a2b	02/14/01	--	--	E6.8	--	230	--	110	--
P MW-26M	Middle-Lower Sand	a2b	03/12/01	--	--	--	--	3	--	6	--
P MW-27M	Middle-Lower Sand	a2b	01/17/01	--	--	--	--	--	--	280	--
P MW-29S	Middle-Lower Sand	a2b	02/13/01	--	--	240	--	--	510	E2.5	--
P MW-30S	Middle-Lower Sand	a2b	02/20/01	--	--	46	--	8	48	1.9	--
CC MW-1A	Intermediate Sand	c2ai	12/11/00	--	--	--	--	--	--	8.4	--
CC MW-2A	Intermediate Sand	c2ai	10/30/00	--	--	4.1	--	3	--	43	--
CC MW-4I	Intermediate Sand	c2ai	01/10/01	--	--	--	--	--	--	63	--
KING ARTHUR MW-5D	Intermediate Sand	c2ai	12/15/99	--	--	2.6	--	2.4	--	100	--
KING ARTHUR MW-6D	Intermediate Sand	c2ai	12/16/99	--	--	--	--	--	--	3.5	--
P MW-11I	Intermediate Sand	c2ai	10/25/00	--	--	--	--	--	--	5	--
P MW-12M	Intermediate Sand	c2ai	12/07/99	--	--	2.3	--	1.1	--	36	--
P MW-14	Intermediate Sand	c2ai	01/11/01	--	--	5.8	--	7.5	--	53	--
P MW-15M	Intermediate Sand	c2ai	02/21/01	--	--	--	--	--	--	6.3	--
P MW-16I	Intermediate Sand	c2ai	12/27/00	20	--	--	--	--	--	10	--
P MW-17I	Intermediate Sand	c2ai	11/28/00	--	--	--	--	--	--	7.7	--
P MW-19I	Intermediate Sand	c2ai	12/18/00	--	--	--	--	2.2	--	13	--
P MW-20I	Intermediate Sand	c2ai	01/18/01	--	--	--	--	--	--	9.7	--
P MW-21I	Intermediate Sand	c2ai	12/12/00	--	--	--	--	1.3	--	48	--
P MW-22I	Intermediate Sand	c2ai	11/08/00	--	--	--	--	12	--	3.2	--
P MW-23M	Intermediate Sand	c2ai	02/12/01	--	--	--	--	--	--	5.7	--
P MW-24I	Intermediate Sand	c2ai	01/04/01	--	--	--	--	--	--	140	--
P MW-25I	Intermediate Sand	c2ai	11/01/00	--	--	2.8	--	3.1	--	35	--
P MW-27I	Intermediate Sand	c2ai	01/17/01	--	--	--	--	--	--	3.3	--
P MW-29I	Intermediate Sand	c2ai	01/09/01	--	--	8.8	--	10	--	4.6	--
P MW-30I	Intermediate Sand	c2ai	10/19/00	--	--	--	--	--	--	5.9	--
P MW-31I	Intermediate Sand	c2ai	03/01/01	--	--	--	--	4.3	--	19	--
P MW-34I	Intermediate Sand	c2ai	03/13/01	--	--	4.9	--	3	--	42	--
P MW-5I	Intermediate Sand	c2ai	09/06/00	--	--	2.7	--	--	--	24	--
P MW-6I	Intermediate Sand	c2ai	11/02/00	--	--	--	--	1.8	--	--	--
P MW-14 BETHEL-I	Lower-Upper Zone	a3a	02/26/01	--	--	2.3	--	2.5	--	17	--
P MW-14I	Lower-Upper Zone	a3a	01/16/01	--	--	--	--	2.6	--	20	--
P MW-15I	Lower-Upper Zone	a3a	03/08/01	--	--	--	--	--	--	5.3	--
P MW-23I	Lower-Upper Zone	a3a	02/12/01	--	--	3.5	--	--	--	25	--
P MW-35I	Lower-Upper Zone	a3a	04/10/01	--	--	--	--	--	--	360	--
P MW-4I	Lower-Upper Zone	a3a	12/13/99	--	--	--	--	1.3	--	52	--
WOODBINE 1	Lower-Upper Zone	a3a	10/27/99	--	--	--	--	1.4	--	6.1	--
CC MW-4A	Lower-Middle Zone	a3b	01/09/01	--	--	--	--	--	--	12	--
MARION 1	Lower-Middle Zone	a3b	11/17/99	--	--	16	--	3.5	--	85	--
PARK AVE 2	Lower-Middle Zone	a3b	11/15/99	--	--	--	--	3.4	--	10	--
P MW-13D	Lower-Middle Zone	a3b	10/24/00	--	--	2.7	--	8	--	19	--
P MW-31D	Lower-Middle Zone	a3b	03/01/01	--	4.7	2.1	--	3.2	--	5.2	--
P MW-4D	Lower-Middle Zone	a3b	08/29/00	--	--	--	--	--	--	9	--
P MW-5D	Lower-Middle Zone	a3b	09/07/00	--	--	--	--	--	--	1.3	--
P MW-6D	Lower-Middle Zone	a3b	11/02/00	--	--	--	--	--	--	9.3	--
CC MW-2D	Lower-Lower Zone	a3c	10/26/00	--	--	--	--	--	--	12	--
PARK AVE 5	Lower-Lower Zone	a3c	11/09/99	--	--	--	--	--	--	1.5	--
P MW-11D	Lower-Lower Zone	a3c	02/28/01	--	--	--	--	--	--	47	--
P MW-12D	Lower-Lower Zone	a3c	02/22/01	--	--	--	--	--	--	110	--
P MW-19D	Lower-Lower Zone	a3c	12/18/00	--	--	--	--	4.3	--	82	--
P MW-20D	Lower-Lower Zone	a3c	01/18/01	--	--	--	--	--	--	9.7	--
P MW-21D	Lower-Lower Zone	a3c	12/13/00	3.1	--	--	--	13	--	19	2.1
P MW-22D	Lower-Lower Zone	a3c	11/09/00	--	--	--	--	--	--	2.6	--
P MW-25D	Lower-Lower Zone	a3c	10/31/00	--	--	--	--	--	--	3	--
P MW-29D	Lower-Lower Zone	a3c	01/22/01	--	--	--	--	--	--	59	--
P MW-34D	Lower-Lower Zone	a3c	03/14/01	--	--	--	--	--	--	55	--
P MW-35D	Lower-Lower Zone	a3c	04/10/01	--	--	--	--	--	--	2.5	--
P MW-3D	Lower-Lower Zone	a3c	01/30/01	--	--	--	--	--	--	3.4	--
P MW-9D	Lower-Lower Zone	a3c	12/14/99	--	--	3.2	--	11	--	46	--

Note: (USGS, U.S. Geological Survey; --, no data exceeds MCL; E, estimated; P, PUCHACK; CC, CAMDEN CITY)

Figure 1-11
Aerial Extent of Volatile Organic Compounds Exceeding Maximum Contaminant Levels in Groundwater from the Potomac-Raritan-Magothy Aquifer System, 1999-2001
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey
(Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

60 (2) ● Location of well. First number is sum of concentrations exceeding MCL's for benzene, 1,1-DCE, CIS-1,2-DCE, PCE, 1,1,1-TCA, TCE, Vinyl Chloride. Second number is the number of compounds represented.

Railroads

Township boundaries

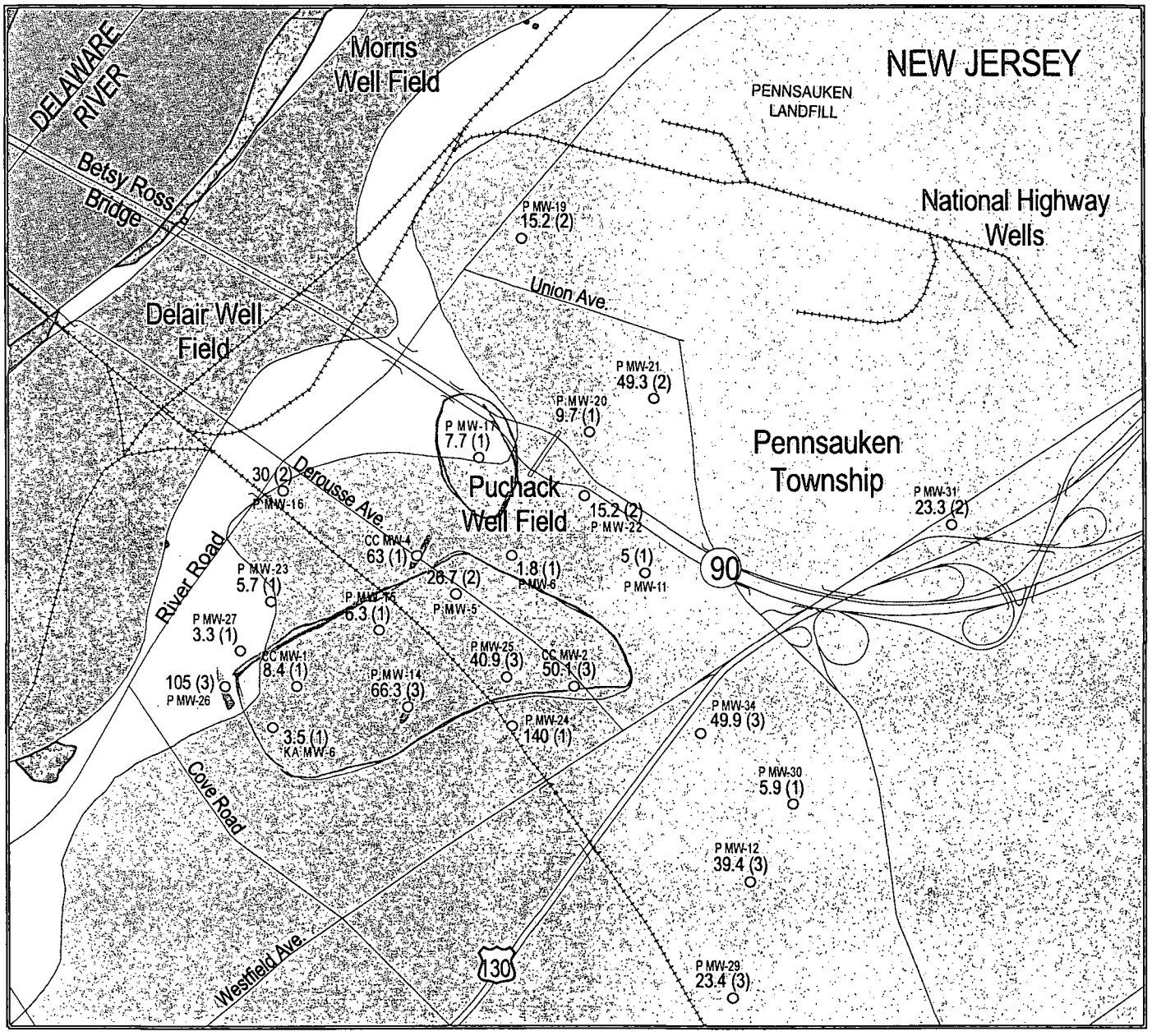
Major Roads

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-12. Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Middle Aquifer, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

60 (2) Location of well. First number is sum of concentrations exceeding MCL's for benzene, 1,1-DCE, CIS-1,2-DCE, PCE, 1,1,1-TCA, TCE, Vinyl Chloride. Second number is the number of compounds represented.

Railroads

Township boundaries

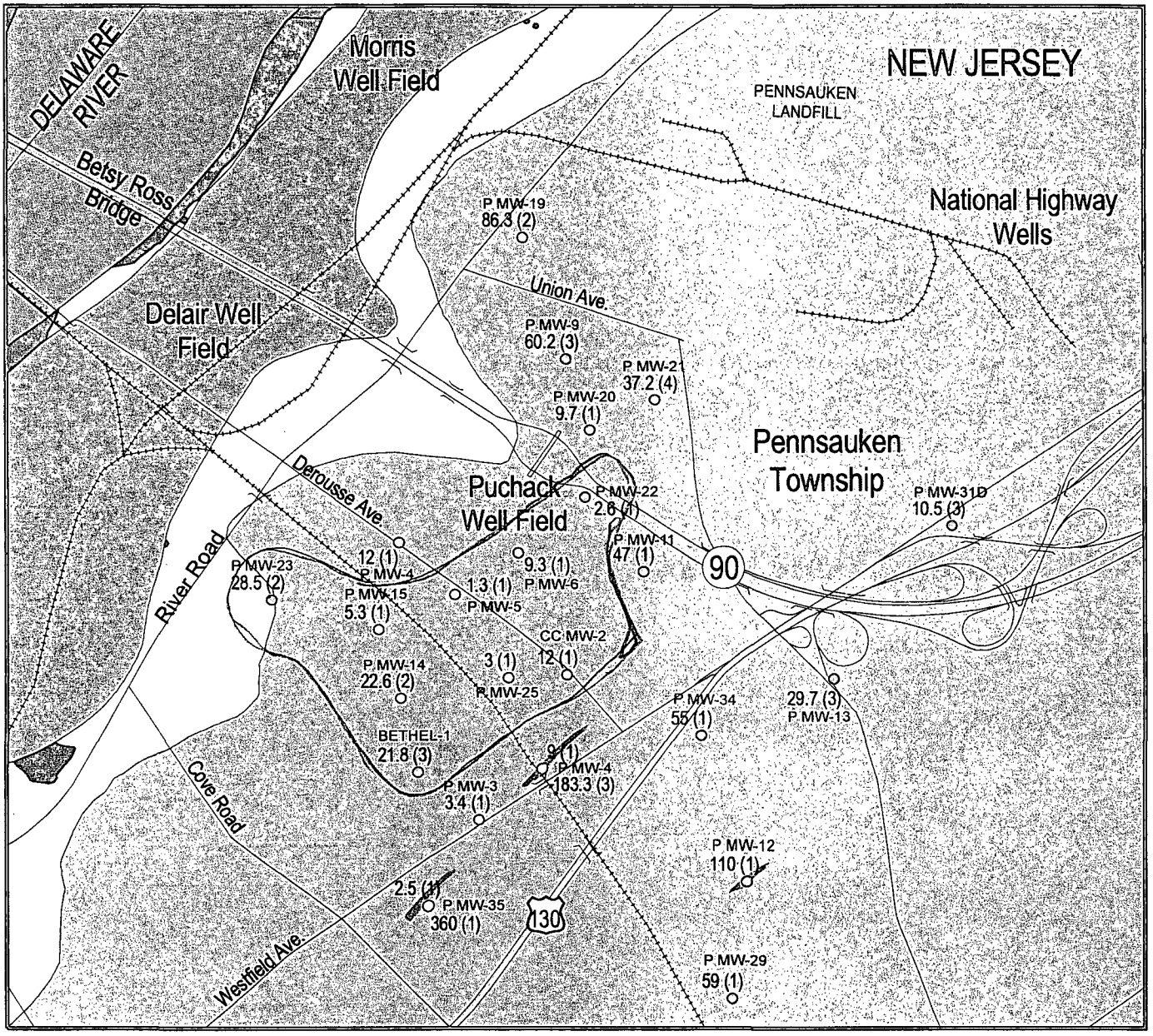
Major Roads

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-13. Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Intermediate Sand, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



Base from U.S. Geological Survey digital line files, 1:24,000

0.5 0 0.5 Miles

N

EXPLANATION

60 (2) Location of well. First number is sum of concentrations exceeding MCL's for benzene, 1,1-DCE, CIS-1,2-DCE, PCE, 1,1,1-TCA, TCE, Vinyl Chloride. Second number is the number of compounds represented.

Railroads

Township boundaries

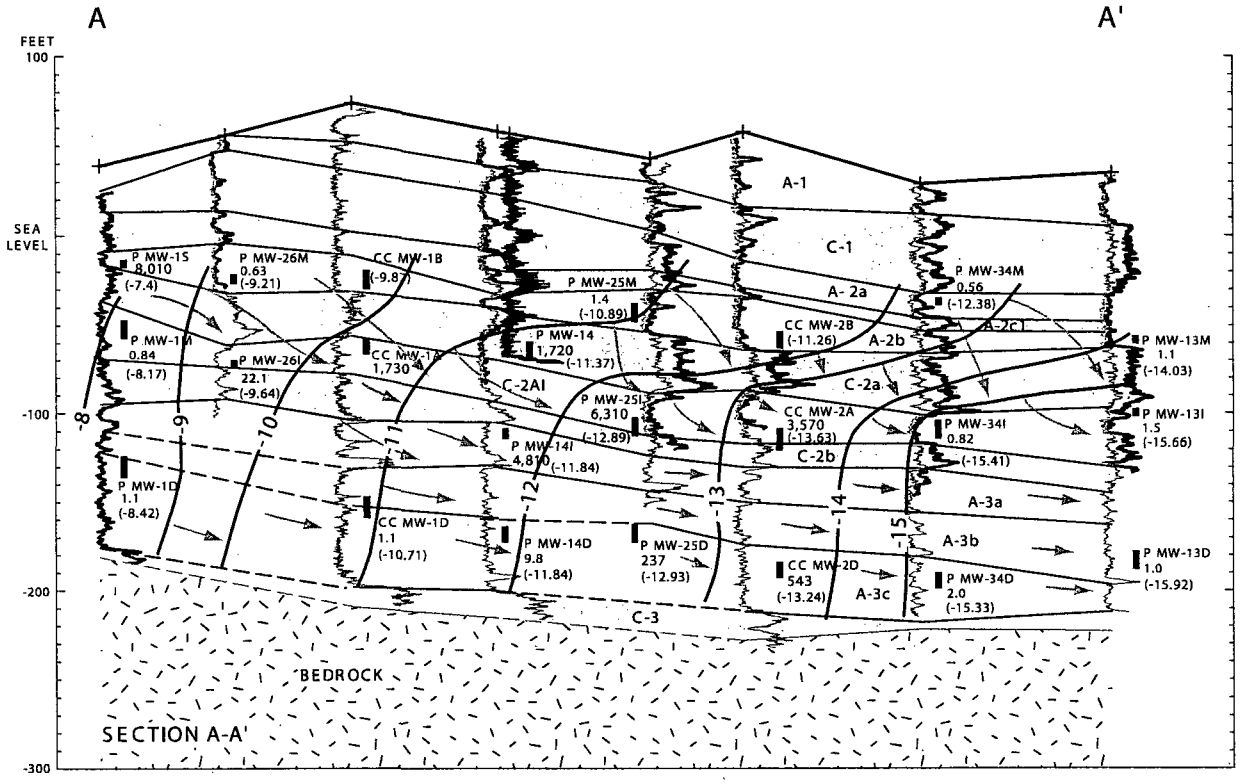
Major Roads

Outcrop area of the Upper aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Middle aquifer of the Potomac-Raritan-Magothy aquifer system.

Outcrop area of the Lower aquifer of the Potomac-Raritan-Magothy aquifer system.

Figure 1-14. Aerial Extent of Volatile Organic Compound Contaminated Groundwater in the Lower Aquifer, 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Figure prepared by the USGS)



EXPLANATION

0 200 400 600 800 1,000 2,000 FEET

0 200 400 METERS

VERTICAL EXAGGERATION x 13

+ Well location shown in hydrostratigraphic section

P MW-25D 237 (-12.93) — Well screen. Top number is well name. Bottom number is the total chromium concentration. Bold number indicates chromium concentration exceeding New Jersey maximum contaminant level of 100 micrograms per liter (1999-2001 data). Number in parenthesis is potentiometric head, in feet. Datum is sea level

P Puchack

CC Camden City

—-10— Potentiometric contour--Shows altitude at which water would have stood in tightly case wells, 2001, Contour interval 1 foot. Datum is sea level

→ Arrows show general direction of groundwater flow

HYDROSTRATIGRAPHY OF THE POTOMAC-RARITAN-MAGOTHY AQUIFER SYSTEM IN THE PENNSAUKEN TOWNSHIP AND VICINITY

Layer	Unit
A-1	Upper aquifer
C-1	Upper/Middle confining unit
A-2a	Middle aquifer, upper sand
A-2C1	Middle aquifer, interbedded confining unit
A-2b	Middle aquifer, lower sand
C-2a	Middle/Lower confining unit, upper confining unit
C-2AI	Middle/Lower confining unit, intermediate sand
C-2b	Middle/Lower confining unit, lower confining unit
A-3a	Lower aquifer, upper zone
A-3b	Lower aquifer, middle zone
A-3c	Lower aquifer, lower zone
C-3	Basal confining unit

GAMMA LOG

Increasing radiation

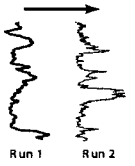


Figure 1-15. Concentrations of Total Chromium in Groundwater of the Potomac-Raritan-Magothy Aquifer System along Section A-A', 1999 - 2001, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey. (Line of section shown on Plate 2, Figure prepared by the USGS)

2 Section Two

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Section 2
Identification and Screening of Technologies

2.1 Introduction

This section presents the RAOs, Applicable or Relevant and Appropriate Requirements (ARARs) and other criteria, GRAs, and related technologies and process options. RAOs are media-specific goals for protecting human health and the environment that must be identified prior to the development of remedial action alternatives. The process of identifying the RAOs follows the identification of affected media and contaminant characteristics; evaluation of exposure pathways, contaminant migration pathways and exposure limits; and the evaluation of chemical concentrations that will result in acceptable exposure. The RAOs are based on regulatory requirements which may apply to the various remedial activities being considered for the Site. This section of the FS reviews the affected media and contaminant exposure pathways and identifies Federal, State, and Local regulations that may affect remedial actions.

GRAs are broad remedial actions and are defined as actions which may satisfy the RAOs and characterize the range of remedial responses appropriate to the media of concern at the Site. Following the development of GRAs, one or more remedial technologies and process options are identified and screened for each of the GRA categories. Screening is performed based on the effectiveness, implementability, and relative cost of each remedial technology.

Although an individual response action may be capable of satisfying the RAOs alone, combinations of response actions to become remedial alternatives are usually required to adequately address site contamination. These alternatives are presented in Section 3.

In the PE (CDM 2001), CDM identified the RAOs, GRAs, and related technologies and process options. This section is an update of the PE since the RI results are now available, and NJDEP has provided feedback to the selected remedial options.

2.2 Remedial Action Objectives

RAOs are medium-specific goals for protecting human health and the environment. The process followed in developing RAOs consists of identification of COPCs; identification of potentially applicable Federal and State regulations and other guidance; identification of applicable site-specific risk-based criteria; and the selection of the preliminary remediation goals (PRGs) based on the ARARs, guidance, or risk-based values.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 121(d), as amended by the Superfund Amendments and Reauthorization Act (SARA), requires that, at a minimum, any remedial action achieve

overall protection of human health and the environment and comply with ARARs. Laws and regulations identified as ARARs are either applicable or, alternatively, relevant and appropriate. Other criteria that do not meet the definition of an ARAR may also be used to develop remedial objectives and are known as to-be-considered criteria (TBC).

Generally, where a chemical-specific ARAR exists, it provides the basis for the corresponding PRG; if more than one chemical-specific ARAR exists, the most stringent is generally used. The selected PRGs provide the basis for the RAOs and are used as a benchmark for use in the technology screening, alternative development and screening, and detailed evaluation of alternatives presented in the subsequent sections of the FS report. A detailed discussion of the PRGs development is included in Section 2.4 below.

The remedial action alternatives developed in Section 3 are required to attain applicable Federal, State of New Jersey and local environmental requirements. Technical requirements of ARARs must be met by the remedial action alternatives; however, Section 121(d) (4) of CERCLA allows selection of remedies that will not attain all ARARs provided one of the following conditions is satisfied: 1) the remedial action is an interim measure where the final remedy will attain the ARAR upon completion; 2) compliance with all ARARs will result in greater risk to human health and the environment than other options; 3) compliance is technically impracticable; 4) an alternative remedial action will attain the equivalent of the ARAR; 5) for State requirements, the State has not consistently applied the requirement in similar circumstances; or 6) compliance with the ARARs will not provide a balance between protecting public health, welfare, and the environment at the facility and the availability of funding for response at other facilities (fund balancing).

The primary contaminant of concern for the Puchack Well Field Site is hexavalent chromium in the groundwater. The chemical-specific ARARs for chromium contaminated groundwater include NJ Groundwater Quality Standards, Federal Primary Drinking Water Standards MCLs and NJ Primary Drinking Water Standards MCLs. The NJ Groundwater Quality Standard is set at 70 μg/L for total chromium, while the Federal and NJ MCLs are all set at 100 μg/L for total chromium.

The groundwater at the Puchack Site is also contaminated with VOCs. The RI results show that VOC contamination is present in areas well beyond the Site's chromium plume; VOC contamination of the groundwater is therefore a regional problem rather than specific to the Puchack Site. Municipal wells in the area have existing treatment facilities to remove VOCs from the extracted groundwater, and the State is directing investigations and clean ups at a number of source areas. In the PE report, remedial options for treatment of VOC contamination have also been evaluated, in addition to the treatment for chromium contamination. The evaluation results indicate that an additional large quantity of groundwater would need to be pumped in order to capture the VOC plumes. It therefore increases substantially the technical complexity and cost to the remedy. Given the above, this FS will only consider treatment of

extracted VOCs together with the chromium. VOC contamination will not be targeted for in situ treatment nor specifically extracted for treatment.

Several RAOs have been identified:

- Restore the chromium contaminated groundwater aquifer for future beneficial use.
- Prevent or minimize the migration of chromium in the groundwater to existing municipal well fields, or well fields potentially impacted in the future due to increased pumping rates.
- Prevent or minimize potential future human exposures including ingestion and dermal contact with chromium contaminated groundwater.

2.3 Potentially Applicable or Relevant and Appropriate Regulations, Guidelines, and Other Criteria

Potential ARARs are broken down into three groups:

- Chemical-specific ARARs
- Location-specific ARARs
- Action-specific ARARs

Additionally, TBC criteria are also evaluated. TBC criteria are not enforceable standards but may be technically or otherwise appropriate to consider in developing site- or media-specific RAOs or cleanup goals.

Each of these groups of ARARs and TBCs is described below. A summary of the potential ARARs and TBCs criteria is provided in Tables 2-1, 2-2, and 2-3.

2.3.1 Chemical-specific ARARs and TBCs

Chemical-specific ARARs are defined as those that specify achievement of a particular cleanup level for specific chemicals or classes of chemicals. These standards usually take the form of health- or risk-based numerical limits that restrict concentrations of various chemical substances to a specified level.

2.3.1.1 Federal Standards and Guidelines

Groundwater in the immediate vicinity of Puchack is currently used as a source of drinking water. Federal primary drinking water standards are considered to be relevant and appropriate because the groundwater is a source of drinking water.

Groundwater Standards and Regulations

- Resource Conservation and Recovery Act (RCRA) Groundwater Protection Standards and Maximum Concentration Limits (40 Code of Federal Regulations [CFR] 264, Subpart F).

Drinking Water Standards and Regulations

- National Primary Drinking Water Standards (40 CFR 141). Drinking water standards (MCLs and non-zero maximum contaminant level goals [MCLGs]) for the COPCs are provided in Table 2-4. Note that these MCLs and MCLGs are considered relevant and appropriate for groundwater which is a current or potential source of drinking water (CERCLA Section 300.430[e][2][i][B]).

- National Secondary Drinking Water Regulations (40 CFR 143). Federal secondary drinking water standards are considered as TBC criteria in the development of remedial alternatives. Federal secondary drinking water standards are based on aesthetic considerations rather than human-health considerations. As such, many of the secondary criteria relate to qualities of finished (treated) potable water (e.g., taste, color, turbidity) and are not applicable to groundwater or water sources.

2.3.1.2 New Jersey Standards and Guidelines

Groundwater in the immediate vicinity of Puchack is currently used as a source of drinking water; New Jersey chemical-specific standards and guidelines exist for the groundwater present at the Site.

Groundwater Standards and Regulations

- New Jersey Groundwater Quality Standards (N.J.A.C. 7:9-6). Used as the primarily basis for setting numerical standards for groundwater cleanups. The standards for the COPCs are included in Table 2-4.

Drinking Water Standards and Regulations

- New Jersey Safe Drinking Water Act (NJSDWA) Primary Drinking Water Standards (N.J.A.C. 7:10).

- State Secondary Drinking Water Regulations (N.J.A.C. 7:10-7)

2.3.2 Location-specific ARARs

Location-specific ARARs are those which are applicable or relevant and appropriate due to the location of the Site or area to be remediated. For Puchack, these consist of regulations applicable to wetlands, floodplains, historical places, archaeological significance, endangered species and wildlife habitats.

2.3.2.1 Federal Standards and Guidelines

Wetlands and Floodplain Standards and Regulations

- Statement on Procedures on Floodplain Management and Wetlands Protection (40 CFR 6).
- Floodplain Management Executive Order (EO 11988).
- Wetlands Executive Order (EO 11990).

Wildlife Habitat Protection Standards and Regulations

- Endangered Species Act (16 USC 1531 *et seq.*; 40 CFR 400).
- Fish and Wildlife Conservation Act (16 USC 2901 *et seq.*).
- Fish and Wildlife Coordination Act (16 USC 661).

Historic Preservation Standards and Regulations

- National Historic Preservation Act (16 USC 469 *et seq.*; 40 CFR 6301 ©.

2.3.2.2 New Jersey Standards and Guidelines

Wetlands and Floodplains Standards and Regulations

- New Jersey Flood Hazard Area Control Act (N.J.A.C. 7:13).
- New Jersey Freshwater Wetland Protection Act Rules (N.J.A.C. 7:7A).

Wildlife Habitat Protection Standards and Regulations

- Endangered and Non-game Species Conservation Act (N.J.S.A. 23:2A-1).
- Endangered Plant Species List Act (N.J.A.C. 7:5B).

Soil Erosion and Sediment Control and Noise Control

- Soil Erosion and Sediment Control (N.J.A.C. 16:25A).
- Noise Control (N.J.A.C. 7:29).

2.3.3 Action-specific ARARs and TBCs

Action-specific ARARs are those which are applicable or relevant and appropriate to particular remedial actions, technologies, or process options. These regulations do not define site cleanup levels but do affect the implementation of specific types of

remediation. For example, treatment, storage and disposal of waste will need to meet the requirements of Land Disposal Restrictions (LDRs) under the RCRA. These action-specific ARARs are considered in the screening and evaluation of various technologies and process options in subsequent sections of this report.

2.3.3.1 Federal Standards and Guidelines

General - Site Remediation

- RCRA: Identification and Listing of hazardous Waste (40 CFR 261); Standards Applicable to Generators of Hazardous Waste (40 CFR 262); Standards Applicable to Owners and Operators of Treatment, Storage, and Disposal Facilities (40 CFR 264).
- Occupational Safety and Health Administration (OSHA) Worker Protection (29 CFR 1904, 1910, 1926).

Discharge of Treated Groundwater

- National Pollution Discharge Elimination System (40 CFR 122, 125).
- Effluent Guidelines and Standards for the Point Source Category (40 CFR 414).
- Clean Water Act Water Quality Standards (40 CFR 131).
- Underground Injection Control Program (40 CFR 144, 146).

Disposal of Hazardous Waste

- Standards Applicable to Transporters of Hazardous Waste (40 CFR 263).
- Land Disposal Restrictions (40 CFR 268).
- Hazardous Materials Transportation Regulations (49 CFR 107, 171, 172, 177 to 179).

Off-Gas Management

- National Primary and Secondary Ambient Air Quality Standards (40 CFR 50)
- Standards of Performance for New Stationary Sources (40 CFR 60).
- National Emission Standards for Hazardous Air Pollutants (40 CFR 61).
- Control of Air Emissions from Superfund Air Strippers (OSWER Directive 9355.0-28)

2.3.3.2 New Jersey Standards and Guidelines

General - Site Remediation

- Technical Requirements for Site Remediation (N.J.A.C. 7:26E)
- Hazardous Waste Regulations (N.J.A.C. 7:26G-5, -8, -11)

Discharge of Treated Groundwater

- New Jersey Pollutant Discharge Elimination System (N.J.A.C. 7:14A)
- Surface Water Quality Criteria (N.J.A.C. 7:9B)

Disposal of Hazardous Waste

- Transportation of Hazardous Materials (N.J.A.C. 16:49)

Off-Gas Management

- Air Pollution Control - Permits and Certificates for Minor Facilities (N.J.A.C. 7:27 Subchapter 8)
- Air pollution Control - Ambient Air Quality Standards (N.J.A.C. 7:27 Subchapter 13)

2.4 Preliminary Remediation Goals

Both Federal and State chemical-specific ARARs were identified for groundwater. New Jersey groundwater quality standards are considered to be applicable to the remediation of groundwater contamination at the Puchack Site. Federal and State primary drinking water standards are considered to be relevant and appropriate for consideration in the remediation of the groundwater since the groundwater represents a source of potable water.

The PRG for chromium is identified in Table 2-4 and is derived primarily from NJ Groundwater Quality Standards, supplemented with the Federal and State Primary Drinking Water Standards when the Groundwater Quality Standards are not available. Site-specific risk-based criteria were not used to develop the PRGs for groundwater since promulgated standards exist for chromium. The PRG for chromium provides the basis for complying with the RAOs for groundwater described above. Additionally, the PRGs for 1,1-dichloroethene, tetrachloroethene, and trichloroethene, the three most prevalent chlorinated VOCs, are also included in Table 2-4. The PRGs for the chlorinated VOCs provide a basis for the treatment of extracted groundwater.

2.4.1 Area and Volume to be Remediated

An estimate was made of the quantity of chromium present in the groundwater at the Puchack Site. The estimate was determined based on the contaminant data presented in the RI Report that exceeded the chromium PRG of 70 µg/L. The aerial and vertical extent of the plume varies with depth. Chromium contamination in the Middle aquifer at SGL Chrome, which is discontinuous at this location, will be addressed as part of OU2. The total zone thickness of each saturated zone was used in calculating the quantity of contaminated groundwater (Appendix A). The Intermediate Sand plume has an areal extent of 3,400 ft long by 1,500 ft wide and covers an area of approximately 70 acres with a thickness of 20 feet. Using the average porosity of 0.316, this results in a volume of contaminated groundwater of 1.9×10^7 cubic feet (1.4×10^8 gallons). Based on the weighted average groundwater chromium concentrations calculated from the RI sampling data, the total mass of chromium in the Intermediate Sand is approximately 2,800 pounds (lbs). The Lower aquifer plume has an aerial extent of 2,800 ft long by 2,600 ft wide and covers an area of approximately 82 acres with a thickness of 90 feet. Using the average porosity of 0.286, this results in a volume of contaminated groundwater of 9.1×10^7 cubic feet (6.8×10^8 gallons). The total volume for both groundwater plumes is estimated to be 820 million gallons. Based on the weighted average groundwater chromium concentrations calculated from the RI sampling data, the total mass of chromium in the Lower aquifer is approximately 8,200 lbs.

2.5 General Response Actions

General response actions are broad remedial actions and are defined as actions which may satisfy the remedial action objectives and which characterize the range of remedial responses appropriate to the media of concern at the Site. General response actions applicable to this Site are described below.

2.5.1 No Action

The National Contingency Plan (NCP - 40 CFR Part 300.430[e][6]) requires that a No Action response action be considered in the detailed analysis of alternatives to provide a baseline from which other alternatives can be evaluated. Under the No Action response action, the current status of the Site would be unchanged and no actions would be taken to reduce the potential for exposure to contamination.

2.5.2 Institutional Controls

Institutional controls are methods taken to prevent or limit exposure to contaminated groundwater. Institutional controls may include administrative controls such as deed restrictions (e.g., prohibition of intrusive activities), Classification Exemption Area (CEA) (e.g., notification that groundwater quality standards are not being met), prohibition of new well construction, or long-term groundwater monitoring.

2.5.3 Monitored Natural Attenuation

Monitored natural attenuation is a response action by which the volume and toxicity of contaminants are reduced by naturally occurring processes in soil and

groundwater. Processes which reduce contamination levels in groundwater include dilution, volatilization, adsorption, biodegradation, and chemical reactions with other subsurface constituents. Extensive site modeling and monitoring are performed as part of the monitored natural attenuation response action to demonstrate that contaminants do not represent significant risk and that degradation is occurring.

2.5.4 Containment

Containment technologies consist of measures which physically isolate contaminants to eliminate routes of exposure or to reduce the rate of migration. Containment technologies may reduce contaminant movement, but do not involve treatment to reduce the toxicity or volume of the contaminants at the Site. These technologies require long-term monitoring to determine whether containment measures are performing successfully. Given the large size of the plume, the multiple and relatively deep aquifer layers impacted, and the high permeabilities at the Site, the groundwater containment option alone was not considered. However, the combination of a slurry wall or grout curtain with a groundwater extraction system may improve the efficiency of the groundwater extraction system by segregating uncontaminated groundwater from contaminated groundwater; or combination of slurry wall or grout curtain with a permeable barrier wall would reduce the treatment cost of the alternative.

2.5.5 In Situ Treatment

An in situ treatment response action provides reduction or elimination of toxicity, mobility, or volume of contaminants without extracting the contaminated groundwater from the subsurface. During the treatment process, the contaminants may be chemically altered to a less toxic form, isolated, or completely destroyed. In situ treatment can be accomplished through biological or physical/chemical means.

2.5.6 Collection/Extraction

Extraction technologies for groundwater typically involve extraction of the contaminant plume using interceptor trenches or extraction wells. This method reduces the mobility of the contaminants through physical removal by changing the hydraulic gradient in the surrounding area. The selection of an appropriate groundwater collection system depends on the objectives of the remedial action, the depth of contamination, and the geologic and hydrogeologic characteristics of the aquifer. For the Puchack Well Field Site, the use of extraction wells were considered given the aquifer depth and the high pumping rates achievable for this aquifer system. Extraction technologies generally are used in combination with treatment technologies.

2.5.7 Ex Situ Treatment

This category of response action is conducted to reduce the toxicity, mobility, and/or volume (TMV) of contaminants by physical, chemical, or biological processes. Treatment systems for the Puchack Well Field Site would consist of one or more plants to handle the expected large flow rates and areal extent of the contaminant plume.

Treatment performed to reduce toxicity or mobility includes methods to destroy or modify the properties of the chemical to render it less harmful. Treatment to reduce volume includes concentrating contaminants. The use of treatment technologies to achieve RAOs is favored by CERCLA, unless site conditions limit their application. Treatment technologies generally afford a higher degree of protection to public health and the environment.

2.5.8 Disposal/ Discharge

Discharge technologies are necessary to release extracted and treated groundwater back to the environment. They include injection wells, discharge to recharge basins (including infiltration galleries), discharge to publicly owned treatment works (POTW), discharge to surface water (including discharge to storm sewer with conveyance to surface water), and discharge for reuse in the public water system. Discharge technologies are needed as an end-point for extraction and treatment of contaminated groundwater.

2.6 Identification and Screening of Technology Types and Process Options

This section provides a brief description and evaluation of the remedial technologies that were identified in the PE report, as well as technologies that were identified subsequent to the PE report. The PE report has identified remedial technologies using various databases, technical reports, and publications. Of particular note are the EPA Hazardous Waste Clean-up Information (CLU-IN) Web Site, EPA Remediation and Characterization Innovative Technologies (EPA REACH IT) Database, Federal Remediation Technologies Roundtable (FRTR) Web Site, and Remediation Technologies Network Remediation Information Management System (RIMS) Database. These resources were used to identify a number of potentially applicable remedial technologies or process options for each of the GRAs identified in Section 2.5. These technology types and process options were initially screened based on technical implementability, and documented in Table 2-5. The technology types and process options that passed this initial screening step were then evaluated on the basis of three CERCLA evaluation criteria: effectiveness, implementability, and relative cost. The comments on the remedial options in the PE report by the NJDEP have also been taken into consideration for this FS. Brief definitions of Effectiveness, Implementability, and Relative Cost, as they apply to the screening process are provided below.

- Effectiveness - This evaluation criteria focuses on: 1) the effectiveness in extracting, treating and/or handling by other means (e.g., in situ treatment or natural attenuation) the estimated volumes of contaminated groundwater, and the ability for meeting the remediation goals; 2) the potential impacts to human health and the environment during construction and implementation phases; and 3) how proven and reliable the process options are expected to be with respect to the contaminants and conditions at the Site.

- Implementability - This evaluation criteria includes: 1) the technical and administrative feasibility of implementing the remedial system components; and 2) the amount of space needed for treatment and disposal facilities, piping and discharge runs, the availability of space, accessibility, and available vendors.
- Relative Cost - Relative cost will play a limited role in evaluating the process options. On the basis of relative capital and operation and maintenance (O&M) costs, each process is evaluated as high, medium, or low compared to other processes within the same or comparable technology type. Typically, only order-of-magnitude costs are developed; however, where vendor quotes or more detailed costs are available, these costs have been included. Both capital as well as O&M costs are considered. For treatment technologies, O&M costs were assumed to include all costs associated with the treatment other than capital costs. Technologies or process options which are significantly more costly without any offsetting benefit over comparable options are screened out at this point.

The EPA guidance document (EPA 1988) recommends that this evaluation focus on the Effectiveness criterion, with less emphasis directed at the Implementability and Relative Cost criteria. This process assisted with identifying the most appropriate remedial options to be considered and combined into remedial alternatives in the FS Report. On the basis of this evaluation, the most promising of these technologies were selected as representative process options and retained for consideration in the development of treatment alternatives. A summary of the screening process is presented in Table 2-6.

2.6.1 No Action

Under the No Action response action, no remedial actions will be conducted to reduce exposure to or the TMV of the contaminated groundwater.

Effectiveness - The effectiveness of No Action will be low because the RAOs will not be met.

Implementability - The No Action general response action is easily implemented from a technical perspective, and no significant administrative difficulties are expected.

Relative Cost - There is no cost for this response action.

Conclusion - No Action is retained as a baseline for comparison to other alternatives, as required by the NCP.

2.6.2 Institutional Controls

Institutional controls do not reduce the TMV of contamination, but can be implemented to reduce the probability of exposure to contaminated groundwater. Institutional controls consist of administrative actions which control use of the Site (e.g., deed restrictions and classification exemption area [CEA] that restrict site access during remediation), or conduct long-term monitoring of groundwater in the area. Institutional controls are discussed in details below.

2.6.2.1 Deed Restrictions

Deed restrictions are regulatory actions which are used to prevent certain types of uses for areas at the Site where direct exposure to groundwater (dermal or ingestion) or inhalation of contaminants partitioned from groundwater represents an unacceptable human health risk. Deed restrictions may be used to prevent installation of drinking water wells and construction of ponds fed by groundwater. In addition, deed restrictions may be used to limit irrigation above designated source areas and limit areas of new construction.

Effectiveness - Deed restrictions may effectively meet RAOs from a human health standpoint through restriction of future site uses or activities which may result in direct contact with contaminated groundwater. The effectiveness of deed restrictions is dependent on proper enforcement. Deed restrictions, however, will not reduce the migration and the associated environmental impact of the contaminant plume.

Implementability - Deed restrictions limit the use of contaminated property and hold owner(s) to the regulatory/statutory requirements for cleanup. Implementation would be difficult because the chromium plume covers a large subsurface area and there would be objections from the property owners. Deed restrictions may be difficult to enforce over the long term and may limit future land use options. However, deed restrictions may be implemented, in addition to remediation activities, as a protective measure to prevent exposure to contaminants during remediation.

Relative Cost - The cost to implement deed restrictions is high compared to costs for CEA, described below.

Conclusion - Deed restrictions is eliminated from further evaluation because CEA could achieve the same results with less administrative difficulty.

2.6.2.2 Classification Exemption Area

A CEA is an area designated by the state as a part of an aquifer that is currently impacted above an applicable groundwater quality standard. A CEA designation requires that interested parties be notified that the area does not meet groundwater quality standards and is enforced until contaminant concentrations within the designated area have decreased to the applicable groundwater quality standard.

Effectiveness - A CEA can effectively protect human health by preventing direct contact and consumption of contaminated groundwater. This is typically achieved in conjunction with permit controls, for example, the denial of a permit for installation of a groundwater pumping well within the affected area. However, the effectiveness of a CEA is dependent on proper enforcement of deed restrictions. A CEA will not reduce the migration and associated environmental impact of the contaminant plume.

Implementability - A CEA is issued by the state. There are no technical or administrative difficulties to implement a CEA. A CEA may be difficult to enforce

over the long term. However, a CEA may be implemented, in addition to remediation activities, as a protective measure to prevent exposure to contaminants during remediation.

Cost - The cost to implement a CEA is low compared to costs for deed restrictions.
Conclusion - A CEA is retained for further evaluation.

2.6.2.3 Long-term Monitoring

Long-term monitoring includes periodic sampling and analysis of groundwater samples. This program would provide an indication of the movement of the contaminants or of the progress of remedial activities.

Effectiveness - Long-term monitoring alone would not be effective in meeting the RAOs. It would not alter the effects of the contamination on human health and the environment. Monitoring is a proven and reliable process for the intended purpose.

Implementability - Long-term monitoring could be easily implemented. All monitoring wells are easily accessible for sample collection. A long-term commitment would be required to implement a long-term monitoring program.

Relative Cost - Long-term monitoring involves low capital and medium O&M cost.

Conclusion - Long-term monitoring is retained for further consideration.

2.6.3 Monitored Natural Attenuation

Monitored natural attenuation (MNA) refers to the use of natural attenuation processes to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by other more active methods. The MNA processes that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, TMV, or concentration of contaminants in groundwater. These in situ processes are described in the EPA guidance document *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (EPA 1999) and include: biodegradation, dispersion, dilution, sorption, volatilization, chemical or biological stabilization, transformation, or destruction of contaminants. At the Puchack Site, hexavalent chromium may be reduced to the less toxic and less mobile trivalent chromium form by natural reductants, which precipitates as a solid iron/chromium phase that is stable under the normal site conditions.

Sorption and oxidation-reduction reactions are the dominant mechanisms responsible for the reduction of mobility, toxicity, or bioavailability of inorganic contaminants. The process controlling the migration of chromium further offsite is expected to be natural reduction processes including the use of available iron and manganese in the groundwater and selected sediments to reduce the hexavalent chromium to the trivalent state. Based on a review of the RI data, these natural reducing agents are

present at relatively high levels in areas surrounding the chromium plume, but have become depleted within the main plume area. As a result, the further conversion of hexavalent chromium to trivalent chromium is not expected to occur in appreciable quantities or to a significant degree within the chromium contaminated areas. A bench scale treatability study was performed to evaluate in situ technologies for remediation of hexavalent chromium in groundwater at the Puchack Site, and an Interim Progress Report has been prepared (PNNL 2005). The study demonstrated that chromium reduction by natural Puchack aquifer sediment can occur in the area downgradient of the chromium plume where the reductive capacity of the aquifer has not been depleted. The study estimated that 63 pore volumes of groundwater containing high chromium concentrations (2 mg/L) would be reduced by natural reductive processes.

Effectiveness - MNA is an effective remediation approach for sites that have been demonstrated to be utilizing natural mechanisms to minimize or prevent the further migration of groundwater contamination; however it is acceptable only if the contaminant concentration reaches the PRG in a reasonable time frame (i.e., 20 years). Although the natural reducing agents have been depleted in the chromium contaminant zone, reducing agents are present outside of the plume area that would reduce the hexavalent chromium as it migrates outside of the existing area, thereby becoming permanently fixed as iron/chromium hydroxide precipitates and reducing the toxicity and mobility of the chromium. Once converted to trivalent chromium, the process is not reversible under normal environmental conditions, as demonstrated by the results of the treatability study.

Implementability - MNA would be moderately easy to implement. The installation of additional wells may be necessary to provide more precise information on contaminant migration, and to demonstrate that the plume has become stable.

The administrative feasibility of implementing this option is expected to be difficult, due to the need to demonstrate that natural attenuation processes are sufficiently protective of the downgradient wellfields. There would be very minor impact to human health and the environment during the installation of additional monitoring wells if deemed necessary, and during periodic monitoring events.

Cost - The capital cost of installing additional monitoring wells would be low. The long term costs of collecting periodic groundwater samples is expected to be low. As a result, the total cost would be low.

Conclusion - MNA is retained for further consideration.

2.6.4 Containment

Containment technologies are implemented to reduce contaminant mobility but do not directly impact contaminant toxicity or volume. However, by reducing contaminant mobility, contaminant toxicity may be indirectly reduced by reducing or eliminating potential routes of exposure. Containment technologies are typically

accompanied by long-term groundwater monitoring to verify that the containment measures have continued to be effective.

Vertical barrier walls were identified as containment technologies with potential applicability at the Site. Vertical barriers can be used to reduce or prevent migration of contaminated groundwater from contaminant source areas. Most vertical barriers are limited by depth and will have limited applicability at the Site where contamination has been detected at depth of 100 feet or more below ground surface (bgs). In addition, these barriers may be difficult to implement due to the presence of clay layers, existing buildings, and below ground utilities. The specific types of vertical barriers which are potentially applicable to the Site are described below and include slurry walls, synthetic membrane barriers, grout curtains, and sheet pile barriers.

2.6.4.1 Slurry Wall

Slurry walls are constructed by pumping low permeability materials in slurry form into an excavated trench. The slurry is typically composed of either a soil-bentonite mixture or a cement-bentonite mixture. The slurry is used to support the walls of the trench and to create a low permeability zone to reduce groundwater flow. Slurry walls are typically keyed into a low permeability layer such as clay or bedrock to minimize leakage beneath the wall. Slurry walls are typically placed at depths less than 30 to 40 feet bgs due to practical trenching limitations. However, using modified trenching equipment (e.g., clamshell bucket), depths up to 100 feet bgs can be achieved.

Effectiveness - Slurry walls can be effective in containing contaminated groundwater or diverting clean groundwater flow around a contaminant source. However, slurry walls are not effective in reducing contaminant concentrations if implemented alone because the slurry wall neither removes nor destroys contaminants. Some types of slurry walls may deteriorate in the presence of certain organic contaminants and become less effective over time.

Implementability - Slurry walls are implementable at the Site, however, slurry wall construction is limited to 100 feet bgs, and can not be implemented to the required depth. The Intermediate Sand is located 130 to 150 feet bgs, and the Lower aquifer is located 160 to 250 feet bgs. Therefore, the chromium plumes in these two intervals could not be contained by slurry wall technology.

Cost - Installation and material costs are estimated to be $10 per square foot (cross-section) of soil/bentonite slurry wall and $20 per square foot (cross-section) of cement/bentonite slurry wall.

Conclusion - Slurry walls are eliminated from further consideration because the chromium contamination is primarily located over 130 feet bgs.

2.6.4.2 Synthetic Membrane Barrier

Synthetic membrane barriers are interlocking sheets of geomembrane placed vertically in the ground to form a barrier. Typically, this barrier is constructed by extending the geomembrane along the wall of an excavated trench from the ground surface to a confining layer. The trench is then backfilled with the excavated material. In some cases, the membrane barrier can be installed using vibratory methods instead of trench construction. A synthetic membrane barrier can be used without a slurry wall or can be installed vertically within a slurry wall to supplement the barrier. A synthetic membrane barrier is typically installed at depths less than 30 to 40 feet bgs (due to practical trenching limitations).

Effectiveness - The effectiveness of synthetic membrane barriers is the same as discussed previously for slurry walls. Some types of synthetic membranes may deteriorate in the presence of certain organic contaminants and become less effective over time.

Implementability - Synthetic membrane barriers are not implementable at this site, as the depth of contamination is deeper than the practical limits of this technology.

Cost - Installation and material costs are estimated to be $15 to $20 per square foot of synthetic membrane barrier using conventional trenching methods.

Conclusion - Synthetic membrane barriers are eliminated from further consideration because the chromium contamination is primarily located over a 130 feet bgs.

2.6.4.3 Grout Curtain Barrier

A grout curtain is formed by injecting grout, either particulate (such as Portland cement) or chemical (such as sodium silicate), into the ground through well points. The grout is typically injected through pipes set in a pattern of multiple adjacent lines with staggered well point spacing between lines. When using grout curtains, it may be difficult to verify whether or not a continuous curtain has been formed; but closer spacing of injection points will improve the likelihood that the curtain is continuous. However, grout curtain installation by injection is not subject to the depth limitations associated with the trenching or vibratory installation methods used for other vertical barriers, and, therefore, may be the only vertical barrier that can contain contamination at depth. For use at the Site, a grout curtain would be installed from the top of Intermediate Sand to the top of the bedrock, to contain chromium contamination present in the Intermediate Sand and Lower aquifer.

Effectiveness - The effectiveness of grout curtains is similar to slurry walls. However, grout curtains may be less effective than slurry walls due to difficulties in achieving complete overlap of grout, particularly at depth. Because grout curtain installation is not subject to depth limitations associated with other vertical barriers, grout curtains may contain the deep contamination found at this Site.

Implementability - Grout curtains are implementable, and resources and materials necessary for their construction are available.

Cost - Installation and material costs are estimated to be $15 to $100 per square foot of grout curtain and as such, grout curtains are the most expensive of the vertical barriers considered.

Conclusion - Grout curtains are retained for further evaluation for potential use with the in situ treatment technologies.

2.6.4.4 Sheet Pile Barrier

Sheet pile barriers are typically constructed by driving or vibrating sections of steel sheet piling into the ground. The practical depth limitation for driving sheet pile barriers is about 75 feet bgs. Each sheet pile section is interlocked at its edges and the void space between sheet piles is tremie grouted to minimize water from leaking through the piling. Sheet piles are usually keyed into a confining layer.

Effectiveness - The effectiveness of sheet pile barriers is the same as discussed previously for slurry walls. Sheet pile barriers may deteriorate in the presence of acidic or alkaline solutions, as well as some organic contaminants, and become less effective over time.

Implementability - Sheet pile barriers are not implementable at this site, as the depth of contamination is deeper than the practical limits of this technology.

Cost - Installation and material costs are estimated to be $15 to $30 per square foot of sheet piling.

Conclusion - Sheet pile barriers are eliminated from further consideration due to the chromium contamination is primarily located over 130 feet bgs.

2.6.5 In Situ Treatment

In situ treatment technologies are designed to destroy or modify contaminants in groundwater without actually removing the groundwater from the subsurface. Avoiding the need to convey groundwater to the surface for treatment can result in significant cost savings. Several in situ treatment technologies were identified as potentially applicable technologies at the Site. These technologies are discussed and evaluated below.

2.6.5.1 Geochemical Fixation

In situ geochemical fixation is a process that reduces hexavalent chromium in groundwater to trivalent chromium, resulting in an iron/chromium precipitate which is permanently immobilized under site conditions. The technology is based upon the concept of extracting contaminated groundwater and treating it above ground, followed by reinjection of the treated groundwater into the aquifer. The reinjected

groundwater is dosed with reductant to further treat any residual hexavalent chromium contamination remaining in the interstitial pore spaces of the aquifer. Alternatively, this technology can be implemented without extracting contaminated groundwater, and by injecting non-contaminated water dosed with reductant. Reductants added to the groundwater for in situ treatment can include ferrous sulfate or chloride, sodium metabisulfite, calcium polysulfide, sodium dithionite or other similar compounds, which remain mobile after injection and can migrate into the contaminated groundwater plume. Sodium metabisulfite and calcium metabisulfide have been used effectively at other chromium contaminated sites. This technique can reduce the hexavalent chromium concentrations in groundwater to levels below the drinking water standard at a fraction of the aquifer pore volume throughput required by typical pump-and-treat methods.

The success of this technology depends on the ability of the applied reductant to reduce hexavalent chromium in groundwater to trivalent chromium, and on the ability to form an immobile chromium(III) precipitate. The total chromium concentration in the aquifer system is not decreased, but chromium is precipitated and fixed (immobilized) onto aquifer solids as trivalent chromium so that it is not available for transport in the groundwater. Sodium metabisulfite injected into the subsurface acts as a reductant. In general, sulfur compounds such as sulfide and sulfite reduce hexavalent chromium.

In the presence of excess sulfite, the reduction of hexavalent chromium follows the reaction (EPA 2000):

$$6H^+ + 2HCrO_4^- + 4HSO_3^-\ (\text{excess}) \Rightarrow 2Cr^{+3} + 2SO_4^{-2} + S_2O_5^{-2} + 6H_2O$$

The metabisulfite ($S_2O_5^{-2}$) formed by the above reaction can then reduce Fe(III) to Fe(II), if it is present. This situation allows for reduction of hexavalent chromium by Fe(II). In the presence of excess hexavalent chromium, the reduction to trivalent chromium by sulfite follows the reaction:

$$5H^+ + 2HCrO_4^-\ (\text{excess}) + 3HSO_3^- \Rightarrow 2Cr^{+3} + 3SO_4^{-2} + 5H_2O$$

Therefore, the process of using sodium metabisulfite reduces the hexavalent chromium to trivalent chromium, in situ, resulting in a chromium precipitate provided that the pH is between 4 and 13.

As the water dosed with the reducing agent migrates through the contaminant plume, hexavalent chromium is reduced to trivalent chromium, its less soluble form. The zone of contamination is swept with the reducing agent, leaving behind an increasingly larger clean water zone. Alternatively, injection can occur in the high concentration areas (source zones) to effect a more rapid remediation. In situ geochemical fixation can be applied to source zones, the concentrated or active zone, or the dilute or neutralized zone of the contaminant plume.

Application of this technology to the Puchack Well Field Site would include multiple injection wells to deliver the reductant into the aquifer. The configuration and quantities of the injection wells would be determined through groundwater simulations and treatability studies.

Effectiveness

The effectiveness of this treatment process is proven at other sites. At the site of a former paper mill on the Delaware River, the hexavalent chromium concentration in the perched aquifer was 85,000 µg/L. After in situ treatment by reduction and precipitation by injection of ferrous sulfate dosed groundwater, the hexavalent chromium concentrations were reduced to 50 µg/L. The project began in 1995 and was completed in 1997. At another site, approximately 6,000 pounds of hexavalent chromium were released into the groundwater. A groundwater pump and treat system maintained hydraulic control of the plume, treated nearly 9 million gallons of water, and recovered approximately half of the hexavalent chromium. It was estimated that recovery of the remaining contamination would have required another ten years of treatment. The treatment approach at that site was switched to in situ treatment using sodium metabisulfite. In situ treatment from February 1998 to October 1999 resulted in a reduction in plume size and mass of dissolved chromium in groundwater by approximately 98 percent. This significant reduction in hexavalent chromium in the groundwater was accomplished in less than two years, following seven years of conventional groundwater extraction and treatment.

This process would be cost effective if favorable site conditions exist. According to the EPA Technical Resource Guide titled *In Situ Treatment of Soil and Groundwater Contaminated with Chromium* (EPA 2000), in situ treatment can remediate sites in a shorter duration (up to 75 percent reduction) and at less cost, when compared to ex situ treatment process. Other advantages include:

- Better hydraulic control is achieved by the reinjection of treated water around the contaminated plume, forming a ridge of treated water.
- Since water is reinjected, the same gradient can be established at lower pumping rates, avoiding stranding chromium in dewatered portions of the previously saturated aquifer.
- In situ reduction of residual hexavalent chromium in interstitial void spaces can be achieved.
- The amount of treatment plant sludges for disposal is reduced since more hexavalent chromium is reduced and precipitated in situ.
- The surface discharge of treated water is reduced since water is reinjected.

The limitations of this in situ treatment technology include:

- Aquifer materials must have the ability to permanently affix trivalent chromium.
- Reduced trivalent chromium could become re-oxidized to hexavalent chromium under certain conditions (e.g., presence of manganese dioxide); however, according to the guidance document (EPA 2000), the re-oxidizing of trivalent chromium to hexavalent chromium has not been observed in the field.

Chromium(III) precipitates are extremely difficult to oxidize and remobilize under almost all conditions.

- Regulatory approval would be required for reinjection of pumped and treated groundwater.
- Aquifer material heterogeneities make design and treatment more difficult. Pilot studies would aid in developing the design parameters.
- Aquifer solids must be porous to water flow. The aquifers at the Puchack Site have high permeabilities.
- Ferrous sulfate-based reductants may result in iron precipitation and clogging of aquifer pore spaces. Proper design and injection rate would alleviate this problem.
- Excess reductant or reductant byproducts may have to be removed if undesirable or if it exceeds groundwater MCLs. Pilot studies and monitoring during operation would mitigate this problem.

The effectiveness of this in situ treatment approach would need to be evaluated by performing treatability studies. This would provide site specific information and predict how well the aquifer would respond to the injection of a reducing agent to treat hexavalent chromium. Of particular importance is to evaluate the ability of the reducing agent to migrate into the interstitial spaces within the aquifer material, and react with the chromium contamination.

Implementability - Injection well installation and piping could be completed with conventional equipment that is readily available in the area. Finding space for the injection wells and routing the piping might prove to be difficult. This technology would be difficult to implement due to the relatively large plume size located in a highly developed area. The technology could be combined with MNA by targeting only highly contaminated areas for treatment thereby reducing the cost and access issues.

The administrative feasibility of implementing this option is dependent on the locations selected for the treatment plant. Low short term impacts are anticipated during construction of the in situ geochemical fixation components, which would involve standard construction methods.

Cost - If this technology is implemented using groundwater extraction, treatment and reinjection, the capital costs associated with installing the extraction wells and piping are expected to be moderately expensive, but less expensive than traditional extraction and treatment using reduction and precipitation processes. The O&M costs should be moderately expensive to maintain the extraction pumps and operate the smaller treatment system. As a result, the total cost is expected to be moderate.

If this technology is implemented using only injection, the capital costs associated with installing the injection wells is comparable to traditional in situ treatment methods. The total cost of in situ treatment is expected to be moderate.

Conclusion - In situ geochemical fixation is retained for further consideration.

2.6.5.2 Permeable Reactive Barrier

Permeable Reactive Barriers (PRBs) provide in situ treatment of groundwater and are designed as preferential conduits for contaminated groundwater flow. These reactive barriers differ from highly impermeable barriers, such as grouts, slurries, or sheet pilings, which restrict the movement of the groundwater plume. PRBs can be installed as permanent, semi-permanent, or replaceable units across the flow path of a contaminant plume and act as a treatment wall. Natural hydraulic gradients transport contaminants through the strategically placed reactive media. When the contaminated groundwater passes through the reactive zone of the barrier, the contaminants are either immobilized or chemically transformed to a more desirable state. In the case of hexavalent chromium, it is reduced to trivalent chromium and immobilized by precipitation onto reactive media or aquifer solids. PRBs are not currently used to directly remediate contaminant source areas, only to intercept and treat contaminant plumes.

PRBs are installed downgradient of a source zone, intersecting the contaminated groundwater flow. They can be installed with trenching, if the targeted portion of the aquifer is shallow and surface structures do not interfere with access. They can also be installed by well injection. Given the relatively significant depth of the contaminant zone at the Puchack Well Field Site of up to 250 ft bgs for the Lower aquifer, the use of trenching would not be technically feasible. Placement by injection wells would be the only option. Injection through standard vertical wells is the least expensive injection option but horizontal borings could be installed beneath existing structures and would create a more uniform reactive zone. This is more difficult to achieve through vertical wells. Environmental impacts from treatment wall installation, as well as maintenance, may be less than with other technologies due to the placement of all treatment materials underground with minimal disturbance to surface activities.

A bench scale treatability study was performed to evaluate in situ technologies for remediation of hexavalent chromium in groundwater at the Puchack Site, and an Interim Progress Report has been prepared (PNNL 2005). The study investigated the use of sodium dithionite ($Na_2S_2O_4$) to chemically reduce hexavalent chromium to trivalent chromium which is the insoluble form. The abiotic reduction of ferric oxides to create a reduced zone is also referred to in situ redox manipulation, or ISRM. This technology has also been successfully demonstrated to treat chromium contaminated groundwater in field tests at the Hanford Site in Washington State, and at the Frontier Hard Chrome Site in Vancouver, Washington. In both cases, hexavalent chromium was reduced and immobilized to below detection limits.

Sodium dithionite is a strong reducing agent that reacts with iron naturally present in the aquifer which subsequently reacts to reduce hexavalent chromium to trivalent chromium. The following reaction describes the reduction of ferric iron by sodium dithionite (PNNL 2005):

$$S_2O_4^{-2} + 2Fe^{3+} + 2H_2O \Rightarrow 2Fe^{2+} + 2SO_3^{-2} + 4H^+$$

The ferrous iron produced then reacts with hexavalent chromium to form trivalent chromium according to the reaction:

$$CrO_4^{2-} + 3Fe^{2+} + 4H_2O \Rightarrow Cr(OH)_3 + 3Fe^{3+} + 5OH^-$$

The treatability study determined that the reductive capacity of the aquifer to reduce and immobilize chromium could be increased significantly by the addition of sodium dithionite into the system. The study estimated that 63 pore volumes of groundwater containing high chromium concentrations (2 mg/L) would be reduced by natural reductive processes, and that through the additional of dithionite, the natural reduction capacity longevity in the treatment zone would be increased to 355 pore volumes.

Effectiveness - Due to uncertainties in the structure of the subsurface geology, pilot-scale testing would need to be conducted to verify the effectiveness of the chosen reductant. Of particular importance is to evaluate whether the contaminated groundwater effectively migrates through the reducing agent and accesses the reactive sites to reduce the chromium contamination. Also, blockage of pore space with precipitated chromium (in trivalent chromium form) could lead to hydraulic flow problems over time.

Implementability - This technology would be difficult to implement due to the very long plume width requiring treatment. Also, the general site area is highly developed and would likely be difficult to inject the reactive material in a continuous line, thereby allowing the potential for hexavalent chromium to migrate further downgradient. The technology could be combined with MNA by targeting only highly contaminated areas for installation of the PRB, thereby reducing the cost and access issues.

Low impact to human health and the environment are anticipated during construction of the reactive wall, and would involve standard construction methods. During operation, very low impact to nearby businesses and residences is anticipated.

Cost - The capital cost of injecting the reactive material to create a permeable reactive barrier is expected to be moderately expensive due to the cost for drilling boreholes for injection along the downgradient edge of the plume. The O&M costs would be low given that very little follow up work would be required after installation. As a result, the total cost is expected to be moderate to high.

Conclusion - PRB is retained for further consideration.

2.6.6 Collection/Extraction Processes

The Puchack Well Field Site lies within the Potomac-Raritan-Magothy (PRM) aquifer system. The PRM aquifer system is a high yielding formation with several stratigraphic layers (see Figures 1-3 and 1-4). The chromium contamination at the Puchack Well Field Site is located primarily in the Middle, Intermediate Sand and Lower aquifers. The RI data indicates that the highest concentrations of chromium

contamination are present in the Middle aquifer near the SGL Chrome site. The chromium contamination in the Intermediate Sand and Lower aquifer is more widespread but at lower concentrations than in the Middle aquifer, which will be remediated under OU2. The remediation for OU1 will concentrate on the chromium groundwater plumes in the Intermediate Sand and Lower aquifer. In addition to the chromium contamination, VOCs were detected in the three aquifers. The VOC contamination is more widespread, with multiple sources. There are municipal wells surrounding the Puchack Well Field, with the closest wells being the Morris/Delair and Delaware Garden well fields (see Figure 1-2).

Groundwater extraction technologies involve the active manipulation and management of groundwater prior to subsequent treatment and/or disposal. Extraction technologies are utilized to remove the contaminated groundwater from the aquifer and to physically prevent or reduce contaminant plume migration. The selection of an appropriate groundwater extraction system depends on the depth of contamination and the hydrogeologic characteristics of the aquifer. Extraction wells are typically used for sandy aquifers, while interceptor trenches are more suitable for shallow, low yielding silty aquifers. Due to the very high permeability and relatively deep PRM aquifers, only extraction wells were considered for groundwater collection.

Groundwater extraction using multiple extraction wells placed within each contaminated aquifer has been evaluated. As part of the Puchack remediation efforts, the USGS has developed an area-wide groundwater computer model to better understand the complex site hydrology and geochemistry and to simulate remediation options. This three-dimensional model of the Pennsauken-Camden area represents a more detailed, smaller area version of a larger USGS regional model of the Camden area. The Puchack area model provides additional vertical detail, including a new intermediate layer that was identified during the RI field effort. This enhancement is important because this layer may provide a conduit for a significant portion of the Puchack chromium plume.

The Puchack area model consists of a MODFLOW based groundwater flow model, developed by USGS. Mass transport simulation modeling for plume representation has not been developed yet. Flow model calibration was performed using available water level and pumping data, and was then refined using an expanded database. Groundwater extraction scenarios were developed and evaluated, using the groundwater flow simulation model as the means for testing effectiveness and predicting impacts on the aquifer system. The most important criteria for development and assessment of the scenarios were as follows:

- Attempt to minimize the duration and volume of remediation pumping.
- Similarly attempt to minimize the number of pumping wells, re-injection/ recharge facilities, treatment plants, and lengths of piping.
- Avoid pipeline crossings of major roads and railroad tracks.

Note that none of the scenarios included pumping of any of the existing Puchack water supply wells as "plume control" wells. This is because the chromium plume

has migrated too far away for these wells to be effective control points. In addition, the Puchack well field is too close to the Morris and Del Air well fields. Mutual interference would be so significant that the Puchack wells would have to be pumped at inordinately high rates to control the plume.

As part of the PE effort, the USGS performed groundwater modeling simulations for six pumping configurations, with varied extraction well locations and pumping rates. The various simulations are described in the PE report. Additional model simulations for 4 pumping and 3 MNA configurations were conducted for the FS (see Appendix B). The pumping scenarios were developed to estimate the placement and numbers of extraction wells, as well as the pumping rates necessary to capture the chromium plume and prevent further downgradient migration. This testing eliminated sub-optimum alternatives and provided the basis for refining the scenarios.

Generally, the scenarios were configured, based on certain assumptions, such that they would capture the chromium plume within a certain time frame. The scenario includes the following basic assumptions:

- Puchack Well Field is not in operation.
- Morris Well Field is pumping at 12 million gallons per day (mgd).
- Treated water is not re-injected or recharged.
- Other municipal wells are operated in their current capacities.

In order to test the effectiveness of the extraction scenarios, the basic assumptions were changed to simulate the impacts on the extraction scenarios. The following variations were simulated for the scenario:

- Morris Well Field pumping would be increased to 20 mgd.
- Delaware Garden Well Field is not in operation.
- Treated water would be recharged using injection wells or recharge basins.

The model has not simulated the groundwater cleanup time. Travel time for chromium particles to reach the extraction wells was simulated. The particle travel time should not be considered as cleanup time, but rather is to serve as a surrogate for comparing time required to flush out the contaminated groundwater and the effectiveness of plume capture. While the maximum travel times for the chromium particles to reach the extraction wells were over 30 years for many of the scenarios, the main plume area would require much less time to reach the extraction wells. As a result, capture time for the main plume area (e.g., 95 percent of particles) is a better indicator for plume capture.

Based on the USGS modeling effort for the FS, scenario EX-I was selected as a representative process option for the FS.

2.6.6.1 Groundwater Extraction using Modeling Scenario EX-I

The EX-I scenario includes five extraction wells located in the Intermediate Sand with one pumping at 150 gallons per minute (gpm), one at 200 gpm, one at 350 gpm, and

two at 400 gpm. One extraction well would be installed in the Middle aquifer pumping at 25 gpm. All Intermediate Sand extraction wells would be located north of the railroad, except for the Middle aquifer pumping well. No wells would be placed in the Lower aquifer. Contaminants in the Lower aquifer would be drawn up into the Intermediate Sand and captured by the 5 extraction wells in this zone. The total quantity of groundwater extracted would be at 1,525 gpm. The extraction wells were placed to facilitate broad coverage of the chromium plume, and minimize pumping. Two injection wells would be placed updip of the plume into the Lower aquifer, which is thicker and more permeable. Baseline pumpage data was used to develop this scenario. Baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens Well. Details of the EX-I configuration are provided in Appendix B.

Effectiveness - Extraction of the chromium contaminated groundwater using a series of extraction wells would be very effective in capturing and containing the plume. The permeable sandy aquifers are amenable to extraction given that the contaminants would migrate readily through this media. However, the high yielding aquifer would require pumping at high flow rates to capture the entire chromium plume in a reasonable time frame. Based on model results, the estimated maximum travel time for the furthest edge of the chromium plume to reach the extraction wells is 120 years in the Middle aquifer, 51 years in the Intermediate Sand, and 28 years in the Lower aquifer. However, 95 percent of the particles would be extracted in much less time for the Intermediate Sand (20 years) and Lower aquifer (15 years), while the Middle aquifer would be the same duration. The difference between the maximum travel times and the travel times for the bulk of the particles indicates that a portion of the particles probably are being delayed in the confining units while moving between aquifers. The time it would take to capture 95 percent of particles is a better indicator of the plume capture. Modeling scenario figures showing travel times are included in Appendix B.

The particle travel times could be significantly affected by other factors, such as pumping of other municipal wells and re-injection or recharge of treated water. Also, the primary goal of EX-I scenario is to capture the chromium plume; it would not capture the VOC contamination in areas beyond the chromium plume effectively without additional pumping and extraction wells. For the pumping configurations, USGS performed the following additional simulations in order to determine the effects of these variables on the plume capture and particle travel times:

- Discharge all treated water at a location outside of the Puchack Well Field Site (EX) - The discharge would not interfere with the Lower aquifer plume capture but would decrease the particle travel times.
- Increase Morris Well Field pumping from current 12 mgd to 20 mgd and re-inject all treated water at a location within the Puchack Well Field Site simultaneously (EX-MD-I) - A significant portion of the plume would be pulled into the Morris Well Field. However, this effect could partially be mitigated, but not eliminated, by injecting treated water between Morris Well Field and the chromium plume.

- Increase Morris Well Field pumping from current 12 mgd to 20 mgd and recharge treated water at a location on the Puchack Well Field Site (EX-MD-R) - The recharge would slow down the plume capture. Again, a significant portion of the plume would be pulled into the Morris Well Field.

The simulation results are included in Appendix B. All these factors have varying degrees of impact on plume capture and particle travel times, with the increase of Morris Well Field pumping having the greatest potential impact.

The EX-1 scenario requires pumping at a substantial rate in order to cleanup the aquifers in a reasonable time frame. Since the Puchack Site is within an area where groundwater is a scarce resource, such a high pumping rate would not be desirable unless the treated water is reinjected into the aquifer. The need to further increase the pumping rate significantly in order to capture the VOC plume makes this scenario less attractive. Nonetheless, EX-1 would be effective in capturing the chromium plume.

The installation and operation of the extraction wells piping network would have very low impact to human health or the environment. There could be traffic congestion during construction of the pipe. The extraction wells and piping would have the low possibility of release through leakage at the well head or along the run of piping. Since the piping runs would be within the plume areas, any leakage or accidental spill would be drained back to the groundwater. The extraction wells would have small pumping facilities with security measures to limit access and potential exposure. The transfer piping is expected to be pressure tested during installation and may include double walled piping should the risk of leakage be considered unacceptable during the design phase.

Implementability - Installation of extraction wells and transfer piping is technically feasible. The administrative feasibility of implementing this option is dependent on the locations selected for placement of the components. The transfer pipes are expected to be placed adjacent to streets and along township right-of-ways. Also, efforts would be made to install the extraction wells in township-owned property to avoid difficulties with property access issues with privately-owned land.

There would be several problems that could have substantial cost and schedule impacts in bringing the extracted water to a central location for processing. The Puchack Site is located in a suburban area. The transfer pipe would need to be laid underground along the street in this highly congested area. Additionally, there is a railroad that transects the Site. Additional time and effort would be required to bring the piping across the railroad and select a suitable location where crossing the railroad would be feasible. In general, crossing of railroad lines is administratively difficult due to coordination issues with railroad companies and the need to place transfer piping underneath the rail. Use of trenchless technologies that would not interrupt rail service may somewhat ease coordination issues.

Since all of the extraction wells in EX-1 would be located north of the railroad, it would be logical to place the treatment plant at the privately owned open space near Mercon. This property would need to be acquired by the government.

Cost - The capital cost for the EX-I extraction scenario is expected to be high.

Conclusion - Groundwater extraction scenario EX-I will be retained for further consideration as a representative extraction scenario.

2.6.7 Ex Situ Treatment

The primary advantage of ex situ treatment over in situ treatment is better process control (i.e., the ability to monitor and continuously mix the groundwater) which typically results in more uniform and effective treatment. Treatment options were evaluated to reduce the TMV of contaminants by physical or chemical processes. The options evaluated include treatment of extracted groundwater at an above ground treatment plant. Treatment in onsite plants would require permanent structures within buildings to accommodate the high flow rates. The applicability of onsite treatment plants depends primarily on the availability of land for the treatment facilities. The applicable treatment technologies for handling chromium and VOCs include physical and chemical processes.

2.6.7.1 Chemical Reduction and Precipitation

Chemical precipitation converts dissolved metals in groundwater into an insoluble form. Metal ions generally precipitate out as hydroxides, sulfides, or carbonates, and are removed as solids through clarification and filtration. The solid sludge containing the metal contaminant then is disposed of properly at an offsite facility.

Treatment of chromium contamination requires the reduction of hexavalent chromium, which is primarily in the form of chromate, CrO_4^{2-} and dichromate, $Cr_2O_7^{2-}$ to the trivalent state. The reducing agents commonly used include ferrous sulfate, sodium meta-bisulfite, or sulfur dioxide. The first two reagents are fed in the dry or liquid form, while the third chemical is diffused as a gas. When ferrous sulfate is used as the reducing agent, the ferrous iron, Fe^{+2} is oxidized to ferric iron, Fe^{+3}, and when sodium metabisulfite or sulfur dioxide is used the negative ion SO_3^{2-} is converted to SO_4^{2-}. The reduction of hexavalent chromium is more effective at low pH values, so addition of an acid may be required.

Following reduction, trivalent chromium is precipitated as a metal hydroxide using lime (more common) or sodium hydroxide as the reagent. This is referred to as the process of reduction and precipitation. The reaction of trivalent chromium with lime forms chromic hydroxide, $Cr(OH)_3$ which is insoluble in water. Precipitation of trivalent chromium is most effective in the pH range of 8.0 to 9.5, due to the low solubility of chromic hydroxide in that range.

Chromium reduction and precipitation generally can achieve an effluent in the range of 50 to 100 μg/L. In order to meet lower effluent limits, it is sometimes necessary to

provide filtration to remove floc carried over from the precipitation process, which consists of small non-settleable chromic hydroxide particles that are not readily removable by standard sedimentation processes. While lower levels are achievable, the use of ion exchange as a polishing step may be necessary to reach lower discharge limits.

In general, the use of ferrous sulfate yields greater quantities of sludge than are produced through the use of sulfur dioxide or sodium meta-bisulfite, due to the formation of additional iron precipitates.

A pilot scale system was installed and operated at the Puchack Well Field Site by CDM in 1992. The goal of this study was to determine whether the Puchack Well Field groundwater could be treated to meet potable water standards for potential use in the public distribution system. Based on an initial literature review and bench scale tests, ferrous iron was selected as the reagent for reduction of hexavalent chromium to trivalent chromium. The bench scale tests with Puchack Well Field groundwater indicated that ferrous iron reacted rapidly with hexavalent chromium at pH 6, which is the natural pH of the groundwater. Chromium reduction with sulfur dioxide and sulfite compounds was considered, but was rejected due to the relatively slower reaction rates at neutral pH.

The pilot scale system was designed to treat the average total chromium level of 2,600 µg/L and hexavalent chromium of 2,500 µg/L. The groundwater was considered to have relatively low iron and manganese concentrations and high carbon dioxide levels. The pilot system pumped 40 gpm for 24 hours per day, five days per week, over a two-month period, and treated 1.7 million gallons of groundwater. Components of the pilot unit included:

- Ferrous iron addition, followed by in-line mixing.
- Iron-chromium contact, for an adjustable contact time of 1 to 14 minutes, to reduce hexavalent chromium to trivalent chromium.
- Aeration to strip out carbon dioxide and thereby reduce calcium carbonate formation after lime addition, and to provide oxygen to oxidize both excess iron added to the water and manganese in the raw water.
- Lime addition, in a rapid mix tank, to raise the pH from 7 (after aeration) to between 8.5 and 9.0, the optimal pH for trivalent chromium removal.
- Chlorination to prevent slime growth in the clarifier and dual media filter.
- Flocculation, in the center zone of a solids contact clarifier, with addition of anionic polymer to improve settling.
- Clarification in the quiescent zone of the clarifier to remove chromium hydroxide, iron hydroxide, manganese oxide, and calcium carbonate solids.
- Dual media gravity filtration to remove any floc in the clarifier overflow.

Finished water was recharged to the groundwater through one of the Puchack wells. Clarifier sludge was thickened by gravity and subsequently dewatered on a plate and frame filter press. As part of the pilot scale test, ferrous iron sources were evaluated including ferrous sulfate, ferrous iron generation using electrochemical methods, and

introduction of nearby Morris Well Field water which contained 30 to 45 mg/L of iron and was reportedly available for use at up to 3 mgd.

The pilot scale system demonstrated that chromium levels below 50 μg/L could be consistently achieved, and levels below 20 μg/L were reached for most of the pilot test conditions. The project goal of 50 μg/L was reached with an iron-chromium contact time of 1.8 minutes, and a stoichiometric ratio for ferrous iron to chromium of 1.25. The clarifier overflow rate was 0.65 gallons per day per square foot (gpd/ft^2), and the filter loading rate was between 4 and 6 gpm/ft^2. The sludge yield was approximately 740 pounds dry weight solids per million gallon of water treated (assuming 2.6 mg/L chromium in the raw water). The amount of sludge generated for the EX-I pumping scenario would therefore be approximately 1,600 pounds per day for 1,525 gpm of pumping.

The sludge cake was tested by the Toxicity Characteristic Leaching Procedure (TCLP) for chromium and indicated that the sludge was well below the hazardous waste limit. The waste is therefore not a characteristic waste and can be disposed in a Subtitle D landfill.

Given the success of the pilot scale system, it is expected that a full-scale groundwater pump and treatment system would be modeled after the pilot unit. Average chromium concentrations to be encountered from the groundwater extraction scenarios is anticipated to be in the range of 1,500 to 2,500 μg/L, based on weighted average chromium concentrations (see Appendix A). The design capacity of the treatment plants would depend on the extraction scenario. For EX-I, a total flow rate of 1,525 gpm would be extracted and treated at a treatment plant north of the railroad tracks.

Effectiveness - Treatment of hexavalent chromium with chemical reduction and precipitation is an effective groundwater remediation technology. It is best suited for the conditions at Puchack with high flow rates and achievable cleanup goals (PRG of 70 μg/L). Pilot scale studies indicate that these cleanup goals can be reached using this approach.

Treatment of chromium contaminated groundwater using reduction and precipitation is a proven technology and is reliable.

Implementability - Chemical reduction and precipitation of chromium contaminated groundwater is technically feasible. The administrative feasibility of implementing this option is dependent on the availability of space for the treatment plant. The treatment plant could be sited on the open space located on a privately owned property on the south side of Derousse Avenue near Mercon. Currently, this space is used for equipment and material storage. Other siting locations may include the two areas within the Puchack Well Field. The drawback is that the Puchack Well Field is further away from the extraction wells and would require a longer piping run to the treatment plant. Depending on the utilization plans by the current owners, EPA could

encounter some administrative difficulties in acquiring any privately owned properties.

Low impact to human health and the environment is anticipated during construction of the treatment plant. Construction would involve standard methods to build a concrete containment pad, equalization tanks, mixing tanks, clarifiers, holding tanks, filter press, associated piping, and a small control building. During operation, potential leakage from tanks and piping would be contained on the bermed concrete pad. Also, treatment chemicals would be placed in a secure storage building to minimize potential exposure to nearby businesses and residences.

Cost - The capital costs to construct a treatment system to handle the groundwater flow of 1525 gpm under scenario EX-I are estimated to be high. The O&M costs for the duration of the pump and treat system operation are estimated to be high.

Conclusion - Chemical reduction and precipitation will be retained for further consideration.

2.6.7.2 Ion Exchange

Ion exchange is a process in which metal contaminants are removed from groundwater through exchange with relatively harmless ions in the ion exchange resin. Ion exchange resins are manufactured for removal of a wide variety of inorganic and organic ions, however, removal of inorganic ions is more common given that most organic compounds are non-ionic. The process is based on the use of specifically formulated resins having an exchangeable ion (e.g., H^+, OH^-, Na^+, Li^+, CO_3^-) bound to the resin with a weak ionic bond. Generally, an array of resin beds containing different resins to treat each type of ion are arranged in series. For chromium removal, the anion exchange can be applied to remove hexavalent chromium (in the chromate and dichromate forms). Cation exchange can be employed for trivalent chromium removal, however this would require low pH and reduction potential prior to ion exchange. The beds require monitoring for breakthrough and must be regenerated by backflushing using regeneration chemicals, which are hazardous. Ion exchange process equipment includes vessels for the resin, regenerant storage tanks, waste regenerant storage tanks, waste backwash tank, chemical feed systems (if necessary to reduce hexavalent chromium to trivalent chromium), transfer pumps, controls, and piping.

Hexavalent chromium removal using ion exchange requires the use of a strong base anion exchange such as an ammonium resin with a copolymer gel matrix. Pilot testing would be required to determine the optimum resin and treatment conditions for removal of chromium.

Ion exchange resins are generally too costly for large-scale groundwater treatment applications or to treat high contaminant levels (i.e., chromium levels greater than 1,000 μg/L), and are predominantly used for polishing of aqueous effluents after other treatment processes in these instances. However, a treatment system has been designed and built by CDM for the Glendale Water Treatment Plant to treat

hexavalent chromium at high flow rates (7 mgd) using ion exchange. This system was selected due to lower chromium levels (100 μg/L) and the need to reach very stringent State of California Public Health Goals (2.5 μg/L total chromium). CDM also prepared an FS for the Sprague Road Superfund Site, a chromium contaminated groundwater site in Texas, in which ion exchange was the chosen technology. This selection was based on the low flow rates being treated (50 gpm), and the reliability and relatively low O&M requirements.

For the Puchack Well Field Site, ion exchange could be used as a polishing step if very low effluent limits are required (such as for use when discharge to a water distribution system is the discharge option). It is expected that an ion exchange system would require less space than a chemical reduction and precipitation system.

Effectiveness - Ion exchange is a proven technology for treating groundwater contaminated with hexavalent chromium. Treatment by ion exchange is more effective for low flow rates and low influent concentrations. However, it is effective in reducing chromium levels to very low levels. It is expected that cleanup of groundwater to 70 μg/L would be easily achievable for this technology, although the expected high influent concentration of 1,500 to 2,500 μg/L may make this technology less cost effective. If low effluent concentration is desirable, ion exchange could be used as a polishing step in combination with other technologies, e.g., chemical reduction and precipitation.

This technology also requires disposal of regenerant waste, which is likely to be hazardous. A secondary treatment step may be required in order to process the regenerant waste to render it non-hazardous.

Treatment of chromium contaminated groundwater using ion exchange is a proven technology and is reliable.

Implementability - The use of ion exchange to treat the high flow rate and high chromium levels at the Puchack Well Field Site would not be cost effective if used as the sole treatment method. It would be more appropriate to use ion exchange as a polishing step. The administrative feasibility of implementing this option would encounter the same limitations and issues as the chemical reduction and precipitation process, whether it is used alone or in combination with other technologies. Space limitation would be the primary concern. It is expected that the treatment plant could be sited on open space located on privately owned property on the south side of Derousse Avenue. EPA could encounter some administrative difficulties in acquiring privately owned properties.

Low impact to human health and the environment are anticipated during construction of the treatment plant, and would involve standard construction methods. During operation, potential leakage from tanks and piping would be contained on the bermed concrete pad. Also, treatment chemicals would be placed in a secure storage building to minimize potential exposure to nearby businesses and residences.

Cost - The capital costs for installation of the ion exchange treatment system including associated tanks, pumps, and piping, is expected to be moderately expensive. O&M costs would be relatively high due to costs for regenerating the resin and disposing of the resin waste. Therefore, the total cost would be relatively high.

Conclusion - Ion exhange is retained for further consideration as a secondary treatment process.

2.6.7.3 Reverse Osmosis

Reverse osmosis is a filtration process whereby pressure is applied to the water to overcome the osmotic pressure and force the water through a membrane. At sufficiently high pressures, usually 400 to 600 pounds per square inch, the water would flow out of the more concentrated solution, leaving the contaminants trapped on the other side of the synthetic membrane. The concentrated waste formed would require additional treatment which is typically expensive. Reverse osmosis is considered the smallest membrane filtration method, with pore size of less than 0.001 micrometers.

There is a tendency for the membrane to foul with the contaminants being removed. Also, colloidal solids, microbiological growth, and insoluble precipitates can collect on the membrane during operation. Periodic shutdown of the system is necessary so that the membrane can be cleaned. This may be somewhat overcome through pretreatment steps such as pH adjustment, precipitation, or pre-filtration.

Reverse osmosis has typically been applied to high concentration chromium plating wastes, whereby the concentrated chromium effluent can be recycled into the plating process. Application to the Puchack Well Field Site may not be appropriate given the high flow rates and high chromium levels present. It may be more beneficial as a final polishing step following chemical reduction and precipitation.

Effectiveness - Reverse osmosis is typically effective for removing chromium and other metals from the groundwater stream, but would be more effective for use at sites with lower flow rates and contaminant concentrations. It is expected that cleanup of groundwater to 70 μg/L would be achievable for this technology. However, this technology would generate large quantities of concentrated chromium wastewater which would require further treatment (e.g., chemical reduction and precipitation) prior to disposal. The large waste stream makes this process unattractive for the Puchack Site.

Implementability - The use of reverse osmosis to treat the high flow rate and high chromium levels at the Puchack Well Field Site would not be cost effective if used as the sole treatment method. It would be more appropriate to use reverse osmosis as a polishing step. The administrative feasibility of implementing this option would be similar to the chemical reduction and precipitation process.

Cost - The capital costs for installation of the reverse osmosis treatment system including associated tanks, pumps, and piping, is expected to be moderately

expensive. O&M costs would be relatively high due to costs for further treatment of the concentrated solution and disposal of the waste. Therefore, the total cost would be relatively high.

Conclusion - Reverse osmosis is retained for further consideration as a secondary treatment process.

2.6.7.4 Electrochemical Precipitation

Electrochemical precipitation uses direct electric current that is applied between two electrodes immersed in the water being treated. The consumable electrodes generate ferrous ions at the anode and hydroxide ions at the cathode. An oxidation-reduction reaction then occurs between the ferrous, chromium, and hydroxide ions to produce ferric hydroxide ($Fe(OH)_3$) and chromic hydroxide ($Cr(OH)_3$), which subsequently precipitate from solution. The precipitates form an inorganic sludge that must be treated and/or disposed offsite. A typical electrochemical cell for hexavalent chromium treatment consists of a tank, consumable iron electrodes, and a direct current electrical supply system. The electrodes require periodic cleaning with an acid solution, and replacement when consumed. Post treatment steps include clarification and filtration.

Effectiveness - Treatment of hexavalent chromium with electrochemical precipitation is an effective and reliable groundwater remediation technology. This technology would be capable of achieving the 70 μg/L treatment goal.

Implementability - Electrochemical precipitation of chromium contaminated groundwater is technically feasible. The administrative feasibility of implementing this option is similar to the chemical reduction and precipitation process.

Cost - The capital costs for installation of the electrochemical precipitation treatment system including associated tanks, pumps, and piping, is expected to be moderately expensive. O&M costs would be relatively high due to costs for periodic replacement of the electrodes and disposal of the waste sludge. Therefore, the total cost would be relatively high.

Conclusion - Electrochemical precipitation is retained for further consideration.

2.6.7.5 Iron Filtration Process

A process for removal of heavy metals from groundwater has been developed by Stevens Institute of Technology, New Jersey. The filtration system consists of a column of zero valent iron filings and a sand filter in series. The reactive media has been designed to prevent the fusion of the iron filings and maintain the iron in an active state. As a result, the need for backwashing and regeneration is minimized. Heavy metals including chromium react with the iron filings by electrochemical precipitation and form solids. The sand filter removes the suspended solids.

This process has been tested at the bench scale in which hexavalent chromium levels were reduced from 10,000 μg/L to less than 2 μg/L. In addition, chlorinated solvents commingled in the Puchack Well Field Site plume could be treated via dechlorination by the iron filings. The process has not been evaluated at the pilot- or full-scale level, so it is considered an emerging technology. As a result, bench- and pilot-scale studies would be required prior to full scale implementation. The iron filtration system requires a smaller footprint than chemical reduction and precipitation given that the system is comprised of a reaction chamber and sand filter.

Effectiveness - The process is promising if proven to be reliable in the full scale operation. The process would be easier to operate and generate less sludge than the chemical reduction and precipitation process. Treatment of hexavalent chromium with the iron filtration process has only been demonstrated to be effective at the bench-scale. The process would require pilot-scale testing to demonstrate its effectiveness and reliability.

Implementability - The basis for the technology which uses zero valent iron to reduce the hexavalent chromium to trivalent chromium appears to be technically feasible but not proven at pilot- or full-scale. The administrative feasibility of implementing this option would be similar to the chemical reduction and precipitation process.

Cost - The capital costs for installation of the iron filtration process is expected to be moderately expensive. O&M costs would be moderate given the relatively low cost for the zero valent iron compared to chemical reagents necessary for chemical reduction and precipitation; however, this technology may be labor intensive due to potential unforeseen implementation problems. As a result, the total cost would be moderate to relatively high.

Conclusion - Iron filtration process is eliminated from further consideration because it has not yet been proven to be reliable in the full-scale operation.

2.6.7.6 Air Stripping

The Puchack Site chromium groundwater plume has a commingled chlorinated solvent plume, which could be easily treated by air stripping. Air stripping is a mass transfer process in which volatile contaminants in water are transferred to a gaseous phase. This process works best on contaminants with high volatility and low solubility (i.e., high Henry's Law constant) including the chlorinated solvents present at the Puchack Site. Several contacting systems can be used, such as mechanical surface aerators, diffused aeration, spray or tray towers, open channel cascades, spray fountains, and counter-current packed towers. The tray tower and packed tower are the most commonly used processes in which water cascades down through a packing material while air is forced up through the packing by means of a blower. Primary factors which govern the efficiency of the process include the air-to-water ratio, pressure drop, tower height, surface area of the packing material, contact time, and temperature of the effluent. The use of steam or heated influent air can be used to increase temperatures thereby improving removal efficiencies, particularly for compounds which are less volatile and more soluble. Pretreatment of suspended

solids and inorganics such as iron and manganese (which become oxidized and precipitate out), may be necessary to avoid deposition on, and subsequent clogging of, the packing material. However, groundwater data from the Puchack Site indicate that iron and manganese levels are relatively depleted in the contaminant zone, so pretreatment to remove suspended solids may be the only necessary step. In addition, pH adjustment may be a consideration to minimize the buildup of bacterial slime in the unit. Treatment of the offgas may be required prior to discharge to the atmosphere depending on contaminant levels and the location of potential receptors. Offgas treatment can be accomplished using vapor phase carbon adsorption or catalytic oxidation.

Based on the relatively high flow rates anticipated at the Puchack Site, it is expected that two to three large air stripping towers would be required to handle the flow rates and chlorinated solvent contaminant levels. The air strippers would be placed after the chromium treatment process. In addition, a vapor phase carbon adsorption unit may be required due to the close proximity of industrial and residential properties.
Effectiveness - Air stripping is a proven technology of treating groundwater contaminated with chlorinated solvents. Depending on the operating conditions used, removal efficiencies of 90 to 95 percent are generally possible. Given that the maximum groundwater contaminant levels for TCE (360 μg/L) is well above the PRG of 1 μg/L, it would be necessary to optimize the air stripping approach or use liquid phase carbon adsorption as a polishing step. Air stripping would be used in conjunction with a chromium treatment process.

Treatment of chlorinated solvents in groundwater using air stripping is a proven technology and is reliable.

Implementability - Air stripping for treatment of chlorinated solvent contaminated groundwater is technically feasible. Air stripping towers are readily available from many vendors. The administrative feasibility of implementing this option is expected to be high as air stripping of VOCs is proven and commonly implemented.

Low impact to human health and the environment are anticipated during construction of the air strippers, and would involve standard construction methods. During operation, potential leakage from tanks and piping would be contained on the bermed concrete pad. Also, offgases would be treated with vapor phase carbon adsorption if deemed necessary to protect nearby businesses and residences.

Cost - The capital cost for this option will be a function of the extraction scenario. For the air stripper, using EX-I, capital costs are estimated to be high. The annual O&M costs are estimated to be low.

Conclusion - Air stripping for VOC removal is retained for further consideration.

2.6.8 Discharge

Discharge options were evaluated which serve as end-points for the extracted and treated groundwater under the pump and treatment remedial approach. They include

reinjection wells, discharge to infiltration facilities, discharge to public drinking water system, and discharge to surface water (including discharge to storm sewer with conveyance to surface water). This evaluation takes into account the various technical, administrative, and regulatory issues which must be considered in order to select the most suitable discharge option.

2.6.8.1 Injection Wells

The use of injection wells consists of reinjecting the treated water back into the groundwater aquifer. For the pump and treatment remedial approach, several injection wells could be installed within the northern part of the Puchack Well Field property. This location was selected based on USGS simulations (EX-I). This open space location is upgradient of the chromium plume and would provide a recharge zone to replenish the extracted groundwater and enhance the process of flushing out the contaminants in the aquifer. Based on the simulations, two injection wells would be screened to discharge 750 gpm each of treated water into the Lower aquifer. It is expected the treated water would be below MCLs and contamination levels from the treated effluent that is reintroduced into the highly utilized PRM drinking water aquifer would not present an unacceptable risk to human health and the environment.

Effectiveness - Based on the lithological features identified from monitoring well boring logs within the Puchack Well Field Site, the Lower aquifer layer is very permeable. The injection well discharge option would be very effective at allowing the discharged effluent to disperse back into the groundwater to replenish the aquifer. The USGS has simulated the effects that re-injection of the treated water would have on the pumping scenario (see Appendix B, Scenarios EX-I and EX-MD-I). These modeling runs indicate that at the proposed re-injection locations, the re-injected water could interfere with the extraction process in the Lower aquifer. This effect could be mitigated by adjusting the injection and extraction locations. The injection could also provide a barrier between the chromium plume and the Morris Well Field. Pennsauken is in critical shortage of drinking water. By re-injecting the treated water into the ground, the remediation would not be a burden to this critical problem and could put the treated water to beneficial use.

The system of groundwater injection wells would provide several benefits to the local environment. The wells would be isolated from the local environment, and would not impact local surface water bodies. Also, very little land space is required for this discharge approach. The effectiveness of this option would rely on proper injection well design and construction, including adequate pipe sizing, proper placement of the wells, and reliable materials of construction.

Implementability - The option to discharge treated effluent to a series of injection wells would be easily and readily implementable, given that standard construction methods and materials would be utilized. A minimum of land space would be necessary for this option, and is available at the Puchack Well Field Site. The subsurface at this location is also suitable for the installation of injection wells for discharge to the Lower aquifer which ranges from approximately 160 to 250 ft bgs. Some implementability problems can arise during long term operation of injection

wells, such as clogging of screen packs with precipitates or microbial fouling, particularly in high iron conditions. These can be overcome by proper removal of excess iron from the treated water, periodic chlorination of the injected water, and redevelopment and cycling on/off of wells. In the short-term time frame during construction, some impacts to the local environment could arise during construction activities.

This option would most likely require application through the NJDEP's Division of Water Quality for a New Jersey Pollution Discharge Elimination System (NJPDES) Discharge to Groundwater (DGW) permit. An alternate option would be permitting through NJDEP's Site Remediation Division. It is expected that local authorities would be receptive to this discharge option.

O&M of this option is not expected to be substantial, and would include periodic monitoring and cleaning of the injection wells.
Cost - The capital cost for the injection wells will be a function of the extraction scenario. The injection well discharge option, using EX-I, capital costs are estimated to be high. The annual O&M costs are estimated to be low.

Conclusion - Injection wells are retained for further consideration.

2.6.8.2 Recharge Facilities

Under this discharge option, treated effluent water would be delivered to recharge basins via discharge piping. Recharge basins are shallow ponds that allow water to infiltrate into the ground gradually, and depending on the permeability of the soil, generally require large surface areas.

Another method of artificial groundwater recharge would be an infiltration gallery. This system would be developed as a series of perforated pipe galleries laid underground, which would receive treated groundwater from the onsite treatment plant, and disperse the flow evenly through the discharge system, down to the underlying aquifer system.

Another variation to recharge basins would be leaching basins. These are underground covered pits that are typically 5 to 10 feet wide and 10 to 20 feet deep. Although more of them may be needed to handle the flow rate, problems of safety and maintenance associated with recharge basins would be avoided, and they would not require extensive land surface, particularly important in highly developed areas such as the Puchack Well Field.

The surface area required depends on the extraction rates and types of facilities. For the EX-I scenario, it is estimated that a recharge basin area of approximately 10 acres would be required. Conditions at the recharge basin location would have an impact on the land area required. These include conditions such as the site-specific lithology and recharge rates in the subsurface soils. There is very limited open space near the Puchack Site which can be used for the recharge facilities. Based on a review of aerial

photographs and site reconnaissance work, only the Puchack Well Field and the adjacent Pennsauken wooded area have the needed space for recharge facilities.

Effectiveness - Given the lithologic conditions at the Puchack Well Field Site, the recharge basins discharge option could be very effective at allowing the discharged effluent to percolate through the unsaturated subsurface material and reach the groundwater zone. Clays or silty materials that could impede the downward flow of effluent are present at approximately 30 feet or greater below the ground surface in the area planned for this option. However, this determination is based on limited information. Additional subsurface investigations would be required to confirm the absence of silt or clay layers in the subsurface and to develop an estimated design loading rate. The effectiveness of this option would rely on the proper construction of the basins, including adequate sizing, and use of suitable sand and gravel.

The recharge basins provide several benefits to the local environment: the system operation would not be intrusive to the local environment; would not impact local surface water bodies; and local authorities and citizens would also realize the benefit of recovering treated water to preserve the groundwater supply in the area, which is a critical situation in this region, and the local townships.

Implementability - The recharge basins discharge option is readily implementable, as standard construction methods and materials would be utilized. However, open land space is very limited. Adequate land space for this option is only available at the Puchack Well Field and the adjacent wooded area. The government would need to obtain the land from the City of Camden.

This option would most likely require application through the NJDEP's Division of Water Quality for an NJPDES DGW permit. An alternate option would be permitting through NJDEP's Site Remediation Division.

During construction, some impacts to the local environment could arise due to excavation and construction of the recharge basins. These could include noise impacts to the local community and construction dust emissions during excavation and hauling activities. O&M of this discharge option is not expected to be substantial, but basin maintenance problems, debris buildup, and safety for intruders would also be a consideration.

Cost - The capital cost for this option is a function of the recharge basin size. For extraction scenario EX-I, capital costs are estimated to be high. The annual O&M costs are estimated to be low.

Conclusion - Recharge facilities are retained for further consideration.

2.6.8.3 Surface Water Discharge

Under this discharge option, effluent from the groundwater treatment system would be delivered to local surface water bodies directly or through the local storm sewer network. Effluent would potentially be delivered to the nearby Delaware River,

located approximately 1 mile to the west/northwest of the Site, or other selected local surface water bodies, such as Tippens Pond, west of the SGL Chrome Site, which eventually discharges to Delaware River. The most favorable option for discharging to the Delaware River would be to pipe the treated water to Puchack Run, adjacent to the Puchack Well Field, which is located along the north side of Interstate 90, and discharges to the Delaware River at the Betsy Ross Bridge located approximately 0.7 miles downstream. Delivery of effluent to Puchack Run would involve the installation of a discharge pipe a distance of approximately 0.4 miles to the north. The same pipe could be used for carrying the water to the injection wells and/or recharge basins, both of which would be located in the Puchack Well Field.

Discharge to the local storm sewers would be less viable because of the large flow rates of treated water involved. This option requires delivery of groundwater treatment effluent at a very high flow rate (1,525 gpm) through a limited portion of the local storm sewer network. Storm sewer lines along Derousse Avenue and the adjacent residential streets located in the contaminant plume area are owned by Pennsauken Township. Stormwater flowing along Derousse Avenue flows northwest to River Road, then flows through industrial property towards several outfall lines running northwest. Stormwater flowing northeast through these pipelines drains to Puchack Run. This joins drainage from the north (the Delair neighborhood) which also discharges to Puchack Run, with ultimate discharge to the Delaware River. Potentially, the effluent discharge from the treatment system could be split, and a combination of discharge options would be utilized, with only a smaller, more manageable flow rate discharged to the local storm sewer network.

Another consideration would be delivery of treated effluent to Tippens Pond, west of the SGL Chrome Site. Delivery to this water body would require piping placed below the railroad right-of-way.

Effectiveness - This option would serve to provide an efficient disposal option for the treated water. Ultimate discharge into the Delaware River would not cause any adverse effects to the local environment, since treated water would contain contaminant levels below drinking water standards. Contaminant levels would also be below any necessary maximum daily discharge limitations under the Camden County Municipal Utilities Authority's (CCMUA) Sewer Use Ordinance. In addition, the flow volume, even at the highest of the options (2.16 mgd), would not adversely impact the Delaware River. In this area, the daily flow of the Delaware River is approximately 4 billion gallons.

Discharge into Puchack Run, a channelized stream located adjacent to the Puchack Well Field and flowing in a northwesterly direction near the Site, could create a small flow impact to this water body, but likely would not create flooding concerns. This concrete-lined stream eventually discharges into the Delaware River adjacent to the Betsy Ross Bridge. At this point in time, the design peak capacity of Puchack Run is not known; however, local officials do not cite drainage or flooding problems in this area. Based on a rough estimate, the Puchack Run is capable of handling 60,000 to 80,000 gpm of flow. Even at the maximum discharge rate, it would only consume a

small fraction of this capacity. Local flooding concerns are experienced upstream where the Puchack Run has earthen construction, at the Westfield Avenue and Route 90 intersection area, near Crescent Burial Park. The Township of Pennsauken is planning a Stormwater Management Plan (SWMP) for this area that may include construction of a stormwater management pond at this intersection area. Furthermore, if a remedial option was developed involving splitting the effluent discharge flow so that a portion is delivered to Puchack Run, the impact would be lessened. During flooding periods, the discharge could be turned off temporarily without impact to the extraction and treatment process if a recharge basin or injection wells were included in the discharge design.

The limited capacity of the storm sewer would eliminate the option of discharging to the storm sewer. Existing sewer lines would not be able to handle a large increase in flow, since the lines are designed for certain local rainfall events along with a certain capacity for local development. Since the immediate neighborhoods are at or close to maximum development, and the amount of impervious surface area cannot significantly increase apart from this remedial action, the existing storm sewers would not likely be upgraded in the future. As a result, rehabilitation or upgraded flow capacity for storm drainage would be necessary.

Implementability - A point source discharge permit may be necessary from NJDEP to allow for this activity. Application for this would be necessary with the NJDEP's Construction and Connections Division. Factors such as the concentration of contaminants and suspended solids in the effluent, flow rates expected, and the purpose of the discharge activity would be considered in determining possible approval of the application.

In addition to the above considerations, local municipality and/or sewer authority approval for the discharge of a considerably large volume of water to storm sewers or surface water bodies such as Puchack Run or Tippens Pond would require local approval. Local objection to the addition of a large volume of flow is unknown at this time. The risk of flooding problems to Puchack Run or possibly Tippens Pond could be managed by the local waterways. In addition, although contaminant discharges would be below regulatory standards, residual levels may impact aquatic and terrestrial life, especially in Tippens Pond. Discharge to the Delaware River would have the lowest impact to surface water; however, the necessary conveyance through the local storm sewer system along Derousse Avenue could create an indirect adverse impact as this system's capacity may be exceeded during rainfall events.

Cost - Costs related to the discharge of treated effluent to local surface water bodies would be in the low to medium range, depending on the surface water body selected. Costs would be incurred for the construction and installation of new pipelines if a discharge to Puchack Run is selected. No new piping costs would be necessary for discharge to the Delaware River, although there would be costs for the installation of new discharge piping from the treatment plant to the existing sewer network. A discharge to Tippens Pond scenario would require new piping costs from the SGL Chrome Site, but much less piping would be required. In addition to these costs, it is

likely that one-time permitting costs would be incurred to receive the necessary regulatory approvals from NJDEP (for a Point Source Discharge Permit) and/or the Pennsauken Water and Sewerage Authority.

The capital cost for this option are estimated to be low. The annual O&M costs for this alternative are estimated to be low.

Conclusion - Surface water discharge is retained for further consideration in combination with another discharge option, such as injection.

2.6.8.4 Public Water System Discharge

Under this discharge option, the treated groundwater would be delivered directly to the local drinking water supply system. After undergoing treatment to reduce contaminant levels to below NJDEP and federal MCLs, potable-quality water would be delivered to the local supply through a connection nearest to the treatment plant location.

This discharge option would require application for a Point Source Permit through consultation with NJDEP's Bureau of Safe Drinking Water.

Effectiveness - Under this option, no direct discharges of treated effluent to the environment would occur. As a result, the local environment would not be affected. Human health impacts would be low as treated water would be of potable quality and would meet the drinking water standards. However, there is a concern that chromium treatment system could potentially fail and risk to potable water users would occur. To mitigate this problem, very frequent or even continuous sampling could be instituted to ensure that safe drinking water is being provided, or to alert the operators to shut off the system and prevent distribution of the water.

The additional fresh drinking water capacity (2.16 mgd) provided by this new source would have positive impact to the local environment. Currently, local water supplies are not abundant and municipalities are in need of additional sources. Delivery of treated water to the potable water distribution system would reduce the need to pump at other well fields, as well as avoiding loss of groundwater to surface water discharge.

Implementability - A point source discharge permit would be necessary from NJDEP's Bureau of Safe Drinking Water to allow for this activity. Factors such as the concentrations of contaminants in the effluent, type of treatment employed, and amount of available water from this activity would be considered. Public agencies and users are not receptive to this option.

Delivery to the drinking water supply of this effluent would be technically possible. Only a connection pipeline to the water supply from the treatment system is needed, and no additional piping would be necessary.

Construction of this option would not be intensive and would involve only minor short-term impacts to the local environment in terms of noise, construction dust emissions, and excavation activity. Under this option, permitted contaminant levels and treatment stipulations as per the NJDEP would help to ensure protection of human health.

Cost - Costs related to the discharge of treated effluent to the potable water supply would be in the low range, and would provide significant cost savings compared to the injection and recharge alternatives.

Conclusion - Public water system discharge is eliminated from further consideration because public agencies are not receptive to this option.

Table 2-1
Potential Chemical-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description
Federal Resource Conservation and Recovery Act	Groundwater Protection Standards and Maximum Concentration Limits	40 CFR 264, Subpart F	Applicable	Establishes standards for groundwater protection
Federal Safe Drinking Water Act	National Primary Drinking Water Standards-Maximum Contaminant Levels (MCLs) and Maximum Contaminant Level Goals (MCLGs)	40 CFR 141	Relevant and Appropriate	Establishes health- and technology-based standards for public drinking water systems. Also establishes drinking water quality goals set at levels at which no adverse health effects are anticipated, with an adequate margin of safety.
Federal Safe Drinking Water Act	National Secondary Drinking Water Standards-Secondary MCLs	40 CFR 143	To Be considered	Establishes standards for public drinking water systems for those contaminants which impact the aesthetic qualities of drinking water.
State of New Jersey Statues and Rules	Groundwater Quality Standards	N.J.A.C. 7:9-6	Applicable	Table 1 and Table 2 establish standards for the protection of groundwater quality. Used as the primary basis for setting numerical criteria for groundwater cleanups.
State of New Jersey Statues and Rules	Primary Drinking Water Standards-Maximum Contaminant Levels (MCLs)	N.J.A.C. 7:10	Relevant and Appropriate	Establishes MCLs that are generally equal to or more stringent than SDWA MCLs.
State of New Jersey Statues and Rules	State Secondary Drinking Water Standards-Secondary MCLs	N.J.A.C. 7:10-7	To Be considered	Establishes standards for public drinking water systems for those contaminants which impact the aesthetic qualities of drinking water.

Table 2-2
Potential Location-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description	FS Consideration
Federal National Environmental Policy Act (NEPA),	Statement of Procedures on Floodplain Management and Wetlands Protection	40 CFR 6, Appendix A	To Be Considered	Establishes EPA policy and guidance for carrying out Executive Order 11988 - Protection of Floodplains. Action must avoid adverse effects, minimize potential harm and restore and preserve natural and beneficial values of the floodplain.	The potential effects of any action will be evaluated to ensure that the planning and decision-making reflect consideration of flood hazards and floodplains management, including restoration and preservation of natural, undeveloped floodplains.
Federal (Non-Regulatory)	Floodplains Executive Order	EO 11988	To Be Considered	Federal agencies are required to reduce the risk of flood loss, to minimize impact of floods, and to restore and preserve the natural and beneficial values of floodplains.	The potential effects of any action will be evaluated to ensure that the planning and decision making reflect consideration of flood hazards and floodplains management, including restoration and preservation of natural undeveloped floodplains.
Federal (Non-Regulatory)	Wetlands Executive Order	EO 11990	To Be Considered	Federal agencies are required to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance natural and beneficial values of wetlands.	Remedial alternatives that involve construction must include all practicable means of minimizing harm to wetlands. Wetlands protection considerations must be incorporated into the planning and decision-making process for remedial alternatives.
Federal Endangered Species Act	Protection of threatened and endangered species	16 USC 1531 et seq.; 40 CFR 400	Applicable	Standards for the protection of threatened and endangered species	The potential effects of any action will be evaluated to ensure that any endangered or threatened species would not be affected.
Federal Fish and Wildlife Conservation Act	Statement of Procedures for Non-game Fish and Wildlife Protection	16 USC 2901 et seq.	Applicable	Establishes EPA policy and guidance for promoting the conservation of non-game fish and wildlife and their habitats. Action must protect fish or wildlife.	Potentially applicable for construction activities which may impact non-game fish and wildlife and their habitats.
Federal Fish and Wildlife Coordination Act	Statement on Procedures for coordination with Fish and Wildlife Services	16 USC 661	Applicable	This law requires that any Federal agency that proposes to modify a body of water consult with the United States Fish and Wildlife Service (USFWS).	During the identification, screening, and evaluation of alternatives, the effects on streams and wetlands will be evaluated. If an alternative modifies a body of water or potentially affects fish or wildlife, EPA must consult the USFWS.

Table 2-2
Potential Location-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description	FS Consideration
Federal National Historic Preservation Act	Procedures for preservation of historical and archeological data	16 USC 469 et. seq.; 40 CFR 6.301(c)	Applicable	Establishes procedures to provide for preservation of historical and archeological data that might be destroyed through alteration of terrain as a result of a federal construction project or a federally licensed activity or program.	Potentially applicable if historical or archeological data is encountered during remediation.
New Jersey Flood Hazard Area Control Act	Floodplain Use and Limitations	N. J. A. C. 7:13	Applicable	State standards for activities within floodplains	Floodplain use and limitations must be considered during remediation.
New Jersey Freshwater Wetland Protection Act	Freshwater Wetlands Protection Act Rules	N. J. S. A. 13:9B-1; N. J. A. C. 7:7A	Applicable	Establish requirements for the protection of freshwater wetlands. Requires permits for construction within wetland areas.	Potentially applicable for construction activities performed in the vicinity of a wetland or waterway.
New Jersey Endangered and Non Game Species Conservation Act	Protection of threatened and endangered species	N. J. S. A. 23:2A-1 to -13	Applicable	Standards for the protection of endangered, non-game and exotic wildlife.	The potential effects of any action will be evaluated to ensure that any endangered or threatened species would not be affected.
New Jersey Endangered Plant Species List Act	Endangered Plant Species Program	N.J.S.A. 13.1B-15.151 to -15.158; N.J.A.C. 7:5B	Applicable	Standards for the protection of endangered plant species.	The potential effects of any action will be evaluated to ensure that any endangered or threatened species would not be affected.
New Jersey Soil Erosion and Sediment Control	Soil Erosion and Sediment Control Standards	N.J.A.C. 16.25A	Applicable	Requires erosion mitigation during construction activities.	Requires erosion control consideration during construction activities.
New Jersey Noise Control Act of 1971	Noise Control	N.J.A.C. 7:29	Applicable	Limits the noise generated from any industrial, commercial, public service or community service facility.	Limits the noise that can be generated during remedial activities.

Table 2-3
Potential Action-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description	FS Consideration
COMMON TO ALL ALTERNATIVES					
Federal Resource Conservation and Recovery Act	Identification and Listing of Hazardous Waste	40 CFR 261	Applicable	Identifies solid wastes which are subject to regulation as hazardous wastes.	Generation of hazardous wastes possibly includes spent carbon or contaminated soil. Hazardous wastes must be handled and disposed of in accordance with RCRA. Chemical testing and characterization of waste is required.
Federal Resource Conservation and Recovery Act	Standards Applicable to Generators of Hazardous Waste	40 CFR 262	Applicable	Establishes requirements (e.g., EPA ID numbers and manifests) for generators of hazardous waste.	Standards will be followed if any hazardous waste is generated onsite.
Federal Resource Conservation and Recovery Act	Standards Applicable to Owners and Operators of Treatment, Storage, and Disposal Facilities	40 CFR 264	Relevant and Appropriate	Establishes the minimum national standards which define acceptable management of hazardous waste.	Generation and storage of hazardous waste. May not apply to remediation sites if owner complies with requirements listed in 264,1(j).
Federal Occupational Safety and Health Act	Worker Protection	29 CFR 1904	Applicable	Requirements for recording and reporting occupational injuries and illnesses	Under 40 CFR 300.38, requirements of OSHA apply to all activities which fall under jurisdiction of the National Contingency Plan.
Federal Occupational Safety and Health Act	Worker Protection	29 CFR 1910	Applicable	Specifies minimum requirements to maintain worker health and safety during hazardous waste operations. Includes training requirements and construction safety requirements.	Under 40 CFR 300.38, requirements of OSHA apply to all activities which fall under jurisdiction of the National Contingency Plan.
Federal Occupational Safety and Health Act	Worker Protection	29 CFR 1926	Applicable	Safety and health regulations for construction.	Under 40 CFR 300.38, requirements of OSHA apply to all activities which fall under jurisdiction of the National Contingency Plan.
New Jersey Statutes and Rules	Technical Requirements for Site Remediation	N.J.A.C. 7:26E	Applicable	Established minimum regulatory requirements for investigation and remediation of contaminated sites in New Jersey.	Operation of any treatment facility must comply with the regulation.
New Jersey Statutes and Rules	Hazardous Waste Regulations	N.J.A.C. 7:26G-5, -8, -11	Applicable	Establish hazardous waste regulations by adopting Federal regulations on identification and listing of hazardous waste, standards for owner and operators of hazardous waste treatment, storage and disposal facilities, and land disposal restrictions.	Alternative development must consider the regulatory requirements.

Table 2-3
Potential Action-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description	FS Consideration
				OFF-SITE DISPOSAL	
Discharge of Treated Groundwater					
Federal Clean Water Act	National Pollution Discharge Elimination System (NPDES)	40 CFR 122 and 125	Relevant and Appropriate	Issues permits for discharge into navigable waters. Establishes criteria and standards for imposing treatment requirements on permits.	Treated water will need to consider discharge requirements.
Federal Clean Water Act	Effluent Guidelines and Standards for the Point Source Category	40 CFR 414	Relevant and Appropriate	Requires specific effluent characteristics for discharge under NPDES permits.	Treated water will need to consider discharge requirements.
Federal Clean Water Act	Ambient Water Quality Criteria	40 CFR 131.36	To Be Considered	Establishes criteria for surface water quality based on toxicity to aquatic organisms and human health.	May take into consideration when discharging treated groundwater to surface water.
Federal Safe Drinking Water Act	Underground Injection Control Program	40 CFR 144	Applicable	Establishes performance standards, well requirements, and permitting requirements for groundwater reinjection wells.	Must comply with requirements for reinjection of treated groundwater.
New Jersey Statutes and Rules	New Jersey Pollutant Discharge Elimination System	N.J.A.C. 7:14A	Applicable	Establishes standards for discharge of pollutants to surface water and groundwater	Disposal of treated groundwater to surface water or by reinjection will require a NJPDES permit.
New Jersey Statues and Rules	Surface Water Quality Criteria	N.J.A.C. 7:9B	Applicable	Establishes standards for the protection and enhancement of surface water resources.	May take into consideration when discharging treated groundwater to surface water.
Transportation and Disposal of Hazardous Wastes					
Federal Resource Conservation and Recovery Act	Standards Applicable to Transporters of Hazardous Waste	40 CFR 263	Applicable	Establishes standards which apply to persons transporting manifested hazardous waste within the United States.	Transport of waste that is characterized as hazardous.
Federal Resource Conservation and Recovery Act	Land Disposal Restrictions	40 CFR 268	Applicable	Identifies hazardous wastes which are restricted from land disposal. All listed and characteristic hazardous waste or soil or debris contaminated by a RCRA hazardous waste and removed from a CERCLA site may not be land disposed until treated as required by LDRs.	Waste disposal must comply with LDRs
Federal Hazardous Material Transportation Act	Hazardous Materials Transportation Regulations	49 CFR 107, 171, 172, 177 to 179	Applicable	Regulates transportation of hazardous materials.	Transportation of hazardous wastes must comply with the regulation.
New Jersey Statutes and Rules	Transportation of Hazardous Materials	N.J.A.C. 16:49	Applicable	Regulates shipping/transport of hazardous materials.	Must comply with requirements for off-site transport of hazardous materials.

Table 2-3
Potential Action-Specific ARARs
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Act/Authority	Criteria/Issues	Citation	Status	Brief Description	FS Consideration
OFF-GAS MANAGEMENT					
Federal Clean Air Act	National Ambient Air Quality Standards	40 CFR 50	Applicable	The air quality standards for particular matter, lead, NO_2, SO_2, CO, and volatile organic matter are specified.	Need to meet requirements when discharging off-gas.
Federal Clean Air Act	Standards of Performance for New Stationary Sources	40 CFR 60	Applicable	Provides emissions requirements for new stationary sources.	Need to meet requirements when discharging off-gas.
Federal Clean Air Act	National Emission Standards for Hazardous Air Pollutants	40 CFR 61	Applicable	Provides emission standards for 8 contaminants including benzene and vinyl chloride. Identifies 25 additional contaminants as having serious health effects but does not provide emission standards for these contaminants.	Need to meet requirements when discharging off-gas.
Federal Directive	Control of Air Emissions from Superfund Air Strippers	OSWER Directive 9355.0-28	To Be Considered	Provides guidance on the use of controls for Superfund site air strippers as well as other vapor extraction techniques in attainment and non-attainment areas for ozone.	Applicable to remediation alternatives which involve air stripping and vapor extraction process.
New Jersey Air Pollution Control Act	Permits and Certificates for Minor Facilities	N.J.A.C. 7:27 Subchapter 8	Applicable	Describes requirements and procedures for obtaining air permits and certificates.	Applicable to remediation alternatives which involve discharge of vapor.
New Jersey Air Pollution Control Act	Ambient Air Quality Standards	N.J.A.C. 7:27 Subchapter 13	Applicable	Rules that govern the emission of and such activities that result in the introduction of contaminants into the ambient atmosphere.	Need to meet requirements when discharging off-gas.

Table 2-4
Preliminary Remediation Goals (PRGs) for Groundwater
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Contaminant of Potential Concern	Federal Standards	New Jersey State Standards		Preliminary Remediation Goals [d]	No. of Samples Exceeding PRGs	Intermediate Sand		Lower Aquifer	
	Drinking Water [a] ug/L	Primary Drinking Water [b] ug/L	Groundwater Quality Standard Class IIA Groundwater[c] ug/L	ug/L		Maximum Detected Conc. ug/L	No. of Samples Exceeding PRGs	Maximum Detected Conc. ug/L	No. of Samples Exceeding PRGs
Chromium, Total	100	100	70 [e]	70	2	6310	9	4810	9
1,1-Dichloroethene	7	2	2 [f]	2	7	8.8	8	16	6
Tetrachloroethene	5	1	1	1	6	12	12	13	11
Trichloroethene	5	1	1	1	12	140	24	360	29

Notes:
(a) National Primary Drinking Water Standards, Maximum Contamination Limits (MCLs) (40 CFR 141).
(b) New Jersey Safe Drinking Water Act (NJSDWA) Primary Drinking Water Standards (N.J.A.C. 7:10 et seq.)
(c) New Jersey Groundwater Quality Standards (N.J.A.C. 7:9-6). Table 1 - Specific Groundwater Quality Criteria - Class II-A and Practical Quantitation Levels (PQLs).
(d) PRGs for groundwater COPCs are the most stringent of the standards.
(e) New Jersey Ground Water Quality Standards (N.J.A.C. 7:9C). Appendix Table 1 - Specific Groundwater Quality Criteria
(f) CLP Method Detection Limit

Table 2-6
Evaluation of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained
In - Situ Treatment	Physical/Chemical Treatment	Geochemical Fixation	A reducing agent (e.g., ferrous sulfate or sodium metabisulfite) is injected into the contaminated groundwater to reduce hexavalent chromium to trivalent chromium which precipitates out of solution and binds to the aquifer sediment material.	The effectiveness of this treatment process is proven at other sites. A treatability study would be required to evaluate the effectiveness at this site.	Injection well installation and piping could be completed with conventional equipment that is readily available in the area. Finding space for the injection wells and piping might prove to be difficult. No administrative difficulties are anticipated.	Moderate, but less expensive than pump and treat.	Yes
		Permeable Reactive Barrier	A PRB is constructed perpendicular to the flow path of a contaminant plume, allowing the plume to move through the barrier (e.g., sodium dithionite) which converts hexavalent chromium to trivalent chromium. Contaminants are removed through reaction with the permeable reactive medium. Barriers may consist of permanent or replaceable units and are typically constructed using conventional trenching techniques. However, barriers can be placed at greater depth using injection methods in which a reactive medium is injected directly into the subsurface.	A bench scale treatability study was performed at the site which determined that sodium dithionite effectively reduced hexavalent chroium to trivalent chromium. Additional pilot scale testing would be required to verify the effectiveness of the reducing agent.	Implementable. Difficulties are anticipated due to long plume width and location in a highly developed area. No administrative difficulties are anticipated.	Moderate, but less expensive than pump and treat.	Yes
Collection/Extraction	Groundwater Extraction	Extraction Wells	Groundwater is extracted from the subsurface using extraction wells screened in the saturated zone. Extracted groundwater is then treated as necessary to meet discharge requirements.	Groundwater extraction is effective in capturing and containing the contaminant plume. However, the high yielding aquifer would require high pumping rates for plume capture, and long pumping duration to acheive cleanup goals. This process must be implemented with a groundwater treatment technology.	Implementable. Extraction wells and piping would be placed in township-owned property in avoid access issue difficulties.	High	Yes
Ex-Situ Treatment	Physical/Chemical Treatment	Chemical Reduction and Precipitation	Treatment of chromium contamination requires the reduction of hexavalent chromium to the trivalent state. Following reduction, trivalent chromium is precipitated as a metal hydroxide.	Previous pilot study completed at the site has shown the process to be effective in treating the contaminated groundwater to achieve the discharge requirement. Chemical reduction and precipitation is a proven technology.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	High	Yes
		Electrochemical Precipitation	Electrochemical precipitation uses direct current to induce an oxidation-reduction reaction, which reduces hexavalent chromium to trivalent chromium. The trivalent chromium is precipitated to form sludge that must be treated and disposed offsite.	Treatment of hexavalent chromium with electrochemical precipitation is an effective and reliable groundwater remediation technology. This technology would achieve the 70 ug/L treatment goal.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	Moderate.	Yes
		Ion Exchange	Ion exchange is a process in which metal contaminants are removed from groundwater through exchange with relatively harmless ions in the ion exchange resins.	Ion exchange is a proven technology for treating groundwater contaminated with hexavalent chromium. Treatment by ion exchange is more effective for low flow rates and low influent concentrations. The high influent concentrations and flow rates may make this technology not cost effective. May be used as a polishing step.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	High. Would only be cost effective if used as a polishing step.	Yes
		Reverse Osmosis	Reverse osmosis is a filtration process whereby pressure is applied to the water to overcome the osmotic pressure and force the water through a membrane. The influent stream is separted into two streams, a clean effelent and a concentrated waste stream. The concentrated waste stream would require additional treatment which is typically expensive.	Reverse osmosis is typically effective for removing chromium and other metals from the groundwater stream, but would be more effective for use at sites with lower flow rates and contaminant concentrations. It is expected that cleanup of groundwater to 70 ug/L would be achievable for this technology, however, would generate large waste stream. May be used as a polishing step.	Reverse osmosis is technically implementable. However, finding a space for the treatment plant could be difficult.	High. Would only be cost effective if used as a polishing step.	Yes
		Iron Filtration Process	The iron filtration process consists of a column of zero valent iron filings and a sand filter in series. Heavy metals including chromium react with the iron filings to form solids. The sand filter removes the suspend solids.	The process has been tested at the bench scale in which hexavalent chromium levels were reduced from 10,000 ug/L to less than 2 ug/L.	The process has not been evaluated at the pilot- or full-scale level, so it is considered an emerging technology.	Moderate.	No
		Air Stripping	Contaminants are partitioned from the extracted groundwater by increasing the surface area of the groundwater in contact with the air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.	Air stripping is effective in removing VOCs from groundwater. Off gas may require treatment prior to discharge. Not effective in the treatment of chromium	Implementable. Minor administrative difficulties anticipated for implementation of air stripping system. May require permit for discharge of VOCs to the atmosphere. Alternatively, off-gas may require treatment (i.e., vapor phase carbon) prior to discharge.	High	Yes

Table 2-5
Identification and Screening of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Screening Comments	Retained
In-Situ Treatment	Physical/Biological	[illegible]	Compounds (e.g. air, hydrogen peroxide, magnesium peroxide) are injected below the groundwater table to increase the dissolved oxygen concentration, thereby enhancing the rate of aerobic biological degradation of contaminants by naturally occuring microbes.	Oxygen enhancement is not effective in treating chromuim.	No
		[illegible]	Water containing dissolved primary substrate and oxygen are injected into contaminated groundwater to enhance biological degradation of the contaminants; as the primary substrate undergoes biodegradation, the contaminants are oxidized as well.	Co-metabolic processes are not effective in treating chromuim.	No
		[illegible]	Solubilized nitrate is circulated throughout groundwater contamination zones to provide electron acceptors for biological activity, thereby enhancing the rate of aerobic biodegradation of contaminants by naturally occuring microbes.	This technology is not effective in treating chromium.	No
		[illegible]	Phytoremediation uses plants and their associated rhizospheric microorganisms to remove and/or degrade contaminants in groundwater. Contaminants are removed through: capture of groundwater; uptake of contaminants and accumulation or processing of contaminants via metabolization, mineralization, and transpiration; and rhizospheric degradation via microorganisms.	Phytoremediation has not been shown to effectively treat chromium. The process is not effective in areas with depth to groundwater is greater than 10 feet bgs; depth to groundwater at the site is greater than 10 feet bgs.	No
		Geochemical Fixation	A reducing agent (e.g., ferrous sulfate or sodium metabisulfite) is injected into the contaminated groundwater to reduce hexavalent chromium to trivalent chromium which precipitates out of solution and binds to the aquifer sediment material.	In situ geochemical fixation is an effective technology to treat chromium contaminated groundwater.	Yes
		Permeable Reactive Barrier	A PRB is constructed perpendicular to the flow path of a contaminant plume, allowing the plume to move through the barrier (e.g., sodium dithionite) which converts hexavalent chromium to trivalent chromium. Contaminants are removed through reaction with the permeable reactive medium. Barriers may consist of permanent or replaceable units and are typically constructed using conventional trenching techniques. However, barriers can be placed at greater depth using injection methods in which a reactive medium is injected directly into the subsurface.	PRBs constructed of reducing agents are effective in the treatment of chromium.	Yes
		[illegible]	Air is injected into the saturated matrix to strip the contaminants from the groundwater via volatilization. The contaminant-containing air is removed from the subsurface using an SVE system and treated above ground.	Air sparging with SVE is not effective in treating chromium.	No
	Physical/Chemical Treatment	[illegible]	Ozone is injected into the subsurface via injection wells to oxidize contaminants.	Oxidation using ozone is not effective in treating chromium.	No
		[illegible]	A mixture of hydrogen peroxide and an iron catalyst are injected into the saturated matrix. Free radicals are formed by interaction of the hydrogen peroxide with the iron catalyst. The free radicals oxidize the contaminants to end products. Reagents can be injected under pressure or dispersed via diffusion.	Oxidation using Fenton's reagent is not effective in treating chromium.	No
		[illegible]	A potassium permanganate ($KMnO_4$) solution is injected into the subsurface via injection wells. Contaminants are destroyed upon reaction with the $KMnO_4$.	Oxidation using potassium permanganate is not effective in treating chromium.	No
		[illegible]	Fracture enhancement is used to increase permeability in low permeability consolidated and unconsolidated material with hydraulic fracturing, pneumatic fracturing, or blasting. During hydraulic fracturing, a slurry of water, sand, and a thick gel is pumped at high pressure into the borehole to propagate the fracture and create a sand-filled lens. Pneumatic fracturing involves injection of air at a high pressure and flow rate to create fractures.	Fracture enhancement is not applicable to site conditions which exhibit highly permeable saturated zones.	No

Table 2-5
Identification and Screening of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Screening Comments	Retained
Collection/Extraction	Groundwater Extraction	Extraction Wells	Groundwater is extracted from the subsurface using extraction wells screened in the saturated zone. Extracted groundwater is then treated as necessary to meet discharge requirements.	Groundwater extraction is effective in removing contaminated groundwater from the impacted aquifer. Sorbed contaminants may result in long pumping time required for cleanup. This process must be implemented with a groundwater treatment technology.	Yes
		Interceptor Trench	A trench is constructed perpendicular to the direction of groundwater flow to intercept and prevent downgradient migration of a contaminant plume. Extraction wells or piping are typically installed within the trench to extract the intercepted groundwater. Extracted groundwater is then treated as necessary to meet discharge requirements.	Interceptor trenches are typically installed in poorly recharging shallow aquifer zones. Therefore, they are not applicable to this site.	No
Ex-Situ Treatment	Biological Treatment	Bioreactor	Contaminated groundwater is placed in contact with microorganisms in attached or suspended growth biological systems. In suspended growth systems, contaminated groundwater is circulated in an aeration basin where a microbial population degrades the contaminants. In attached growth systems, microorganisms are established on a fixed surface and degrade the contaminants as the groundwater passes over the surface.	Bioreactors are used primarily to treat non-chlorinated VOCs and SVOCs, and are not effective for treating chromium.	No
	Physical/Chemical Treatment	Chemical Reduction and Precipitation	Conversion of hexavalent chromium to the trivalent state, with subsequent clarification and filtration. Treatment of chromium contaminatio requires the reduction of hexavalent chromium to the trivalent state. Following reduction, trivalent chromium is precipitated as a metal hydroxide.	Chemical reduction and precipitation is effective for removing chromium from groundwater prior to discharge.	Yes
		Ion Exchange	Ion exchange is a process in which metal contaminants are removed from groundwater through exchange with relatively harmless ions in the ion exchange resins.	Ion exchange is a proven technology for treatment of groundwater contaminated with chromium. Treatment by ion exchange is more effective for low flow rates and low influent concentrations, making it more expensive for this site.	Yes
		Reverse Osmosis	Reverse osmosis is a filtration process whereby pressure is applied to the water to overcome the osmotic pressure and force the water through a membrane. The influent stream is separated into two streams, a clean effluent and a concentrated waste stream. The concentrated waste stream would require additional treatment which is typically expensive.	Reverse osmosis is typically effective for removing chromium and other metals from the groundwater stream, but would be more effective for use at sites with lower flow rates and contaminant concentrations. It is expected that cleanup of groundwater to 100 ug/L would be achievable for this technology.	Yes
		Electrochemical Precipitation	Electrochemical precipitation uses direct current to induce an oxidation-reduction reaction, which reduces hexavalent chromium to trivalent chromium. The trivalent chromium is precipitated to form sludge that must be treated and disposed offsite.	Treatment of chromium with electrochemical precipitation is an effective and reliable groundwater remediation technology. This technology would achieve the 100 ug/L treatment goal.	Yes
		Iron Filtration Process	The iron filtration process consists of a column of zero valent iron filings and a sand filter in series. Heavy metals including chromium react with the iron filings to form solids. The sand filter removes the suspend solids.	The process has been testad at the bench scale in which chromium levels were reduced from 10,000 ug/L to less than 2 ug/L.	Yes
		Air Stripping	Contaminants are partitioned from the extracted groundwater by increasing the surface area of the groundwater in contact with the air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.	Air stripping is effective in removing VOCs from groundwater. Off gas may require treatment prior to discharge. Not effective in treating chromium.	Yes
		Carbon Adsorption	Liquid phase carbon may be used to treat groundwater, vapor phase carbon may be used to treat off-gas. Contaminants are adsorbed on to activated carbon by passing the extracted groundwater or off-gas through a series of reactor vessels containing activated carbon. Spent carbon must be reactivated or replaced periodically.	Carbon adsorption is effective in removing VOCs, but not applicable to high flow rates anticipated at the site. Not effective in treating chromium.	No
		UV Oxidation/Hydrogen Peroxide	Contaminated groundwater is transferred to a reactor where it is combined with ozone and/or hydrogen peroxide and irradiated with UV light. Contaminants are destroyed as a result of the synergistic action of the oxidant with the UV light. System may require off-gas treatment to destroy unreacted ozone, if used, and volatilized contaminants.	UV oxidation is not effective in treating chromium.	No

Table 2-5
Identification and Screening of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Screening Comments	Retained
Disposal/Discharge	On-Site Disposal	Injection Wells	Treated groundwater is discharged on site to the subsurface through a series of injection wells.	Groundwater must be treated to meet discharge requirements. Effectiveness of reinjection is expected to be good due to physical properties of the subsurface (e.g., high hydraulic conductivity and aquifer capacity).	Yes
		Recharge Facilities	Treated groundwater is disposed on site via a subsurface discharge system consisting of excavated trenches backfilled with drain rock (gravel) and perforated piping .	Groundwater must be treated to meet discharge requirements. Effectiveness of infiltration is expected to be good due to physical properties of the subsurface (e.g., high hydraulic conductivity and aquifer capacity).	Yes
	Off-Site Disposal	[redacted]	Treated groundwater is disposed of at a publicly-owned treatment works via a sanitary sewer.	Extracted groundwater must be treated to meet POTW influent criteria prior to disposal. Discharge volume is limited by capacity of existing conveyance and treatment systems Therefore this technology is not an effective option.	No
		Surface Water Discharge	Treated groundwater is discharged via a storm sewer to a surface water body located off-site.	Discharge to an off-site surface water body requires that the extracted groundwater be treated to applicable standards and meet NJDPES requirements. Discharge volume may be somewhat limited by capacity of conveyance system (storm sewer).	Yes
		Public Water System Discharge		Will provide additional capacity to the drinking water supply. Potential for concern over untreated chromium contaminated water reaching potable water users should the treatment system fail to operate effectively.	Yes

NOTES:
[redacted]: Technology eliminated from further evaluation.

Table 2-6
Evaluation of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained
No Action	None	Not Applicable	No remedial actions are implemented.	Does not meet remedial action objectives. No Action alternative retained as baseline for comparison with other alternatives as required by the NCP.	Implementable. No significant administrative difficulties anticipated.	No cost for this reponse action.	Yes
Institutional Controls	Deed Restrictions	Not Applicable	Deed restrictions are regulatory actions that prevent certain uses of the site where exposure to groundwater represents unacceptable human health risks.	Deed restrictions may be effective in reducing or eliminating human health risk. Deed restrictions will not reduce risk to the environment.	Implementable. May be difficult to enforce deed restrictions on a long-term basis. CEA could achieve same results with less administrative difficulty.	Low, some long-term costs for periodic reassessment.	No
	Classification Exemption Area (CEA)	Not Applicable	The CEA is defined as the area of the aquifer that is currently and is anticipated to be impacted above the applicable groundwater quality standard. The CEA remains in effect until the contaminant concentrations have decreased to the applicable groundwater quality standards.	Effective in protection of human health by preventing the installation of pumping wells in the affected area.	Implementable. The CEA is issued by the state. May be difficult to enforce on a long-term basis.	Low	Yes
	Long-term Monitoring	Not Applicable	Periodic sampling and analysis of groundwater.	Effective in tracking the movement of contamination or progress of remediation. Does not reduce contaminant concentrations.	Highly implementable. All monitoring wells are easily accessible for sample collection. Will require access agreement with property	Low to Moderate	Yes
Monitored Natural Attenuation	None	Not Applicable	Natural subsurface processes (e.g., dilution, volatilization, biodegradation, adsorption, and reaction with subsurface materials) reduce contaminant concentrations to acceptable levels. Concentrations of hexavalent and trivalent chromium and indicator parameters (e.g., oxidation/reduction potential) are monitored to verify effectiveness of natural attenuation.	Effective remediation approach that utilizes natural mechanisms to control plume migration. Natural reducting agents are present outside the plume area to reduce hexavalent chromium to trivalent chromium. Monitoring would be performed to demonstrate that MNA meets remedial action objectives.	Moderately implementable. Administrative feasibility would be difficult due to need to demonstrate natural attenuation processes are protective of downgradint wells.	Low.	Yes
Containment	Vertical Barrier	Slurry Wall	A slurry wall is a subsurface barrier consisting of a vertically excavated trench filled with a slurry. The slurry (typically either a soil/bentonite/water mixture or a cement/bentonite/water mixture) shores the trench to prevent collapse and provides a physical barrier to groundwater flow.	Will not meet PRGs if implemented alone. Barrier is effective in containing contaminated groundwater in relatively small areas, diverting the contaminant plume to a treatment system, or diverting uncontaminated groundwater around a contaminant source. Contaminant concentrations are not reduced.	Not implementable. Slurry walls are keyed into a low permeability layer and placed at depth of up to 100 feet bgs. However, contaminants are present in the Intermediate Sand at 130 to 150 ft bgs, and Lower aquifer at 160 to 250 ft bgs. No administrative difficulties anticipated for slurry wall construction.	Moderate. Soil/Bentonite: $10 per square foot (cross-section). Cement/Bentonite: $20 per square foot (cross-section).	No
		Synthetic Membrane Barrier	Synthetic membrane barriers consist of interlocking sheets of geomembrane placed vertically in the ground to form a barrier wall. The barrier can be constructed by placing the geomembrane in an excavated trench or by using vibratory methods without trench construction.	Will not meet PRGs if implemented alone. Barrier is effective in containing contaminated groundwater in relatively small areas, diverting the contaminant plume to a treatment system, or diverting uncontaminated groundwater around a contaminant source. Contaminant concentrations are not reduced.	Not implementable. Synthetic membrane barriers are typically keyed into a low permeability layer and placed at depth of 30 to 40 feet bgs. However, contaminants are present in the Intermediate Sand at 130 to 150 ft bgs, and Lower aquifer at 160 to 250 ft bgs. No administrative difficulties anticipated for synthetic membrane barrier construction.	Moderate. $15 to $20 per square foot (cross-section).	No
		Grout Curtain Barrier	A grout curtain is a solid, low-permeability subsurface vertical barrier formed by injecting grout (Portland cement or sodium silicate) through well points.	Will not meet PRGs if implemented alone. Barrier is effective in containing contaminated groundwater in relatively small areas, diverting the contaminant plume to a treatment system, or diverting uncontaminated groundwater around a contaminant source. Contaminant concentrations are not reduced.	Implementable. Grout curtains are not subject to the depth limitations of other vertical barriers considered. However, it may be difficult to verify whether or not a continuous barrier has been formed. No administrative difficulties anticipated for the grout curtain barrier.	High. $15 to $100 per square foot (cross section).	Yes
		Sheet Pile Barrier	Sheet pile barriers are interlocking sheets of steel sheet piling placed vertically in the ground to form a barrier wall. The barrier can be constructed by placing the sheet piling in an excavated trench or by driving or vibrating sections of sheet piling into the ground.	Will not meet PRGs if implemented alone. Barrier is effective in containing contaminated groundwater in relatively small areas, diverting the contaminant plume to a treatment system, or diverting uncontaminated groundwater around a contaminant source. Contaminant concentrations are not reduced.	Not implementable. Sheet pile walls are typically keyed into a low permeability layer and placed at depth of 75 feet bgs. However, contaminants are present in the Intermediate Sand at 130 to 150 ft bgs, and Lower aquifer at 160 to 250 ft bgs. No administrative difficulties anticipated for sheet pile barrier construction.	Moderate. $15 to $30 per square foot. (Cross-section)	No

Table 2-6
Evaluation of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained
In - Situ Treatment	Physical/Chemical Treatment	Geochemical Fixation	A reducing agent (e.g., ferrous sulfate or sodium metabisulfite) is injected into the contaminated groundwater to reduce hexavalent chromium to trivalent chromium which precipitates out of solution and binds to the aquifer sediment material.	The effectiveness of this treatment process is proven at other sites. A treatability study would be required to evaluate the effectiveness at this site.	Injection well installation and piping could be completed with conventional equipment that is readily available in the area. Finding space for the injection wells and piping might prove to be difficult. No administrative difficulties are anticipated.	Moderate, but less expensive than pump and treat.	Yes
		Permeable Reactive Barrier	A PRB is constructed perpendicular to the flow path of a contaminant plume, allowing the plume to move through the barrier (e.g., sodium dithionite) which converts hexavalent chromium to trivalent chromium. Contaminants are removed through reaction with the permeable reactive medium. Barriers may consist of permanent or replaceable units and are typically constructed using conventional trenching techniques. However, barriers can be placed at greater depth using injection methods in which a reactive medium is injected directly into the subsurface.	A bench scale treatability study was performed at the site which determined that sodium dithionite effectively reduced hexavalent chrome to trivalent chromium. Additional pilot scale testing would be required to verify the effectiveness of the reducing agent.	Implementable. Difficulties are anticipated due to long plume width and location in a highly developed area. No administrative difficulties are anticipated.	Moderate, but less expensive than pump and treat.	Yes
Collection/Extraction	Groundwater Extraction	Extraction Wells	Groundwater is extracted from the subsurface using extraction wells screened in the saturated zone. Extracted groundwater is then treated as necessary to meet discharge requirements.	Groundwater extraction is effective in capturing and containing the contaminant plume. However, the high yielding aquifer would require high pumping rates for plume capture, and long pumping duration to acheive cleanup goals. This process must be implemented with a groundwater treatment technology.	Implementable. Extraction wells and piping would be placed in township-owned property in avoid access issue difficulties.	High	Yes
Ex-Situ Treatment	Physical/Chemical Treatment	Chemical Reduction and Precipitation	Treatment of chromium contamination requires the reduction of hexavalent chromium to the trivalent state. Following reduction, trivalent chromium is precipitated as a metal hydroxide.	Previous pilot study completed at the site has shown the process to be effective in treating the contaminated groundwater to achieve the discharge requirement. Chemical reduction and precipitation is a proven technology.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	High	Yes
		Electrochemical Precipitation	Electrochemical precipitation uses direct current to induce an oxidation-reduction reaction, which reduces hexavalent chromium to trivalent chromium. The trivalent chromium is precipitated to form sludge that must be treated and disposed offsite.	Treatment of hexavalent chromium with electrochemical precipitation is an effective and reliable groundwater remediation technology. This technology would achieve the 100 ug/L treatment goal.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	Moderate.	Yes
		Ion Exchange	Ion exchange is a process in which metal contaminants are removed from groundwater through exchange with relatively harmless ions in the ion exchange resins.	Ion exchange is a proven technology for treating groundwater contaminated with hexavalent chromium. Treatment by ion exchange is more effective for low flow rates and low influent concentrations. The high influent concentrations and flow rates may make this technology not cost effective. May be used as a polishing step.	The treatment process is technically implementable. However, finding a space for the treatment plant could be difficult.	High. Would only be cost effective if used as a polishing step.	Yes
		Reverse Osmosis	Reverse osmosis is a filtration process whereby pressure is applied to the water to overcome the osmotic pressure and force the water through a membrane. The influent stream is separted into two streams, a clean effelent and a concentrated waste stream. The concentrated waste stream would require additional treatment which is typically expensive.	Reverse osmosis is typically effective for removing chromium and other metals from the groundwater stream, but would be more effective for use at sites with lower flow rates and contaminant concentrations. It is expected that cleanup of groundwater to 100 ug/L would be achievable for this technology, however, would generate large waste stream. May be used as a polishing step.	Reverse osmosis is technically implementable. However, finding a space for the treatment plant could be difficult.	High. Would only be cost effective if used as a polishing step.	Yes
		[illegible]	The iron filtration process consists of a column of zero valent iron filings and a sand filter in series. Heavy metals including chromium react with the iron filings to form solids. The sand filter removes the suspend solids.	The process has been tested at the bench scale in which hexavalent chromium levels were reduced from 10,000 ug/L to less than 2 ug/L.	The process has not been evaluated at the pilot- or full-scale level, so it is considered an emerging technology.	Moderate.	No
		Air Stripping	Contaminants are partitioned from the extracted groundwater by increasing the surface area of the groundwater in contact with the air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.	Air stripping is effective in removing VOCs from groundwater. Off gas may require treatment prior to discharge. Not effective in the treatment of chromium.	Implementable. Minor administrative difficulties anticipated for implementation of air stripping system. May require permit for discharge of VOCs to the atmosphere. Alternatively, off-gas may require treatment (i.e., vapor phase carbon) prior to discharge.	High.	Yes

Table 2-6
Evaluation of Remedial Technologies and Process Options
OU1 Feasibility Study
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained
Disposal/Discharge	On-Site Disposal	Injection Wells	Treated groundwater is discharged on site to the subsurface through a series of injection wells.	Groundwater must be treated to meet discharge requirements. Effectiveness of reinjection is dependent on physical properties of the subsurface (e.g., hydraulic conductivity and aquifer capacity). Formation is highly permeable and suitable for reinjection.	Implementable. Minor administrative difficulties anticipated for groundwater reinjection; discharge permit may be required for injection to the subsurface.	High.	Yes
		Recharge Facilities	Treated groundwater is disposed on site via a subsurface discharge system consisting of excavated trenches backfilled with drain rock (gravel) and perforated piping .	Groundwater must be treated to meet discharge requirements. Effectiveness of infiltration is dependent on physical properties of the subsurface (e.g., hydraulic conductivity and aquifer capacity). Formation is highly permeable, however less permeable lenses may be present 30 ft bgs. Therefore, the site is moderately suitable for recharge facilites.	Implementable. Minor administrative difficulties anticipated for groundwater infiltration; discharge permit may be required for infiltration to the subsurface.	High	Yes
	Off-Site Disposal	Surface Water Discharge	Treated groundwater is discharged via a storm sewer to a surface water body located off-site.	Discharge to an off-site surface water body requires that the extracted groundwater be treated to applicable standards and meet NJDPES requirements. Discharge volume may be limited by capacity of existing storm sewer lines.	Implementable. Can use existing storm sewer system. Discharge permit would be required.	Low.	Yes
		[illegible]	Treated water is delivered directly to the local drinking water supply.	Discharge of treated water to public water supply system requires that the extracted groundwater be treated to drinking water standards. The addition of treated drinking water would increase the capacity of the existing drinking water system, which is not abundant.	Implementable. Would require connection of pipeline to water supply. A point source discharge permit would be necessary. Public agencies and users are not receptive to this option	Low.	No

NOTES:
[illegible]: Technology eliminated from further evaluation.

3 Section Three

Section 3
Development and Screening of Remedial Action Alternatives

In Section 2, potentially applicable general response actions and related technologies and process options were identified and a preliminary screening was performed. In this section, those technologies and process options retained after the preliminary screening are combined to form remedial action alternatives. Assumptions used in developing the remedial action alternatives are discussed in Section 3.1. The remedial action alternatives developed for the site groundwater are described briefly in Section 3.2.

3.1 Development of Remedial Action Alternatives

In this section, remedial alternatives developed for treating contaminated groundwater at the Site are described briefly. Alternatives were developed using remedial technologies and process options retained in the screening process presented in Section 2. The technologies and process options include:

- No action (retained for comparison only)
- Institutional controls, including CEA, extraction well restrictions and long-term monitoring
- Monitored natural attenuation
- Grout curtain (retained only in combination with in situ treatment, if deemed necessary by groundwater modeling)
- In situ treatment, including:
  - Permeable reactive barriers
  - Geochemical fixation
- Groundwater extraction using groundwater extraction scenario EX-I
- Ex situ treatment, including:
  - Chemical reduction and precipitation
  - Electrochemical precipitation
  - Ion exchange (as secondary treatment)
  - Reverse osmosis (as secondary treatment)
  - Air stripping (for treatment of VOCs only)
- Disposal (retained only in combination with groundwater extraction and treatment), including:
  - Injection wells
  - Recharge facilities
  - Surface water discharge, as necessary

In developing remedial alternatives for the groundwater at the Site, representative process options were selected from some groups of remedial technologies, as appropriate. For example, chemical reduction and precipitation was selected in place of electrochemical precipitation as the representative ex situ treatment process because it is an effective and technically feasible treatment option. However, electrochemical

precipitation may still be applicable and should be considered during the remedial design.

Assumptions used to develop remedial alternatives for the Site are:

- In situ treatment using permeable reactive barriers would use sodium dithionite as a reducing agent.
- In situ geochemical fixation would use sodium metabisulfite as a reducing agent.
- The ex situ remediation alternative would implement groundwater extraction scenario EX-I.
- The ex situ treatment train would include chemical reduction and precipitation using ferrous iron as a reducing agent, and air stripping.
- Treated groundwater would be re-injected through injection wells. Any excess groundwater would be discharged to off-site surface water.
- All remedial alternatives, except the No Action alternative, include institutional controls during remediation.

3.2 Description of Remedial Action Alternatives

3.2.1 Alternative 1 - No Action

The No Action alternative was retained for comparison purposes as required by the NCP. No remedial actions would be implemented as part of the No Action alternative. This alternative does not include institutional controls.

3.2.2 Alternative 2 - MNA/In Situ Treatment (Contingency Remedy)/Institutional Controls

In this alternative, hexavalent chromium would be allowed to be reduced to trivalent chromium by the natural reducing capacity of the aquifer sediment. Groundwater would be sampled to monitor the groundwater contaminant concentrations and hexavalent chromium reduction over time. Additional monitoring wells may be installed, as necessary, to allow for comprehensive monitoring of the contamination.

A compliance zone would be designated to monitor the plume movement. Groundwater monitoring would be performed to monitor changes in contaminant concentrations and distribution over time within the compliance zone. If monitoring indicates that a certain portion of the plume has migrated past the compliance zone, an in situ treatment zone would be installed upgradient of the compliance zone, either within or downgradient of the plume area that passes the compliance zone, in either or both the Intermediate Sand and Lower aquifer. Groundwater modeling would be performed to determine whether a grout curtain would be necessary to direct the groundwater towards the treatment zone. Depending on the in situ treatment approach, either PRB using a reducing agent such as sodium dithionite (Sub-alternative 2A), or geochemical fixation using a reducing agent such as sodium metabisulfite (Sub-alternative 2B) would be selected. Institutional controls such as

CEA and prohibition to new well installation would be implemented to prevent exposure to contaminated groundwater.

3.2.3 Alternative 3 - In Situ Treatment/MNA/Institutional Controls

In this alternative, an in situ treatment zone would be installed in selected areas either downgradient of or within the plume area to reduce hexavalent chromium to trivalent chromium in the Middle Aquifer, Intermediate Sand and Lower aquifer. Depending on the in situ treatment approach either PRB using a reducing agent such as sodium dithionite (Sub-alternative 3A), or geochemical fixation using a reducing agent such as sodium metabisulfite (Sub-alternative 3B and 3C) would be selected. Sub-alternatives 3A and 3B would target the chromium plume greater than 1,000 μg/L, while Sub-alternative 3C would treat the entire plume above the 70 μg/L chromium PRG. The target value of 1,000 ug/L was selected because it is sufficiently higher than the PRG and, yet, about half the plume exceeds this value. This target value will allow for roughly half the plume to be treated in situ, to 1,000 ug/L, and the remainder to be treated via MNA to the PRG of 70 ug/L. Groundwater modeling would be performed to determine whether a grout curtain would be necessary to direct the groundwater towards the treatment zone. In areas that do not have an in situ treatment zone, hexavalent chromium would be allowed to be reduced to trivalent chromium by the natural reducing capacity of the aquifer sediment. Groundwater monitoring would be performed to determine if a treatment zone is required. Institutional controls would be implemented to prevent exposure to contaminated groundwater.

3.2.4 Alternative 4 – Groundwater Extraction/Treatment/Off-Site Disposal/Long-Term Groundwater Monitoring/ Institutional Controls

In this alternative, contaminated groundwater would be extracted and treated ex situ. Groundwater extraction would be implemented using groundwater extraction scenario EX-I (Appendix B). Treatment of extracted groundwater would include inorganic removal using chemical reduction and precipitation using a reducing agent such as ferrous iron, and VOC removal using air stripping. Treated water would be re-injected or recharged back into the ground. Any excess groundwater would be discharged to off-site surface water. Groundwater monitoring would be performed to evaluate changes in contaminant concentrations and distributions over time. Institutional controls would be implemented to prevent exposure to contaminated groundwater during remediation.

3.3 Screening of Remedial Alternatives

Since only a limited number of remedial alternatives were developed, all alternatives will be carried forward for detailed analysis. Screening of remedial alternatives will not be performed.

4 Section Four

Section 4
Detailed Analysis of Remedial Action Alternatives

In this section, detailed analysis is provided for those alternatives that were developed in Section 3, work quantities and the duration of work are estimated, components of the alternatives listed in the previous section are broken down, and specific work items associated with these components are defined in greater details.

In Section 4.1, the nine criteria used in the detailed analysis of alternatives are defined. The detailed analysis of the alternatives is presented in Section 4.2. A comparison of the alternatives is presented in Section 4.3.

4.1 Introduction

The detailed analysis of each alternative consists of an evaluation against the following nine criteria specified in the EPA RI/FS Guidance Document (EPA 1988):

Threshold Criteria:

Threshold criteria are requirements that must be met in order for alternatives to be eligible for selection.

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

Balancing Criteria:

Balancing criteria are used to assess the relative effectiveness of alternatives based upon their strengths and weaknesses.

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

Modifying Criteria:

Two additional criteria, designated as "modifying criteria," are also specified for assessment after the public comment period. These are:

- State acceptance
- Community acceptance

In this FS, alternatives are evaluated with respect to the first seven criteria listed above. NJDEP comments on the Draft FS have been incorporated into this Final FS report. The community acceptance criterion will be evaluated after the public

comment period. A further definition of these criteria is presented in the following paragraphs; the definitions presented herein are taken from the EPA RI/FS Guidance Document (EPA 1988).

4.1.1 Overall Protection of Human Health and the Environment

This criterion provides a final evaluation of each alternative to assess whether it achieves adequate protection of human health and the environment. This overall assessment is based on other evaluation criteria, especially long term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Evaluation of alternatives against this criterion focuses on whether an alternative achieves adequate protectiveness and describes how risks through each pathway are eliminated, reduced, or controlled through treatment, engineering, or institutional controls. This criterion considers any unacceptable short-term or synergistic (e.g., cross-media) effects posed by an alternative.

4.1.2 Compliance with ARARs

This criterion is used to evaluate whether each alternative will meet the ARARs, identified in Section 2 of this FS. The detailed evaluation considers which ARARs are applicable to each of the specific alternatives, and describes how the alternative meets the ARARs. These include chemical-specific, location-specific, and action-specific ARARs. The final determination of applicable ARARs is made by the lead agency.

4.1.3 Long-Term Effectiveness and Permanence

This criterion evaluates the results of a remedial alternative subsequent to its implementation in terms of the risk remaining at the Site. The two main components of this are: (a) magnitude of residual risk from untreated waste or treatment residuals; and (b) adequacy and reliability of controls, if any, used to manage untreated wastes or treatment residuals.

4.1.4 Reduction of Toxicity, Mobility or Volume through Treatment

This criterion addresses the EPA policy preference for remedial alternatives which utilize technologies that permanently and significantly reduce the TMV of hazardous substances as their principal element. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated medium.

4.1.5 Short-Term Effectiveness

This criterion evaluates the effects of the alternative during the construction and implementation phase of the alternative. The main factors addressed in this evaluation are: (a) protection of the community during remedial actions; (b) protection of workers during remedial actions; (c) potential adverse environmental

impacts resulting from construction and implementation; and (d) time until remedial response objectives are met.

4.1.6 Implementability

This criterion addresses the technical and administrative feasibility of implementing the alternative, and the availability of services and materials required for its implementation. The specific components of this criterion are described below.

- Technical feasibility includes: (a) construction and operation, including technical difficulties and unknowns associated with the technologies included in the alternative; (b) reliability of the technologies; (c) ease of undertaking additional remedial actions (more significant at sites for which an interim action is being conducted); and (d) monitoring considerations.

- Administrative feasibility refers primarily to the necessary coordination with other offices and agencies such as for permit acquisition.

- Availability of services and materials includes assessment of the availability of the treatment, storage, and disposal services necessary to implement the alternative; the availability of the technologies; and the availability of additional equipment or specialists. The EPA RI/FS Guidance Document (EPA 1988) also includes the potential for obtaining competitive bids as part of this criterion.

4.1.7 Cost

The cost criterion is divided into the two categories: capital costs and O&M costs. Capital costs include: (a) direct capital costs such as construction, equipment, land and site development, buildings and services, and disposal costs; (b) indirect capital costs such as engineering expenses, construction management costs, license and permit costs, startup and shakedown costs; and (c) contingency allowances. O&M costs are costs associated with long-term operation of the remedy after completion of the construction that include operating labor, maintenance material and labor, auxiliary materials and energy, costs for residue disposal, administrative work, and equipment rehabilitation or replacement costs. For the purposes of this FS, mobilization and demobilization costs, start-up and health and safety expenses are included as capital costs.

Analysis of costs was performed using vendor-supplied information and other references (e.g., R.S. Means Site Work Cost Data; R.S. Means Environmental Cost Data), supplemented by the RAC II Team's experience and vendor data.

In order to compare economic costs of the various alternatives, present worth analyses were performed. For these analyses, it was assumed that the resources and activities required to perform operation and maintenance will remain constant over the period of remediation. A discount rate of 7 percent was assumed for the purposes of this FS. Capital costs were calculated in 2006 dollars and not discounted; only O&M costs

incurred after the first year were discounted for the net present worth analysis. Pursuant of the EPA FS Costing Guidance (EPA 2000a), the costs are expected to be within -30 to +50 percent accuracy.

4.1.8 State Acceptance

This criterion addresses technical and administrative preferences and issues that the State of New Jersey may have regarding each alternative. Alternatives are evaluated based upon their support/acceptance by the NJDEP and other regulatory agencies. NJDEP comments on the Draft FS have been incorporated into this Final FS.

4.1.9 Community Acceptance

This criterion will incorporate public comments which have been provided to federal and state agencies during the RI/FS process. The assessment of community acceptance will address those alternatives that the community formally supports or opposes. Community input on the FS Report will be solicited during the public comment period, during which time the FS Report will be available for public review. A responsiveness summary will be prepared to address comments received during the public comment period. A summary of the public comments and responses will be included in the Record of Decision (ROD). As a result, no assessment or estimate of community acceptance will be made in this FS Report.

4.2 Individual Analysis of Remedial Action Alternatives

Based upon the results of the screening analysis of remedial technologies presented in Section 2 and the development and screening of remedial action alternatives in Section 3, four candidate remedial action alternatives were developed. They are as follows:

Alternative 1 - No Action

Alternative 2 - MNA/In Situ Treatment (Contingency Remedy)/ Institutional Controls
- Sub-alternative 2A - In situ treatment (contingency remedy) via permeable reactive barrier
- Sub-alternative 2B - In situ treatment (contingency remedy) via geochemical fixation

Alternative 3 - In Situ Treatment/MNA/Institutional Controls
- Sub-alternative 3A - In situ treatment via permeable reactive barrier for chromium plume > 1,000 μg/L
- Sub-alternative 3B - In situ treatment via geochemical fixation for chromium plume > 1,000 μg/L
- Sub-alternative 3C - In situ treatment via geochemical fixation for chromium plume > 70 μg/L

Alternative 4 - Groundwater Extraction/Treatment/Off-Site Disposal/Long-term Groundwater Monitoring/ Institutional Controls

These alternatives were developed based upon the RAOs described in Section 2 and the procedures for developing a range of remedial action alternatives, as specified in the NCP and the EPA RI/FS Guidance Document (EPA 1988).

The above alternatives are not intended to account for all possible combinations associated with the remedial technologies retained for further consideration following the screening analysis (Section 2). Rather, the alternatives are representative of the full range of plausible remedial action alternatives, considering variable degrees of design conservatism and cost. When more than one process options were retained, representative process options were used to develop the alternatives for evaluation and costing purposes. The selection of any particular process option will be determined during the remedial design or remedial action phase. The remedial action ultimately selected for this Site is expected to be similar to one of these alternatives, but is in no way limited to them.

The remedial action alternatives are described in this section with sufficient detail to complete detailed analyses. Preliminary design assumptions were developed for each alternative for the purpose of completing detailed analyses and estimating implementation costs. The design assumptions were based upon existing site data and information, and are expected to be representative of the conditions that would be encountered during the remedial action. The final configuration of the remedial action alternative selected for implementation will be determined during the remedial design phase of this project.

The detailed analysis of remedial alternatives is discussed in detail below. The results of this analysis and the corresponding cost estimates are summarized in Tables 4-1 and 4-2, respectively.

4.2.1 Alternative 1 - No Action

The No Action alternative was retained for comparison purposes as required by the NCP. No remedial actions would be implemented as part of the No Action alternative. This alternative does not include institutional controls.

4.2.1.1 Overall Protection of Human Health and the Environment

The RI results indicate that hexavalent chromium contamination was primarily detected in the Intermediate Sand and Lower aquifers. Figure 1-2 highlights the aqueous chromium plume areas based on hexavalent chromium concentrations greater than 70 µg/L. The Lower aquifer is a drinking water source for the area and several municipal well fields are located in the vicinity of the Puchack Well Field Site. The Puchack well field has been shut down and the chromium contaminated groundwater is not being consumed. However, the chromium plume has spread into multiple aquifers from the source areas over the years. There is the potential for the plume to continue to migrate towards the municipal well fields east of the Westfield Avenue. The chromium plume may be attenuated or fixated by the natural reduction capacity of the aquifer sediment. However, because no remedial action would be implemented under this alternative, no means would be available to assess or monitor the migration and fate of the chromium plume.

This alternative would not provide protection to the environment since contamination would persist in groundwater and there would be no mechanism to monitor the migration of the contaminants.

This alternative would not achieve the RAOs.

4.2.1.2 Compliance with ARARs

Because of the presence of high concentrations of hexavalent chromium in the environment, this alternative would not meet the groundwater quality standards for chromium (chemical-specific ARAR).

No location-specific ARARs were identified. As this alternative involves no action, action specific ARARs are not applicable.

4.2.1.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - No Action is not considered to be a permanent remedy, the contaminants would not be destroyed, except gradual reductions through natural attenuation. Potential future human health risks would not be altered by implementation of this alternative.

Adequacy of Controls - Currently there is no risk to human health since the contaminated groundwater is not being used. This alternative would not provide adequate control of risks to human health or the environment because there are no mechanisms to prevent future exposure.

Reliability of Controls - Under this alternative there would be no mechanism in place to prevent future risk to human health, therefore this alternative would not be considered reliable.

No Action is considered not to be effective in the long term.

4.2.1.4 Reduction of Toxicity, Mobility or Volume through Treatment

The implementation of this alternative would not affect the TMV of the residual contaminants. The toxicity and mass (volume) of contaminants in groundwater would be gradually reduced over the long-term by natural attenuation processes.

4.2.1.5 Short-Term Effectiveness

This alternative would not include a remedial action. Therefore, it would have no short-term impact to workers or the community.

There would be no adverse environmental impacts to habitats or vegetation due to the implementation of the alternative.

4.2.1.6 Implementability

This alternative is easily implemented, since no services or permits would be required.

4.2.1.7 Cost

There would be no cost under this alternative.

4.2.1.8 State Acceptance

NJDEP comments on the draft report have been incorporated into this Final FS report.

4.2.1.9 Community Acceptance

Alternatives are evaluated based upon their acceptance by the community. Community acceptance would be formally addressed after the Final FS and Proposed Plan have been issued to the public for formal review and comment, and a public meeting/availability session has been held by EPA. Community acceptance would be formally addressed in the Responsiveness Summary of the ROD, which would present EPA's responses to the public's questions and concerns regarding the FS and Proposed Plan.

4.2.2 Alternative 2 - MNA/In Situ Treatment (Contingency Remedy)/Institutional Controls

Alternative 2 consists of the following components:

- Long-term groundwater monitoring of natural attenuation
- In situ treatment (contingency remedy) via permeable reactive barrier (Sub-alternative 2A)
- In situ treatment (contingency remedy) via geochemical fixation (Sub-alternative 2B)
- Institutional controls
- Periodic site reviews

Under this alternative, the chromium plume would be allowed to become attenuated or fixated through the natural reduction capacity of the aquifer sediment. Hexavalent chromium is toxic and mobile (very soluble in water). However, hexavalent chromium is very unstable and can be easily converted (reduced) to trivalent chromium, which is non-toxic, not mobile (precipitates and fixates to the soil matrix), and extremely stable. The reaction is not reversible under all normal environmental conditions. A bench scale treatability study conducted by PNNL (PNNL 2005) has demonstrated that there is more than sufficient natural reduction capacity in the aquifer (outside the plume area) to reduce the hexavalent chromium before it will reach any municipal wells. Soil particles can adsorb hexavalent chromium, thereby impeding the mobility of hexavalent chromium. The chromium plume is expected to migrate a few feet to tens of feet per year. The migration and reduction of the chromium plume would be monitored through the long-term groundwater monitoring program. A contingent remedy using in situ treatment is also included in

this alternative in the event that the hexavalent plume migrates past a designated compliance zone.

Long-term Groundwater Monitoring. A long-term groundwater monitoring program would be instituted to collect data on contaminant concentrations and plume properties at the Site. Eleven existing wells in the Intermediate Sand, and nine existing wells in the Lower aquifer would be used for the long-term groundwater monitoring program. It is expected that three new Intermediate Sand monitoring wells and four new Lower aquifer monitoring wells would be installed to enhance the existing monitoring well network. Locations of monitoring wells to be sampled for MNA are shown in Figure 4-1. Groundwater samples would be collected annually and analyzed for total and hexavalent chromium and natural attenuation parameters including oxygen, nitrate, soluble manganese, ferrous iron, sulfate, total organic carbon, chloride, pH, temperature, and oxidation/reduction potential. The monitoring data collected would be evaluated and used to assess the migration and attenuation of the contaminant plume through time and to plan for remedial action, if required.

In addition, a clean area (e.g., 100 foot zone) downgradient of the existing hexavalent chromium plume would be designated as a compliance zone. An additional 10 monitoring wells would be installed in this zone (5 Intermediate Sand, 5 Lower aquifer). Data collected from the groundwater monitoring would be used to assess the effectiveness of MNA. The compliance zone would be monitored for evidence of breakthrough. Should MNA prove to be unsuccessful, the contingency remedy of in situ treatment would be instituted. Sub-alternative 2A would include in situ treatment by installation of a PRB using a reducing agent such as sodium dithionite. Sub-alternative 2B would include in situ treatment by geochemical fixation using a reducing agent such as sodium metabisulfite. The final treatment method and reducing agent would be determined at the time of implementation.

In Situ Treatment (Contingency Remedy) via Permeable Reactive Barrier (Sub-alternative 2A). A PRB would be installed on the downgradient edge of the portion of the contaminant plume that had passed through the 100 foot wide compliance zone. A conceptual drawing is provided in Figure 4-1. Compliance zone monitoring wells (one Intermediate Sand and one Lower aquifer monitoring well) would be installed every 800 feet along Westfield Avenue. Should the chromium plume enter a 800-foot long compliance zone segment, then a PRB would be installed in that segment. For costing purposes it has been assumed that 2 of the 5 compliance zone segments shown in Figure 4-1 would be impacted and require PRB installation. The PRB would be installed through standard vertical injection wells. Multiple injection wells would be placed and the reactive media would be injected into these wells to create a uniform reactive zone. This method of injection could be installed beneath existing structures, such as the railroad at the Puchack Site. At each node, an injection well cluster consisting of 1 well screened in the Intermediate Sand and one well screened in the Lower aquifer is envisioned. For costing purpose, a total of 80 injection wells (40 locations, each at 2 depths to treat Intermediate Sand and Lower aquifer) would be installed to address the assumed 2 of 5 compliance zone segments.

A continuous reactive zone design would be used for this alternative, allowing the water to follow the natural gradient and pass through the barrier. The PRB would be situated across the entire path of the contaminated groundwater that has passed through the compliance zone. The PRB would use a reducing agent such as sodium dithionite to treat chromium. The PRB would reduce the hexavalent chromium to trivalent chromium, which would then precipitate and be immobilized by absorbing onto reactive media or aquifer solids. The PNNL treatability study estimated that the PRB would have reducing capacity to last several decades. Groundwater modeling would be performed to determine whether a grout curtain would be necessary to direct the groundwater towards the treatment zone.

In Situ Treatment (Contingency Remedy) via Geochemical Fixation (Sub-alternative 2B). Geochemical fixation would be performed to treat the portion of the contaminant plume that had passed through the 100 foot wide compliance zone. A conceptual drawing is provided in Figure 4-2. Compliance zone monitoring wells (one Intermediate Sand and one Lower aquifer monitoring well) would be installed every 800 feet along Westfield Avenue. Should the chromium plume enter a 800-foot long compliance zone segment, then geochemical fixation would be conducted in that segment. For costing purposes it has been assumed that 2 of the 5 compliance zone segments shown in Figure 4-2 would be impacted and require geochemical fixation.

In situ treatment using geochemical fixation would be performed in the Intermediate Sand and Lower aquifer. In situ geochemical fixation is a process that reduces hexavalent chromium in groundwater to trivalent chromium, which is then allowed to geochemically fix onto the aquifer solids. The specific reducing agent application method would be determined during the remedial design. For costing purposes, it has been assumed that instead of conducting a recirculation type remediation in which contaminated groundwater is extracted and treated to remove contaminants, dosed with a reducing agent and reinjected into the ground to form a closed loop. This alternative would be implemented by injecting non-contaminated water dosed with a reducing agent such as sodium metabisulfite, ferrous sulfate or chloride, or calcium polysulfide. No pumping of contaminated groundwater would be performed.

During the design phase of the project, bench- and pilot-scale studies would be conducted to evaluate various process options and injection well spacing. Bench-scale and pilot-scale testing would determine the most cost effective process options as well as obtain design parameters.

For full-scale treatment, it is estimated that multiple injection wells would be installed in the Intermediate Sand and Lower aquifer. The reducing agent would migrate from the point of application through the plume to impact the contaminants down to the compliance zone. Injection wells would be installed in areas where access is more available, such as along streets, alleyways, or open space. It is envisioned that two rows of treatment wells would be installed within the downgradient portion of the plume, as shown in Figure 4-2. For costing purpose, it is assumed that a total of 24

injection wells (12 locations, each at 2 depths to impact Intermediate Sand and Lower aquifer) would be installed to address the assumed 2 of 5 compliance zone segments.

It is expected that the reagents would be added in two rounds of treatment consisting of two injection events. For each round of treatment, approximately one-half of the reagents estimated to be required for complete treatment would be applied during each injection event. There would be a waiting period between injection events (such as one year) to allow the reducing agent to flow through the contaminant area. The subsequent treatment would be applied only in areas where analytical data indicates that additional treatment is required. A treatment duration of about three years, including injection well installation, treatment (including the waiting period between injection events), and injection well abandonment is assumed.

Treatment verification monitoring would include collection of groundwater samples from wells within and downgradient of the treatment areas; samples would be analyzed for chromium. Results from the monitoring program would determine whether or not additional rounds of reagent application are required to meet the treatment objectives.

Soil cuttings resulting from installation of the injection wells would be characterized for disposal. It is assumed that this material would be drummed and disposed off-site as non-hazardous waste.

Institutional Controls. Institutional controls would include placing restrictions on the installation of wells and the use of groundwater within the Puchack site. The purpose is to reduce potential future exposure to contaminants by legally restricting use of contaminated groundwater. NJDEP would establish a CEA designation for the area of the aquifer where the contamination exceeds the PRGs. The CEA would require interested parties to be notified that the groundwater does not meet the groundwater quality standards. Additionally NJDEP, could deny the interested party a permit for the installation of a new groundwater extraction well in the contaminated part of the aquifer.

Periodic Site Reviews. A review of site conditions would be conducted every five years using data obtained through the annual groundwater sampling program. The site reviews would include an evaluation of the extent of contamination and an assessment of contaminant migration and attenuation over time.

Duration of Alternative. This alternative would be evaluated for the 30-year FS evaluation period. It is not known if the PRGs would be attained at the end of the 30-year period. See discussion under Compliance with ARARs. At the end of this period, a new evaluation would be performed based on the data available at that time.

4.2.2.1 Overall Protection of Human Health and the Environment

Alternative 2 would be protective of human health and the environment through natural processes. Natural attenuation would reduce the aqueous plume and prevent contaminants from migrating beyond the compliance zone. Should MNA prove

unsuccessful, contamination in the Intermediate Sand and Lower aquifer would be reduced by in situ treatment, after reacting with the reducing agent injected either as a PRB or through geochemical fixation.

Sorption and reduction reactions are the dominant MNA mechanisms responsible for the reduction of mobility, toxicity, or bioavailability of inorganic contaminants. The process controlling the migration of chromium further offsite is expected to be natural reduction processes including the use of available iron and manganese in the groundwater to reduce the hexavalent chromium to the trivalent state. Based on a review of the RI data, these natural reducing agents are present at relatively high levels in areas surrounding the chromium plume, but have become depleted within the main plume area. As a result, the further conversion of hexavalent chromium to trivalent chromium is not expected to occur in appreciable quantities or to a significant degree within the chromium contaminated areas. A bench scale treatability study was performed to evaluate in situ technologies for remediation of hexavalent chromium in groundwater at the Puchack Site, and an Interim Progress Report has been prepared (PNNL 2005). The bench scale study demonstrated that chromium reduction by natural Puchack aquifer sediment can occur in the area downgradient of the chromium plume where the reductive capacity of the aquifer has not been depleted. The study estimated that 63 pore volumes of groundwater containing high chromium concentrations (2 mg/L) would be reduced by natural reductive processes. Therefore, there is sufficient reduction capacity in the aquifer to reduce the hexavalent chromium before it will reach any municipal wells. It is expected that the chromium plumes would only migrate a short distance before the hexavalent chromium is reduced and fixated onto the soil particles (see discussion under "Long-term effectiveness and Permanence."

Institutional controls would prevent future exposure to contaminated groundwater. Monitoring and five-year reviews would assess the site conditions and effectiveness of natural attenuation, and recommend corrective measures when necessary.

This alternative would be protective of the environment. MNA (or in situ treatment if required) would reduce the contaminants from the areas of concern. Groundwater monitoring would be conducted annually to monitor the contamination and to determine the effectiveness of the remedy.

4.2.2.2 Compliance with ARARs

Natural attenuation would rely on the natural reductive capacity of the aquifer to gradually reduce the hexavalent chromium. Based on the bench scale study, the aquifers have enough capacity to reduce and fixate all hexavalent chromium to below the PRGs. The reduction reaction is fast. However, chromium must be in contact with the reductant for it to be reduced. Two attenuation mechanisms are possible:

- The attenuation process could be slow if the sediment reduction capacity is depleted within the plume area. The chromium must then flow to the sediment with reduction capacity, which is located outside of the current plume area. The chromium plume migration is a slow process.

- Groundwater in the Puchack well field area is known to contain high concentrations of ferrous iron, which is a reductant for the hexavalent chromium. Ferrous iron can migrate with the groundwater to the chromium in a faster rate than chromium migration.

It is not known if this alternative would attain the PRGs (derived from chemical-specific ARARs) for groundwater within a reasonable time frame (e.g., 20 years considered by NJDEP) using MNA. A significant reduction of chromium concentrations was observed in the groundwater samples between 1998 and 2000. Additional sampling of the groundwater would provide the needed information to better predict the attenuation rate. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time.

No location-specific ARARs were identified. The reducing agent may contain sodium. NJDEP has a groundwater quality standard of 50 mg/L for sodium. Based on preliminary calculations (Appendix A), this standard would not be exceeded once sodium is dispersed into the aquifer. Other reducing agents that do not contain sodium would also be considered during the design phase. This alternative would be designed to comply with action-specific ARARs. Table 2-3 summarizes the action-specific ARARs and their FS considerations.

4.2.2.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - This alternative would reduce the residual contaminants gradually through the natural reducing capacity of the aquifer solids. If necessary, as a contingency, installation of in situ treatment would further reduce the migration of the plume.

Estimation of contaminant migration rates for chromium in groundwater strongly suggests that MNA processes are important for degrading and impeding the migration of hexavalent chromium. Five monitoring wells (CCMW-1A, CCMW-2A, MW-5I, MW-14, MW-5D, and MW-6D) were sampled in 1998 and again in 2000. Over 50% reduction in hexavalent chromium concentrations were observed in those monitoring wells. Calculations were completed to estimate the natural reductive capacity of the aquifer systems at the Site using data obtained from the PNNL treatability study (see Appendix A calculations). Estimates were made of: 1) the time that a given volume of the Intermediate Sand and Lower aquifer are effective in attenuating the chromium in groundwater, and 2) the total attenuating capacity of the Intermediate Sand and Lower aquifer for a given volume of water. Based on these calculations, the effective time that the natural reductive capacity within a 100 foot compliance zone would continue to reduce the chromium migrating through the zone in the Intermediate Sand was between 400 and 1,100 years depending upon the chromium and dissolved oxygen concentrations. Similar calculations for the Lower aquifer determined that the effective time for reducing chromium in a 100 foot compliance zone was between 1,300 and 1,500 years. Also, it was estimated that a 100 foot compliance zone would have 75 to 96 times enough capacity to remove all of the chromium in the groundwater plume upgradient of the zone. Therefore, it is unlikely

for the hexavalent chromium plume to move beyond the compliance zone due to the natural reductive capacity of the aquifer soil particles.

An estimate can be made of the rate that hexavalent chromium would migrate from the leading edge of the plume under MNA conditions. Given the groundwater velocity of 310 ft/yr and the retardation factor (calculated in Appendix A) of 26 to 65 (hexavalent chromium near the downgradient plume boundary), this would yield a hexavalent chromium velocity in the groundwater of only between 5 and 12 ft/yr. These estimates are conservatively low, reflecting mostly adsorption and do not include complete reduction and precipitation.

Currently there are no risks to human health as the groundwater is not being used as potable water. Potential future human health risks would be minimized through the implementation of institutional controls.

Adequacy of Controls - Risks to human health would be further reduced through institutional controls that would require continued enforcement and monitoring.

The groundwater is currently not being used and institutional controls would prevent future use of the groundwater. Monitoring and five-year reviews would assess the effectiveness of the remedy.

Reliability of Controls - Based on the bench scale treatability study results, natural attenuation would be reliable to reduce hexavalent chromium to trivalent chromium. The process is not reversible under normal environmental conditions. MNA is further supported by contingency in situ treatment, as necessary.

Institutional controls, if properly enforced, would be considered reasonably adequate and reliable for protection of human health.

Long-term groundwater monitoring enables risks to be tracked over a period of time, but would not reduce them. The long term effectiveness of this alternative would be assessed through routine groundwater monitoring and five-year reviews. As part of the monitoring program, groundwater would be sampled to monitor plume properties over time to verify that the plume would not be increasing over time or posing an unacceptable risk to human health and the environment.

4.2.2.4 Reduction of Toxicity, Mobility or Volume through Treatment

Monitored natural attenuation would have no direct effect in reducing the TMV of residual contaminants through treatment. The toxicity and mass (volume) of residual contamination in the groundwater would be gradually reduced over time by natural attenuation processes. If necessary, as a contingency, in situ treatment would reduce the mobility of the contaminants in groundwater, and the toxicity and volume (mass) would be reduced through treatment. The reduction process is permanent and irreversible.

Institutional controls would not reduce the toxicity of contaminants, but would reduce the potential for human exposure to contaminated groundwater; thereby reducing the risks.

4.2.2.5 Short-Term Effectiveness

MNA includes limited site work in the implementation of the long-term groundwater monitoring program. Should in situ treatment become necessary, as a contingency, construction could be performed without significant risk but would create significant inconvenience to the community. Short-term fugitive dust would occur during construction. Operational controls, along with air monitoring for both particulates and relevant contaminants, would be established to minimize these impacts. Site workers would wear appropriate personal Protective equipment (PPE) to minimize exposure to contamination and as protection from physical hazards. There would be a temporary negative impact on the commercial business and the residences located near the proposed treatment area during construction.

The construction period for this alternative is estimated at one year for MNA only (mobilization and installation of monitoring wells), and two to three years for the PRBs or in situ geochemical fixation (one year for mobilization/site preparation/ demobilization and 1 to 2 years for installation of in situ treatment, including the waiting period), if it becomes necessary. A monitoring time period of 30 years, the maximum specified for evaluation under EPA's RI/FS Guidance Document (EPA 1988), is assumed for this alternative. It is anticipated that PRGs would be met in the aqueous plumes at the end of this time period.

No adverse impacts to habitats or vegetation would be anticipated from activities associated with implementation of this alternative.

4.2.2.6 Implementability

Technically, the alternative would be implementable as proposed. Supplies and services for long-term groundwater monitoring and well drilling services are readily obtainable. Should it become necessary, construction of an in situ treatment system would utilize conventional construction methods and equipment. No technical difficulties would be anticipated. Implementation of this alternative would require access to the neighboring properties, which would be somewhat difficult. No problems are forecasted for the implementation and enforcement of the institutional controls.

4.2.2.7 Cost

A summary of the capital costs, annual O&M costs, five-year review costs, and total present worth is provided in Table 4-1. The details of this alternative and the associated estimated costs are presented in Appendix C. Total net present worth for Sub-alternative 2A is $1.2 (MNA only) and $10.5 million (MNA with contingency remedy using PRB) over the 30-year life of the alternative. Total net present worth for Sub-alternative 2B is $1.2 (MNA only) and $7.8 million (MNA with contingency remedy using in situ geochemical fixation).

4.2.2.8 State Acceptance

NJDEP comments on the draft report have been incorporated into this Final FS report.

4.2.2.9 Community Acceptance

Alternatives are evaluated based upon their acceptance by the community. Community acceptance would be formally addressed after the Final FS and Proposed Plan have been issued to the public for formal review and comment, and a public meeting/availability session has been held by EPA. Community acceptance would be formally addressed in the Responsiveness Summary of the ROD, which would present EPA's responses to the public's questions and concerns regarding the FS and Proposed Plan.

4.2.3 Alternative 3 - In Situ Treatment/MNA/Institutional Controls

Alternative 3 consists of the following components:

- In situ treatment via:
  - permeable reactive barrier for chromium plume > 1,000 µg/L (Sub-alternative 3A), or
  - geochemical fixation for chromium plume > 1,000 µg/L (Sub-alternative 3B), or
  - geochemical fixation for chromium plume > 70 µg/L (Sub-alternative 3C)
- Long-term groundwater monitoring
- Institutional controls
- Periodic site reviews

<u>In Situ Treatment via Permeable Reactive Barrier for Chromium Plume > 1,000 µg/L (Sub-alternative 3A).</u> In situ treatment via permeable reactive barrier would be implemented in the location of expected highest chromium contamination (e.g. areas above 1,000 µg/L) as described under Sub-alternative 2A, however, without first evaluating the effectiveness of MNA. For costing purposes it has been assumed that a 3,500 foot long PRB wall, with injection wells placed every 40 ft would be required. Portions of the wall would require treatment in the Middle aquifer (600 ft), the Intermediate Sand (2,500 ft), and the Lower Aquifer (2,500 ft). A total of 141 injection wells would be required to treat the chromium plume greater than 1,000 µg/L in the three aquifers. This alternative is shown in Figure 4-3.

<u>In Situ Treatment via Geochemical Fixation for Chromium Plume > 1,000 µg/L (Sub-alternative 3B)</u>. In situ treatment via geochemical fixation would be implemented in the location of the expected highest chromium contamination (e.g. areas above 1,000 µg/L), however, without first evaluating the effectiveness of MNA. For costing purposes it has been assumed that a geochemical fixation treatment zone would be required in the Middle aquifer (600 ft), the Intermediate Sand (4200 ft), and the Lower aquifer (3,700 ft), with injection wells placed every 150 ft. A total of 58 injection wells

would be required to treat the chromium plume greater than 1,000 µg/L in the three aquifers. This alternative is shown in Figure 4-4.

In Situ Treatment via Geochemical Fixation for Chromium Plume > 70 µg/L (Sub-alternative 3C). In situ treatment via geochemical fixation would be implemented in the locations where the chromium plume exceeds the PRG of 70 µg/L, however, without first evaluating the effectiveness of MNA. For costing purposes it has been assumed that a geochemical fixation treatment zone would be required in the Middle aquifer (600 ft), the Intermediate Sand (7,400 ft), and the Lower aquifer (7,000 ft), with injection wells placed every 150 ft. A total of 102 injection wells would be required to treat the chromium plume greater than 70 µg/L in the three aquifers. This alternative is shown in Figure 4-5.

Long-Term Groundwater Monitoring. Long-term groundwater monitoring would be implemented as described under Alternative 2.

Institutional Controls. Institutional controls would be implemented as described under Alternative 2.

Periodic Site Reviews. Periodic site reviews would be implemented as described under Alternative 2.

Duration of Alternative. This alternative would be evaluated for the 30-year FS evaluation period. At the end of this period, a new evaluation would be performed based on the data available at that time.

4.2.3.1 Overall Protection of Human Health and the Environment

The in situ treatment process would be effective in treating chromium contamination. By applying in situ treatment, either as a PRB or through geochemical fixation, most chromium within the treatment area would be immobilized. This alternative would be protective of human health and the environment by the reduction of the contaminant mass within the location of the highest chromium contamination. A reduction in contaminant mass would reduce the amount of contamination present in the groundwater. Institutional controls would prevent potential future human exposure to groundwater contamination. Monitoring and 5-year reviews would assess the site conditions and effectiveness of the remedy.

Natural attenuation processes would be effective in reducing chromium concentrations in the portions of the plume where in situ treatment is not being performed.

4.2.3.2 Compliance with ARARs

The quantity of mobile hexavalent chromium would be greatly reduced through in situ treatment. After treatment the rate and amount of groundwater contamination would be low. For Sub-alternative 3A (PRB for chromium plume > 1,000 µg/L) and Sub-alternative 3B (geochemical fixation for chromium plume > 1,000 µg/L), MNA

would be the primary mechanism to reduce hexavalent chromium for the area outside of the treatment zone. As discussed under Alternative 2, the rate of natural reduction of hexavalent chromium is not known. Therefore, it is not known if the PRGs would be attained within a reasonable time frame (e.g., 20 years considered by NJDEP) using MNA. Additional sampling would provide the needed information to better predict the reduction rate.

For Sub-alternative 3C (geochemical fixation for chromium plume > 70 μg/L), PRGs are expected to be achieved in 5 to 10 years (the predicted time for the reducing agent to migrate within the treatment zone). These assumptions would be verified during the pilot scale study, and the actual remediation time could be significantly longer. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time.

No location-specific ARARs were identified. The reducing agent may contain sodium. NJDEP has a groundwater quality standard of 50 mg/L for sodium. Based on preliminary calculations (Appendix A), this standard would not be exceeded once sodium is dispersed into the aquifer. Other reducing agents that do not contain sodium would also be considered during the design phase. This alternative would be designed to comply with action-specific ARARs. Table 2-3 summarizes the action-specific ARARs and their FS considerations.

4.2.3.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - This alternative would be considered a permanent remedy as contaminants are immobilized in the locations of highest chromium contamination, and MNA would reduce levels in the remainder of the plume for the long-term. Currently there are no risks to human health as the contaminated groundwater is not being used as potable water. Potential future human health risks would be reduced through the implementation of institutional controls.

Adequacy of Controls - In situ treatment would be effective in reducing contaminant mass. The effectiveness would be confirmed through groundwater monitoring.

Risks to human health would be controlled through institutional controls, which would require continued enforcement as well as monitoring.

Reliability of Controls - The reduction in contaminant concentration through in situ treatment and the implementation of institutional controls, if properly enforced, would be considered reasonably adequate and reliable for protection of human health.

MNA would reduce levels in the remainder of the plume. Based on the bench scale treatability study results, natural attenuation would be reliable to reduce hexavalent chromium to trivalent chromium. The process is not reversible under normal environmental conditions.

Institutional controls, if properly enforced, would be considered reasonably adequate and reliable for protection of human health.

Long-term groundwater monitoring enables risks to be tracked over a period of time, but would not reduce them. The long-term effectiveness of this alternative would be assessed through routine groundwater monitoring and five-year reviews. As part of the monitoring program, groundwater would be sampled to monitor plume properties over time to verify that the plume is not increasing over time or posing an unacceptable risk to human health and the environment.

4.2.3.4 Reduction of Toxicity, Mobility or Volume through Treatment

The TMV of the contaminants in groundwater would be reduced through in situ treatment reduction. The reduction process is permanent and irreversible. Concentration of contaminants present outside the treatment area would decrease slowly through natural attenuation.

Institutional controls would not reduce the toxicity of contaminants, but would reduce the potential for human exposure to contaminated groundwater, thereby reducing the associated risks.

4.2.3.5 Short-Term Effectiveness

Installation and operation of the in situ treatment system would have significant impact to the community. Short-term and low-level generation of fugitive dust would occur during construction. Operational controls, along with air monitoring for both particulates and relevant contaminants, would be established to minimize these impacts. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards. This alternative would have temporary impact to the commercial business and residences due to installation and operation of injection wells. Also, traffic patterns would be impacted due to potential road closings during construction activities.

The construction period for this alternative is estimated at five years (one year for mobilization/site preparation/demobilization and up to four years for installation of in situ treatment, including the waiting period). A time period of 30 years, the maximum specified for evaluation under EPA's RI/FS Guidance Document (EPA 1988), is assumed for implementation of Sub-alternative 3A, 3B and 3C. A shorter time period for Sub-alternative 3C may be determined based on pilot scale testing results.

No adverse impacts to habitats or vegetation are anticipated from activities associated with implementation of this alternative.

4.2.3.6 Implementability

This alternative would be implemented using conventional construction methods and equipment. Both the PRB and in-situ geochemical fixation are innovative technologies and would require bench and pilot scale treatability studies to determine the

effectiveness of treatment. Results of the bench and pilot scale studies may indicate that additional injection wells would be needed. The installation of additional injection wells may increase the cost and duration of this alternative. The technical feasibility of installing and operating an in situ system has been established at other sites.

There may be some administrative implementability issues related to obtaining regulatory approval for an innovative remedial technology such as in situ treatment.

Implementation of this alternative would require access to the neighboring properties, which would be somewhat difficult. Services and materials for implementation of this alternative would be readily available. No problems are forecasted for the implementation and enforcement of the institutional controls.

4.2.3.7 Cost

A summary of the capital costs, annual O&M costs, five-year review costs, and total present worth is provided in Table 4-1. The details of this alternative and the associated estimated costs are presented in Appendix C. Total net present worth for Sub-alternative 3A is $14.5 million, Sub-alternative 3B is $12.0 million, and Sub-alternative 3C is $17.6 million over the 30-year life of the alternative. The cost estimate for Sub-alternatives 3A, 3B, and 3C are highly dependent on the effective radius of treatment for each injection point, which can vary significantly. See Section 4.4 for a cost sensitivity discussion.

4.2.3.8 State Acceptance

NJDEP comments on the draft report have been incorporated into this Final FS report.

4.2.3.9 Community Acceptance

Alternatives are evaluated based upon their acceptance by the community. Community acceptance would be formally addressed after the Final FS and Proposed Plan have been issued to the public for formal review and comment, and a public meeting/availability session has been held by EPA. Community acceptance would be formally addressed in the Responsiveness Summary of the ROD, which would present EPA's responses to the public's questions and concerns regarding the FS and Proposed Plan.

4.2.4 Alternative 4 - Groundwater Extraction/Treatment/Off-Site Disposal/Long-Term Groundwater Monitoring/ Institutional Controls

Alternative 4 consists of the following major components:

- Installation of extraction wells and submersible pumps
- Groundwater treatment
- Off-site disposal
- Operation and maintenance

- Long-term groundwater monitoring
- Institutional controls
- Periodic site reviews

Installation of Extraction Wells and Submersible Pumps. Groundwater extraction and injection simulations have been conducted by the USGS. For alternative development, groundwater would be extracted following extraction scenario EX-I. A total of five extraction wells would be installed in the Intermediate Sand with one pumping at 150 gpm, one at 200 gpm, one at 350 gpm, and two at 400 gpm. One extraction well would be installed in the Middle aquifer pumping at 25 gpm. All extraction wells would be located north of the railroad line, except for the Middle aquifer pumping well. No wells would be placed in the Lower aquifer. Contaminants in the Lower aquifer would be drawn up into the Intermediate Sand and captured by the 5 extraction wells in this zone. The total quantity of groundwater extracted would be at 1,525 gpm. The extraction wells were placed to facilitate broad coverage of the chromium plume, and minimize pumping. Two injection wells would be placed updip of the plume to re-inject the treated water into the Lower aquifer, which is thicker and more permeable. Details of the EX-I configuration modeled by USGS are shown in Appendix B, and well layouts are shown in Figure 4-6. Additional modeling would be performed during the design phase to finalize the extraction and injection scheme.

The extraction wells would be drilled into the Middle aquifer and Intermediate Sand, and equipped with submersible pumps. A system of transfer pipes would be installed to convey the contaminated groundwater from the extraction wells to the groundwater treatment building.

Soil cuttings resulting from installation of the extraction wells would be characterized for disposal. It is assumed that this material would be drummed and disposed off-site as non-hazardous waste.

Groundwater Treatment. Precipitation of metals has long been the primary method of treating inorganics in wastewater. Metals precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that would precipitate. Treatment of chromium would be achieved by reduction of hexavalent chromium to the trivalent state. Common reducing agents include ferrous sulfate, sodium meta-bisulfite, or sulfur dioxide. The precipitate can then be removed from treated water by physical methods such as clarification (settling) and/or filtration.

The design of the chromium treatment system would be based on a pilot scale system that was installed and operated at the Puchack Site by CDM in 1992. As in the pilot scale system, chemical reduction and precipitation would be implemented at the groundwater treatment facility. Chemical reduction and precipitation would convert dissolved metals in groundwater into an insoluble form. First, ferrous iron would be used to reduce hexavalent chromium, which is primarily in the form of chromate (CrO_4^{2-}) and dichromate ($Cr_2O_7^{2-}$) to the trivalent state. Following reduction, trivalent chromium would be precipitated as a metal hydroxide using lime or sodium hydroxide as the reagent. The reaction of trivalent chromium with lime forms

chromic hydroxide ($Cr(OH)_3$) which is insoluble in water. Precipitation of trivalent chromium is most effective in the pH range of 8.0 to 9.5, due to the low solubility of chromic hydroxide in that range. Metal ions generally precipitate out as hydroxides, sulfides, or carbonates, and are removed as solids through clarification and filtration. The solid sludge containing the metal contaminant would then be disposed of properly at an offsite facility.

Following chromium treatment, the groundwater would undergo an air stripping step to remove VOCs commingled with chromium contamination, with off-gas treatment by carbon adsorption.

For costing purposes, it is assumed that treatment of extracted groundwater would include:

- Ferrous iron addition, followed by in-line mixing.
- Iron-chromium contact to reduce hexavalent chromium to trivalent chromium.
- Aeration to strip out carbon dioxide and thereby reduce calcium carbonate formation after lime addition, and to provide oxygen to oxidize both excess iron added to the water and manganese in the raw water.
- Lime addition, in a rapid mix tank, to raise the pH from 7 (after aeration) to between 8.5 and 9.0, the optimal pH for trivalent chromium removal.
- Chlorination to prevent slime growth in the clarifier and dual media filter.
- Flocculation, in the center zone of a solids contact clarifier, with addition of anionic polymer to improve settling.
- Clarification in the quiescent zone of the clarifier to remove chromium hydroxide, iron hydroxide, manganese oxide, and calcium carbonate solids.
- Dual media gravity filtration to remove any floc in the clarifier overflow.
- Air stripping to remove VOCs, with off-gas treatment by granular activated carbon.

Off-Site Disposal. Following treatment, the treated groundwater would be reinjected into the groundwater through two injection wells, installed within the northern part of the Puchack Well Field property. This location was selected based on USGS simulations (EX-I). This open space location is upgradient of the chromium plume and would provide a recharge zone to replenish the extracted groundwater and enhance the process of flushing out the contaminants in the aquifer. The precipitated metals sludge must be dewatered such that it passes the paint filter test. The sludge would be transported off-site and disposed in a landfill provided it passes the TCLP test. For costing purposes, it is assumed that the sludge would be non-hazardous.

The pilot scale system tested by CDM in 1992 determined that the sludge yield was approximately 740 pounds dry weight solids per million gallon of water treated (assuming 2.6 mg/L chromium in the raw water). The amount of sludge generated for the EX-I pumping scenario would therefore be approximately 1,600 pounds per day for 1,525 gpm of pumping.

Operation and Maintenance. System maintenance that includes maintenance of the wells, pumps, and treatment process equipment would be conducted as required

during the operation of the groundwater pump and treat system. Treatment performance monitoring would include collection of groundwater samples from locations upgradient and downgradient of the plume. Results from the monitoring program would be used to evaluate performance and adjust operating parameters for the extraction system, as necessary. Periodic samples would be collected from various sample locations along the groundwater treatment train to verify the effectiveness of each treatment process. Effluent samples would be collected to verify compliance with the NJPDES discharge requirements.

Long-Term Groundwater Monitoring. Long-term groundwater monitoring would be implemented as described under Alternative 2.

Institutional Controls. Institutional controls would be implemented as described under Alternative 2.

Periodic Site Reviews. Periodic site reviews would be implemented as described under Alternative 2.

Duration of Alternative. This alternative would be evaluated for the 30-year FS evaluation period. At the end of this period, a new evaluation would be performed based on the data available at that time.

4.2.4.1 Overall Protection of Human Health and the Environment

This alternative would actively extract contaminated groundwater. The main goal of pumping groundwater is to create an inward gradient that would prevent further downgradient migration of the plume. This alternative would be protective of human health and the environment by the active pumping and treatment of contaminated groundwater. It is expected that the pumping would reduce the plume size and contaminant concentration in the aqueous phase. Currently there are no risks to human health as the groundwater is not being used. Institutional controls would prevent potential future human exposure to groundwater contamination. Monitoring and 5-year reviews would assess the site conditions and effectiveness of the remedy.

4.2.4.2 Compliance with ARARs

Contaminant concentrations in the plume and plume size are expected to decrease over time. It is not known if the PRGs would be met within the 30-year time frame. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time.

No location-specific ARARs were identified. The reducing agent may contain sodium. NJDEP has a groundwater quality standard of 50 mg/L for sodium. Based on preliminary calculations (Appendix A), this standard would not be exceeded once sodium is dispersed into the aquifer. Other reducing agents that do not contain sodium would also be considered during the design phase. This alternative would be

designed to comply with action-specific ARARs. Table 2-3 summarizes the action-specific ARARs and their FS considerations.

4.2.4.3 Long-Term Effectiveness and Permanence

Magnitude of Residual Risk - The main purpose of this alternative is to create an inward gradient that would prevent downgradient migration of the contaminated plume. Specifically, the pumping would remove chromium contaminated groundwater. Currently there are no risks to human health as the groundwater is not being used as potable water. With the institutional controls in place, the possibility of exposure to the chromium is remote.

The time to achieve PRGs can be estimated based on pore volume flushing predicted from the EX-1 groundwater model. The time for 1 pore volume flush for EX-1 can be predicted based on the time to flush the combined volume of water in the Intermediate Sand and Lower aquifer of 820 million gallons (see Section 2.4.1 for volume estimates). Using the EX-1 flow rate of 1,525 gpm (788 million gallons/year) this would indicate that the one pore volume would take 1.04 years. Using the estimated chromium plume retardation factor calculated in the range of 26 to 65 (see Appendix A), it is expected that many pore volume flushes, and perhaps many decades would be required to reduce the chromium concentration to the 70 μg/L NJ Groundwater Quality Standard using pump and treat. Also, the time to capture 95 percent of the groundwater particles was predicted by the modeling scenario to be 20 years for the Intermediate Sand and 15 years for the Lower aquifer (see Appendix B). These particle track time frames are for groundwater molecules and do not take into account chromium retardation factors. Given the uncertainties for these estimates, a time period of 30 years, the maximum specified for evaluation under EPA's RI/FS Guidance Document (EPA 1988), is assumed for implementation of this alternative.

Adequacy of Controls - Pump and treat would be considered an effective hydraulic barrier as it has been demonstrated at other sites. The effectiveness would be confirmed through groundwater monitoring.

Risks to human health would also be controlled through institutional controls, which would require continued enforcement as well as monitoring.

Reliability of Controls - The reduction in contaminant concentration and the implementation of institutional controls, if properly enforced, would be considered reasonably adequate and reliable for protection of human health.

Long-term groundwater monitoring enables risks to be tracked over a period of time, but would not reduce them. The long term effectiveness of this alternative would be assessed through routine groundwater monitoring and five-year reviews. As part of the monitoring program, groundwater would be sampled to monitor plume properties over time to verify that the plume would not be increasing over time or posing an unacceptable risk to human health and the environment.

4.2.4.4 Reduction of Toxicity, Mobility or Volume through Treatment

The TMV of the contaminants in groundwater would be reduced through extraction and treatment. The extraction is designed to remove chromium and VOCs that are commingled with the chromium plume. The collected metals sludge would be disposed in a landfill where it would pose no threat to human health or the environment. The VOCs captured on the vapor phase carbon adsorption units following air stripping would be destroyed during the carbon regeneration process.

4.2.4.5 Short-Term Effectiveness

Installation and operation of the groundwater extraction and treatment system would have significant impact to the community. Short-term and low-level generation of fugitive dust or contaminant emissions may occur during construction. Operational controls, along with air monitoring for both particulates and relevant contaminants, would be established to minimize these impacts. Site workers would wear appropriate PPE to minimize exposure to contamination and as protection from physical hazards. Also, traffic patterns would be impacted due to potential road closings during construction activities.

The construction period for this alternative is estimated at two years (one year for mobilization/site preparation/demobilization and one year for treatment plant procurement/ installation). A 30-year duration for this alternative was assumed for O&M and for long-term groundwater monitoring. It is not known if PRGs would be met in the aqueous plume at the end of this time period. No adverse impacts to habitats or vegetation would be anticipated from activities associated with implementation of this alternative.

4.2.4.6 Implementability

This alternative would be implemented using conventional construction methods and equipment. The technical feasibility of pump and treat systems has been established through the pilot study at this site.

Implementation of this alternative would require access to the neighboring properties. The availability of open space within Pennsauken Township is limited. The treatment plant location shown on Figure 4-6 is an open field which is a private property. Siting the plant at this location would require a long-term lease or land acquisition by the government, which could be administratively difficult. Also, the extraction and reinjection piping is proposed to be located on township and private property, which would require access agreements and/or permanent easements.

Services and materials for implementation of this alternative are readily available. Competitive bids can be obtained from a number of equipment vendors and remediation contractors.

No problems are forecasted for the implementation and enforcement of the institutional controls.

4.2.4.7 Cost

A summary of the capital costs, annual O&M costs, five-year review costs, and total present worth is provided in Table 4-1. The details of this alternative and the associated estimated costs are presented in Appendix C. Total net present worth for this alternative is $32.1 million over the 30-year life of the alternative.

4.2.4.8 State Acceptance

NJDEP comments on the draft report have been incorporated into this Final FS report.

4.2.4.9 Community Acceptance

Alternatives are evaluated based upon their acceptance by the community. Community acceptance would be formally addressed after the Final FS and Proposed Plan have been issued to the public for formal review and comment, and a public meeting/availability session has been held by EPA. Community acceptance would be formally addressed in the Responsiveness Summary of the ROD, which would present EPA's responses to the public's questions and concerns regarding the FS and Proposed Plan.

4.3 Comparative Analysis of Alternatives

This section compares the alternatives using the evaluation criteria. Table 4-2 summarizes the comparison among the four alternatives.

4.3.1 Overall Protection of Human Health and the Environment

Alternative 1 would not provide protection of human health, since contamination would persist in groundwater, and potential exposure to contaminated groundwater would not be restricted. Currently there are no risks to human health because the groundwater at the site vicinity is not being used. However, the plume could, even though unlikely, potentially migrate towards the municipal well fields east of Westfield Avenue. Alternatives 2 through 4 are equally protective of human health by implementation of institutional controls restricting the future use of contaminated groundwater. However, Alternative 2 would not provide active treatment, unless MNA is unsuccessful and in situ treatment is required as a contingency remedy. Alternatives 3 and 4 would utilize active treatment processes to reduce the TMV of the contaminants, Sub-alternative 3C would attain the PRGs in a shorter time than other alternatives.

Alternative 1 would not be protective of the environment. Alternatives 2 through 4 would provide protection of the environment as the contaminant migration would be restricted by natural attenuation or active treatment, and would not migrate to other media.

4.3.2 Compliance with ARARs

Alternative 1 would not comply with chemical-specific ARARs, while Alternative 2 through 4 would comply with chemical-specific ARARs. Long-term groundwater

monitoring is a component of Alternatives 2 through 4 to assess the degree of compliance achieved over time. All alternatives would comply with location- and action-specific ARARs.

4.3.3 Long-Term Effectiveness and Permanence

Alternative 1 would not be effective or permanent, since the contaminants would not be destroyed and there would be no mechanism to prevent future exposure to contaminated groundwater. Alternatives 2 through 4 would be effective when combined with institutional controls. Alternative 2 would rely on natural mechanisms to reduce contaminant levels. Alternative 2 would utilize in situ treatment as a contingency remedy should the chromium plume migrate pass the compliance zone. Alternatives 3 and 4 would provide additional protection as the contaminants would be removed and treated. The effectiveness of these alternatives would be assessed through routine groundwater monitoring and five-year reviews. The relative degrees of effectiveness and permanence associated with Alternatives 2, 3, and 4 are generally comparable.

4.3.4 Reduction of Toxicity, Mobility or Volume through Treatment

Alternative 1 would not reduce the TMV through treatment as no active treatment of contaminated groundwater occurs. The toxicity and volume would eventually be reduced for Alternative 1 due to natural attenuation. Alternative 2 would reduce the TMV through treatment if in situ treatment is necessary as a contingency to MNA. Alternatives 3 and 4 would significantly reduce the TMV of the contaminated groundwater. These alternatives involve reduction and immobilization of contaminants in the groundwater, thereby reducing toxicity. It is anticipated that Sub-alternative 3C would achieve the most reduction in TMV, followed by Alternative 4.

4.3.5 Short-Term Effectiveness

For Alternative 1, protection of the community and workers during remedial activities would not be applicable as no remedial action is occurring. Air monitoring, engineering controls and appropriate worker PPE would be used to protect the community and workers for Alternatives 2 through 4.

There are no potential adverse impacts associated with construction and implementation of Alternative 1. Construction of the injection wells under Alternative 2 (if required as a contingency remedy) would have temporary negative impacts on the commercial business and the residences located near the proposed installation location. Alternative 3 would also have temporary impact to the commercial business and residences due to installation and operation of injection wells.

Alternative 4 would have the greatest impact to the community. The pump and treat system would be operated for approximately 30 years in the commercial business and residential areas.

4.3.6 Implementability

Alternative 1 would be easiest both technically and administratively to implement. Alternatives 2 and 3 would be moderately difficult to implement. Alternative 4 is the most difficult to implement as there is limited space available to lay the piping and build the treatment facility. Alternatives 2, 3 and 4 would require access agreements from the neighboring properties.

4.3.7 Cost

A summary of the cost estimates for each alternative is presented in Table 4-1. Alternative 1 incurs no cost but also provides no protection to human health or the environment. Alternative 2 costs are low unless the in situ treatment contingency remedy is required. Alternative 3 costs are higher than Alternative 2, and Alternative 4 is the most expensive. Alternative 3 has higher uncertainty in cost.

4.4 Cost Sensitivity Analysis

Due to the innovative nature of the in situ treatment, the cost estimates for Alternatives 2 and 3 are highly dependent on the effective radius of treatment for each injection location. To assess the effect of the radius of treatment on cost, a cost sensitivity analysis was performed. The spacing between injection points was reduced by 50% from the original assumptions and the resulting costs were calculated for Sub-alternatives 3A, 3B, and 3C. The results are presented in Table 4-3. A cost increase of up to 71 percent was experienced as a result of 50 percent reduction in injection point spacing.

Other factors that could have significant effect on the cost estimates may include the injection duration at each location and the number of injection events.

Table 4-1
Cost Estimate Summary for Alternatives 2 through 4
Puchack Well Field Superfund Site

Item No.	Item Description	Alternative 2A		Alternative 2B		Alternative 3A	Alternative 3B	Alternative 3C	Alternative 4
		MNA	MNA with Contingency	MNA	MNA with Contingency				
CAPITAL COSTS									
1	Work Plan Preparation	$ 17,700	$ 70,600	$ 17,700	$ 70,600	$ 70,600	$ 70,600	$ 70,600	$ 70,600
2	Mobilization/Demobilization	$ 5,000	$ 66,000	$ 5,000	$ 66,000	$ 66,000	$ 66,000	$ 66,000	$ 132,000
3	Construction Management	-	$ 672,765	-	$ 411,607	$ 1,035,310	$ 789,544	$ 1,283,936	$ 1,087,929
4	Construction QC/Chemcial Analysis/H&S	$ 152,467	$ 672,765	$ 152,467	$ 411,607	$ 1,035,310	$ 789,544	$ 1,283,936	$ 1,087,929
5	Permeable Reactive Barrier and Monitoring Wells	-	$ 4,485,099	-	$ 2,744,048	$ 6,902,069	$ 5,263,624	$ 8,559,574	$ 7,252,860
6	Institutional Controls	$ 17,700	$ 17,700	$ 17,700	$ 17,700	$ 17,700	$ 17,700	$ 17,700	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS	**$ 192,867**	**$ 5,984,929**	**$ 192,867**	**$ 3,721,562**	**$ 9,126,989**	**$ 6,997,011**	**$ 11,281,746**	**$ 9,649,018**
7	General Contractor Fee (10% construction)	$ 19,287	$ 598,493	$ 19,287	$ 372,156	$ 912,699	$ 699,701	$ 1,128,175	$ 964,902
8	Design Engineering	$ 38,573	$ 500,000	$ 38,573	$ 500,000	$ 500,000	$ 500,000	$ 500,000	$ 600,000
9	Bench / Pilot Scale Studies		$ 750,000		$ 1,000,000	$ 750,000	$ 1,000,000	$ 1,000,000	-
10	Resident Engineering/Inspection	$ 19,287	$ 400,000	$ 19,287	$ 400,000	$ 500,000	$ 500,000	$ 500,000	$ 500,000
11	Contingency (20%)	$ 38,573	$ 1,196,986	$ 38,573	$ 744,312	$ 1,825,398	$ 1,399,402	$ 2,256,349	$ 1,929,804
	TOTAL CAPITAL COSTS	**$ 308,587**	**$ 9,430,408**	**$ 308,587**	**$ 6,738,031**	**$ 13,615,086**	**$ 11,096,114**	**$ 16,666,269**	**$ 13,643,723**
MONITORING COSTS									
12	Project Planning and Organization	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700	$ 1,700
13	Sampling Labor	$ 24,300	$ 32,400	$ 24,300	$ 32,400	$ 24,300	$ 24,300	$ 24,300	$ 24,300
14	Sampling Equipment	$ 14,600	$ 18,800	$ 14,600	$ 18,800	$ 14,600	$ 14,600	$ 14,600	$ 14,600
15	Sample Analysis and Data Validation	$ 10,200	$ 13,400	$ 10,200	$ 13,400	$ 10,200	$ 10,200	$ 10,200	$ 10,200
16	Data Evaluation and Reporting	$ 16,800	$ 16,800	$ 16,800	$ 16,800	$ 16,800	$ 16,800	$ 16,800	$ 16,800
	TOTAL ANNUAL MONITORING COST	**$ 67,600**	**$ 83,100**	**$ 67,600**	**$ 83,100**	**$ 67,600**	**$ 67,600**	**$ 67,600**	**$ 67,600**
ANNUAL O&M COSTS									
17	Groundwater Treatment Plant O&M	---	---	---	---	---	---		$ 1,395,197
MEDIA REPLACEMENT									
18	Media Replacement, 5 yr	---	---	---	---	---	---		**$ 19,564**
FIVE YEAR REVIEW									
19	Five Year Review Report	**$ 35,300**	**$ 35,300**	**$ 35,300**	**$ 35,300**	**$ 35,300**	**$ 35,300**	**$ 35,300**	**$ 35,300**
PRESENT WORTH									
20	Total Capital Costs	$ 308,587	$ 9,430,408	$ 308,587	$ 6,738,031	$ 13,615,086	$ 11,096,114	$ 16,666,269	$ 13,643,723
21	O & M Costs/ (30 year duration)	---	---	---	---	---	---	---	$ 17,313,005
22	Media Change Out	---	---	---	---	---	---	---	$ 242,770
23	Long-term Monitoring Cost (30 year duration)	$ 838,848	$ 1,031,188	$ 838,848	$ 1,031,188	$ 838,848	$ 838,848	$ 838,848	$ 838,848
24	Five Year Reviews (30 year duration)	$ 76,171	$ 76,171	$ 76,171	$ 76,171	$ 76,171	$ 76,171	$ 76,171	$ 76,171
	TOTAL PRESENT WORTH	**$ 1,224,000**	**$ 10,538,000**	**$ 1,224,000**	**$ 7,845,000**	**$ 14,530,000**	**$ 12,011,000**	**$ 17,581,000**	**$ 32,115,000**

Table 4-2
Summary of Comparative Analysis of Remedial Alternatives
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Evaluation Criteria	Alternative 1 No Action	Alternative 2 MNA/In Situ Treatment (Contingency Remedy)/ Institutional Controls
Summary of Components	■ No action	■ Long-term groundwater monitoring ■ In situ treatment (contingency remedy) via permeable reactive barrier (Sub-alternative 2A) ■ In situ treatment (contingency remedy) via geochemical fixation (Sub-alternative 2B) ■ Institutional controls ■ Periodic site reviews
Overall Protection of Human Health and the Environment	Would not provide overall protection of human health and the environment because no remedial action would be implemented under this alternative, no mechanism to monitor the migration of contamination.	Would be protective of human health and the environment through natural reduction processes including the use of available iron and manganese in the groundwater to reduce hexavalent chromium to trivalent chromium. This process is expected to occur primarily in the area downgradient of the plume, given that iron and manganese have become depleted within the plume. Monitoring would be used to evaluate the migration and reduction of contaminant concentrations through time. Should MNA prove unsuccessful, groundwater contamination would be reduced by in situ treatment, after reacting with the reducing agent injected either as a PRB or through geochemical fixation. Institutional controls would prevent future exposure to chromium and contaminated groundwater. Monitoring would be used to evaluate the migration and reduction of contaminant concentrations through time.
Compliance with ARARs	Would not meet MCL for chromium (chemical specific ARAR). No location- or action specific ARARs were identified.	It is not known if this alternative would meet the chemical-specific ARARs within 30 years. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time. No location-specific ARARs were identified. Alternative would be designed to comply with action-specific ARARs.
Long-term Effectiveness and Permanence	Not considered a permanent remedy, contaminants would not be destroyed, except gradual reductions through natural attenuation.	Natural attenuation would provide long-term protection by reducing the quantity of hexavalent chromium present in the groundwater, thereby reducing potential for further downgradient migration of the plume. If necessary, as a contingency, in situ treatment would be installed to further reduce plume migration and enhance long-term effectiveness. The groundwater in the contaminated area is not currently being used so there is no risk to current human receptors. Institutional controls would restrict drilling of new drinking water wells in the contaminated area and protect against future human health risks.
Reduction of Toxicity, Mobility, and Volume through Treatment (TMV)	No reduction in TMV.	No reduction in TMV through active treatment, unless in situ treatment is implemented as a contingency remedy. Contaminant concentrations would decrease slowly through natural attenuation.
Short-term Effectiveness	There is no short-term impact to workers and the community as there is no remedial activity under this alternative.	Limited site work would be performed for MNA and would have minimal short-term impact to workers and the community. Should in situ treatment become necessary, as a contingency, construction could be performed without significant risk. Use of PPE by workers would minimize the exposure. A time period of 30 years is assumed for implementation of this alternative.
Implementability	Could be easily implemented.	MNA would be easily implementable. Should it become necessary, construction of an in situ treatment system would utilize conventional construction methods. Securing access to neighboring properties would be administratively difficult. Treatability study would be required for the is situ treatment.
Cost	$0	$1.2 million (Sub-alternative 2A - MNA) $10.5 million (Sub-alternative 2A - MNA with Contingency) $1.2 million (Sub-alternative 2B - MNA) $7.8 million (Sub-alternative 2B - MNA with Contingency)

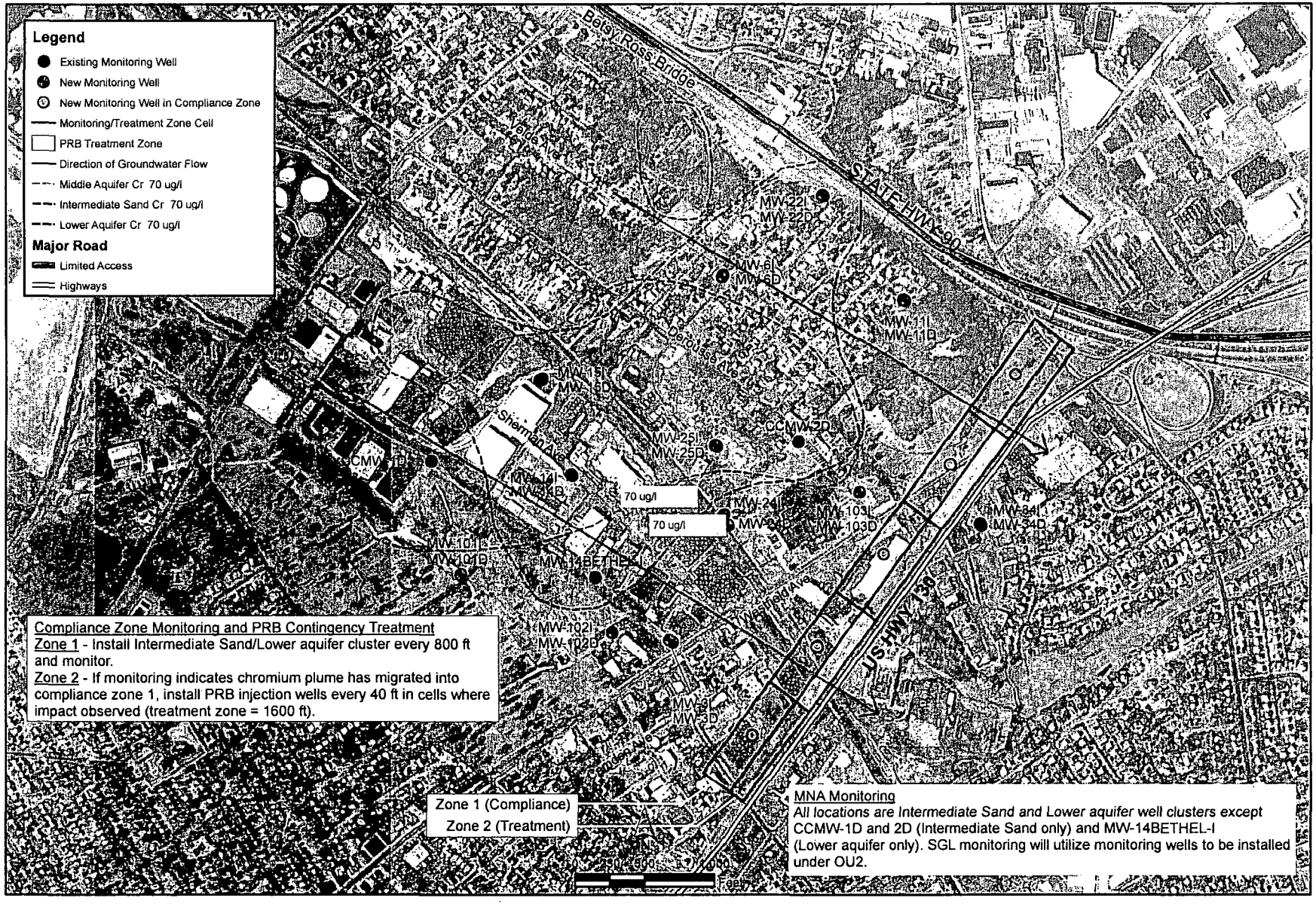
Table 4-2
Summary of Comparative Analysis of Remedial Alternatives
Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Evaluation Criteria	Alternative 3 In Situ Treatment/MNA/Institutional Controls	Alternative 4 Groundwater Extraction/Treatment/Off-Site Disposal/Long-term Groundwater Monitoring/Institutional Controls
Summary of Components	▪ In situ treatment via permeable reactive barrier, chromium plume > 1,000 µg/L (Sub-alternative 3A) ▪ In situ treatment via geochemical fixation, chromium plume > 1,000 µg/L (Sub-alternative 3B) ▪ In situ treatment via geochemical fixation, chromium plume > 70 µg/L (Sub-alternative 3C) ▪ Long-term groundwater monitoring ▪ Institutional controls ▪ Periodic site reviews	▪ Installation of extraction wells and submersible pumps ▪ Groundwater treatment ▪ Off-site disposal ▪ Operation and maintenance ▪ Long-term groundwater monitoring ▪ Institutional controls ▪ Periodic site reviews
Overall Protection of Human Health and the Environment	In situ treatment would be effective in reducing hexavalent chromium to trivalent chromium in the highest areas of chromium contamination by injecting a reducing agent either as a PRB or through geochemical fixation. Institutional controls would prevent future exposure to chromium and contaminated groundwater. Monitoring would be used to evaluate the migration and reduction of contaminant concentrations through time. Natural attenuation processes would be effective in reducing chromium concentrations in the portion of the plume where in situ treatment is not being performed.	Would be protective of human health and the environment by active pumping and treatment. Pumping would reduce the chromium contaminant plume size and concentrations, and the VOCs commingled with chromium contamination in the aqueous phase. Currently there are no risks to human health as the groundwater is not being used. Institutional controls would prevent future exposure to chromium and contaminated groundwater. Monitoring would be used to evaluate the migration and reduction of contaminant concentrations through time.
Compliance with ARARs	The quantity of mobile hexavalent chromium would be greatly reduced through in situ treatment. It is not known if Sub-alternatives 3A and 3B would meet the chemical-specific ARARs within 30 years. Sub-alternative 3C is expected to meet the PRGs in 5 to 10 years. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time. No location-specific ARARs were identified. Alternative would be designed to comply with action-specific ARARs.	Contaminant concentrations in the plume and plume size are expected to decrease over time. It is not known if the PRGs would be met within 30 years. Long-term groundwater monitoring would be conducted to assess the degree of compliance achieved over time. No location-specific ARARs were identified. Alternative would be designed to comply with action-specific ARARs.
Long-term Effectiveness and Permanence	In situ treatment would immobilize chromium in the highest contamination areas, and provide long-term effectiveness. MNA in the remainder of the plume would minimize potential further downgradient migration. The groundwater in the contaminated area is not currently being used so there is no risk to current human receptors. Institutional controls would restrict drilling of new drinking water wells in the contaminated area and protect against future human health risks.	Groundwater pump and treat would create an inward gradient that would remove chromium contaminated groundwater from the aquifer, and prevent downgradient migration of the contaminated plume. The groundwater in the contaminated area is not currently being used so there is no risk to current human receptors. Institutional controls would restrict drilling of new drinking water wells in the contaminated area and protect against future human health risks.
Reduction of Toxicity, Mobility, and Volume (TMV)	Reduction of TMV of the contaminants in groundwater would be achieved through treatment (reduction and immobilization). Contaminant concentrations outside the treatment area would decrease slowly through natural attenuation.	Reduction of TMV of the chromium and VOC contaminants in groundwater would be achieved through treatment. The contaminants would be removed through groundwater extraction. Chromium would be reduced and precipitated out of solution, and the sludge would be disposed in an offsite landfill. VOCs collected on the carbon adsorption media following air stripping would be destroyed during the carbon regeneration process.
Short-term Effectiveness	Installation and operation of the in situ system would have significant impact to the community. Use of PPE would minimize exposure to workers. A time period of 30 years is assumed for implementation of this alternative.	Installation and operation of the groundwater pump and treatment system would have significant impact to the community. Use of PPE would minimize exposure to workers. A time period of 30 years is assumed for implementation of this alternative.
Implementability	Construction of an in situ treatment system would utilize conventional construction methods. Securing access to neighboring properties would be administratively difficult.	Construction of a groundwater pump and treatment system would utilize conventional construction methods. Securing access to neighboring properties would be administratively difficult.
Cost	$14.5 million (Sub-alternative 3A) $12.0 million (Sub-alternative 3B) $17.6 million (Sub-alternative 3C)	$32.1 million

Table 4-3
Cost Sensitivity Analysis for Sub-alternatives 3A, 3B, and 3C
Puchack Well Field Superfund Site

Alternative	Base Cost	Cost for Reduced Injection Well Spacing	Cost Increase	% Cost Increase
3A	$ 14,530,000	$ 24,865,000	$ 10,335,000	71%
3B	$ 12,011,000	$ 19,490,000	$ 7,479,000	62%
3C	$ 17,581,000	$ 29,853,000	$ 12,272,000	70%

Notes:
Permeable reactive barrier well spacing reduced from 40 ft to 20 ft for Sub-alternative 3A, and geochemical injection well spacing reduced from 150 ft to 75 ft for Sub-alternatives 3B and 3C.

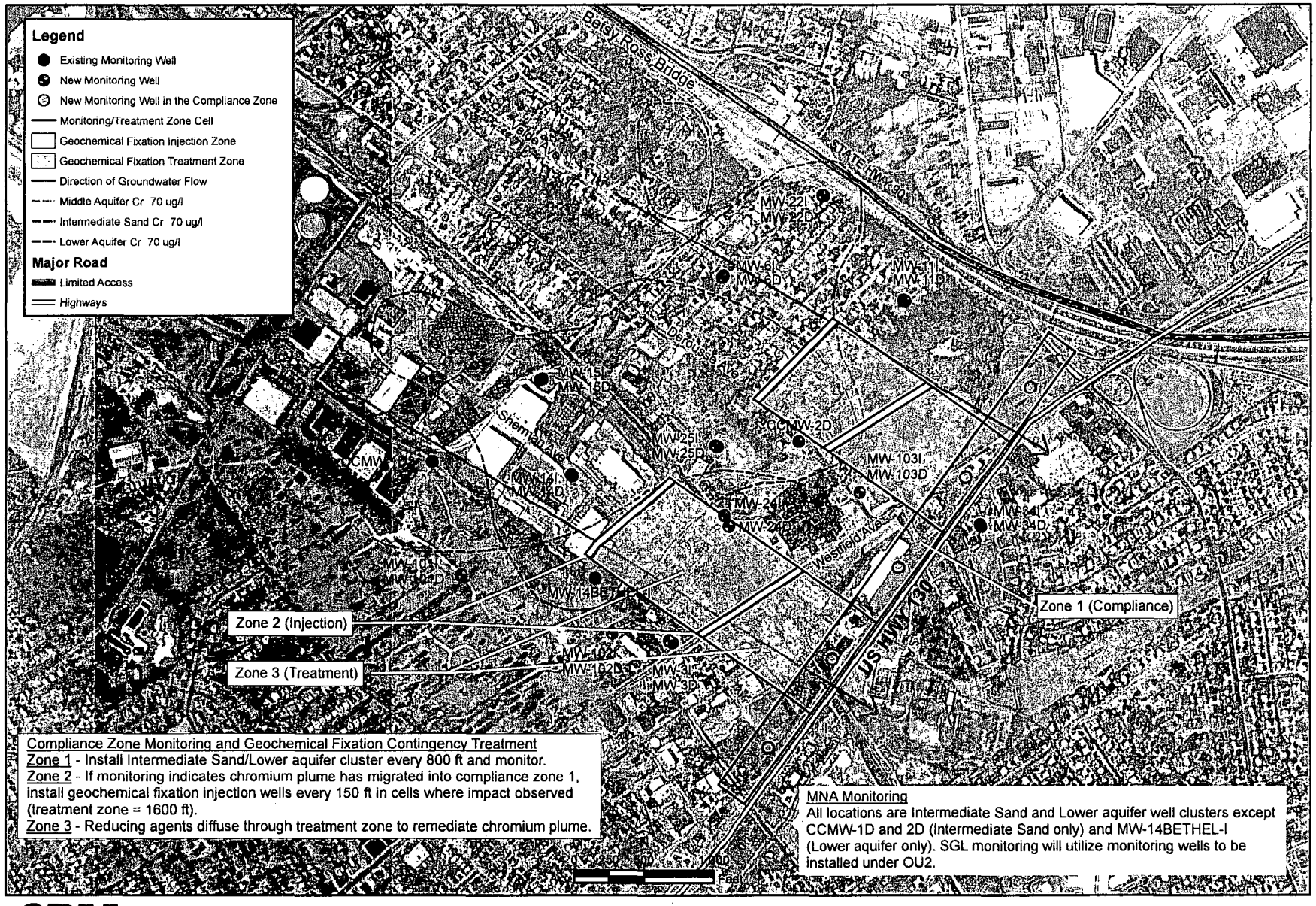


CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Figure 4-1
Alternative 2A
Monitored Natural Attenuation
with In Situ Treatment
(PRB Contingency Remedy)

400151

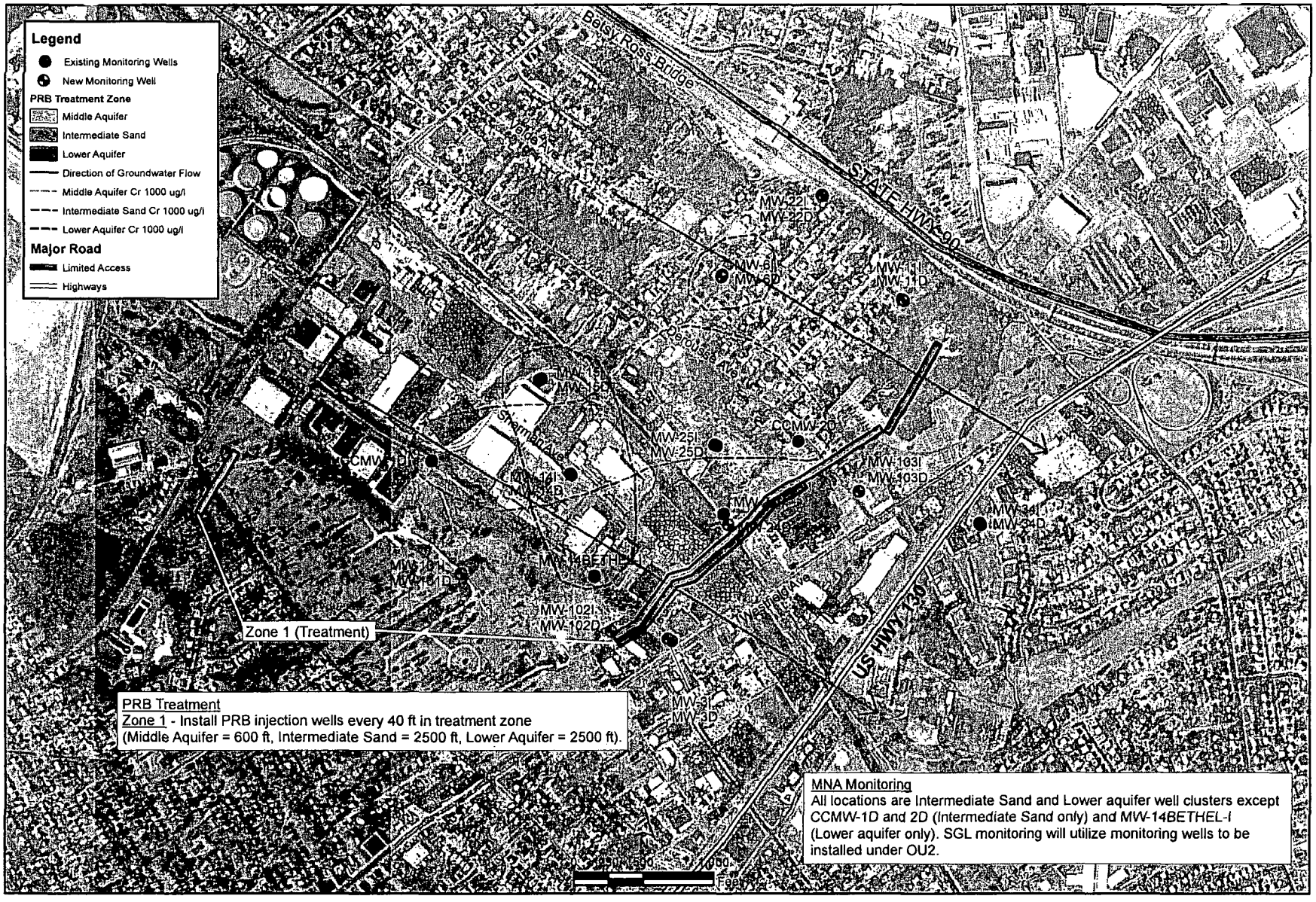


CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

400152

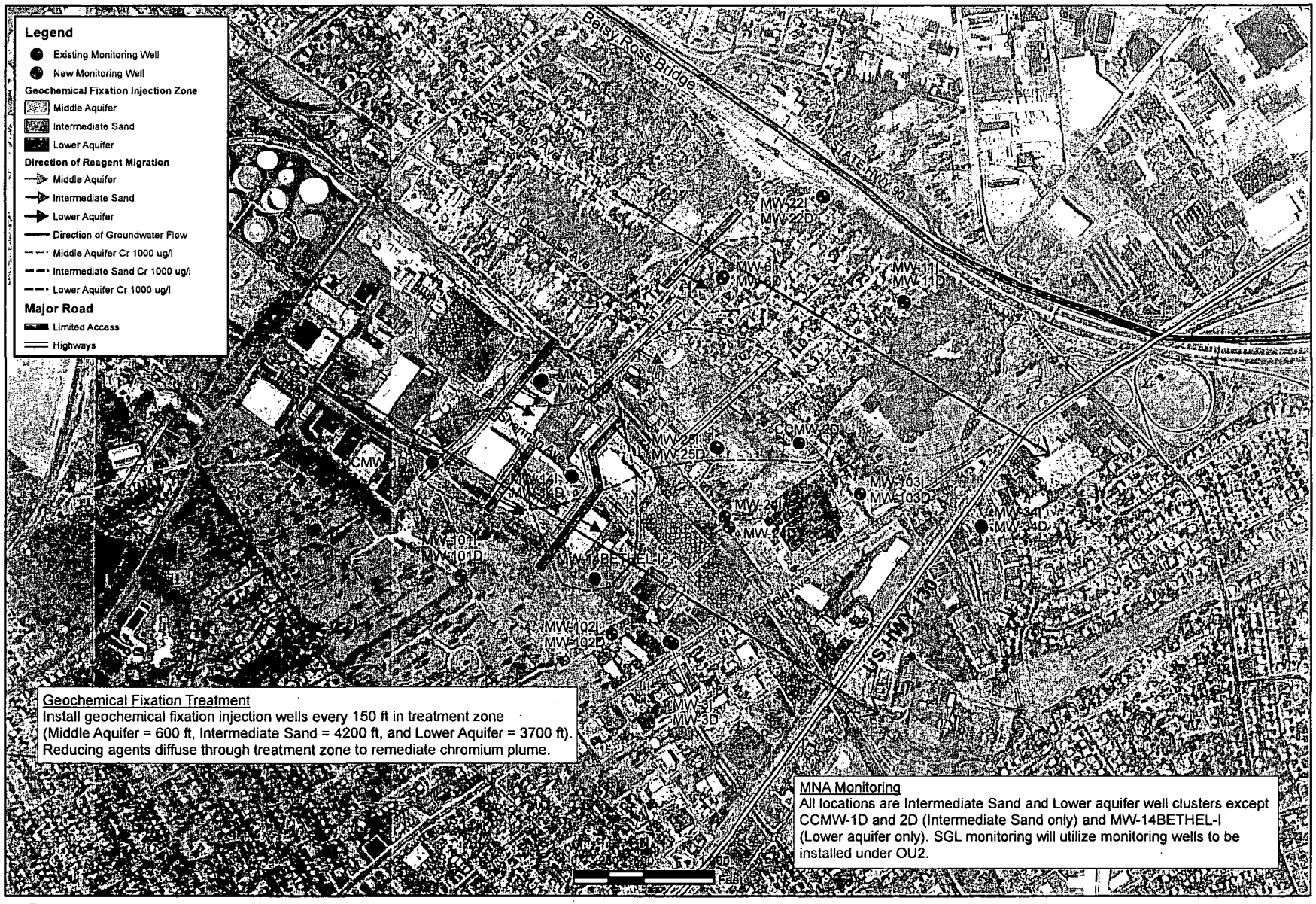
Figure 4-2
Alternative 2B
Monitored Natural Attenuation
with In Situ Treatment
(Geochemical Fixation Contingency Remedy)



CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

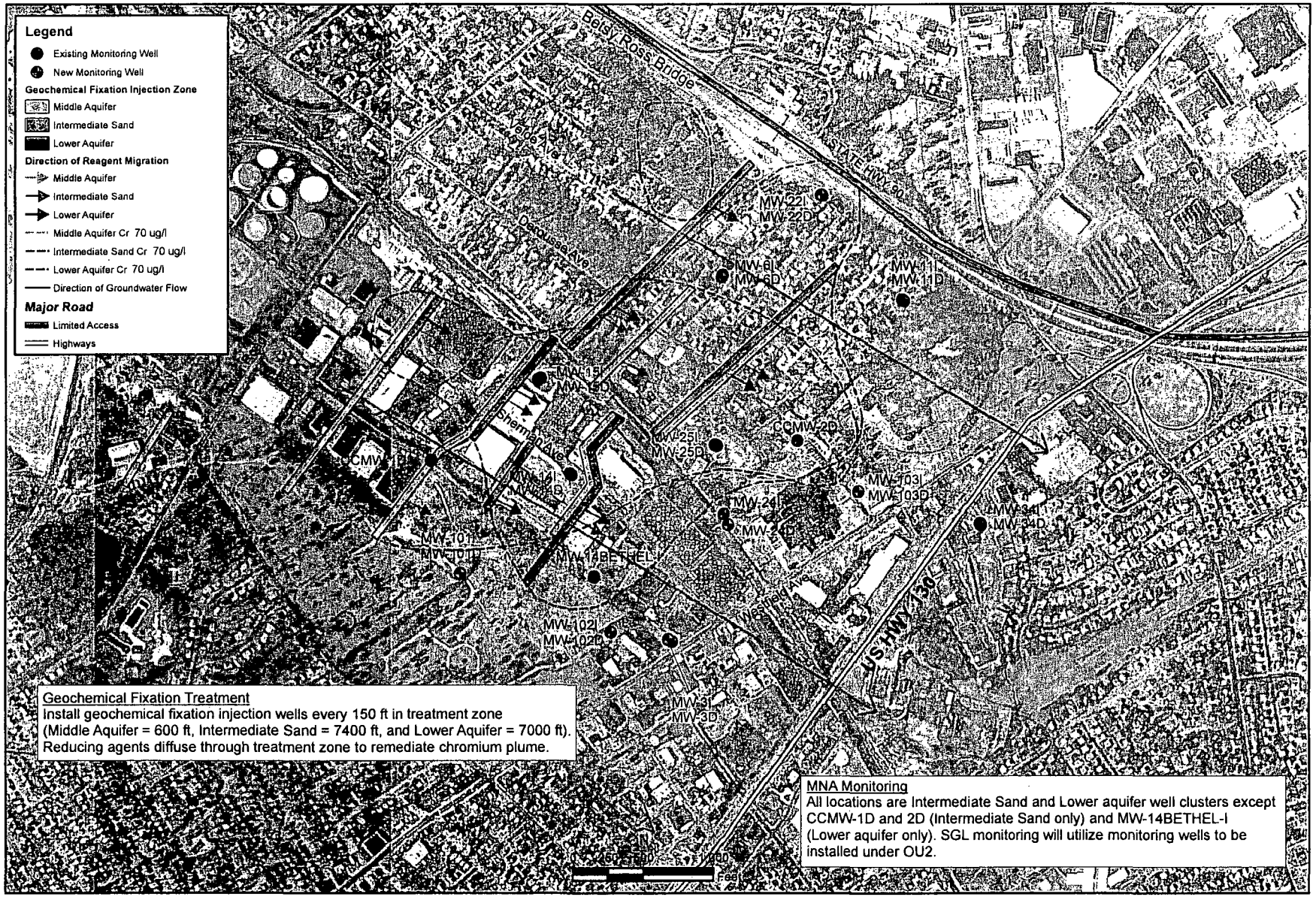
Figure 4-3
Alternative 3A
In Situ Treatment (PRB)
for Chromium Plume > 1000 ug/l



CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

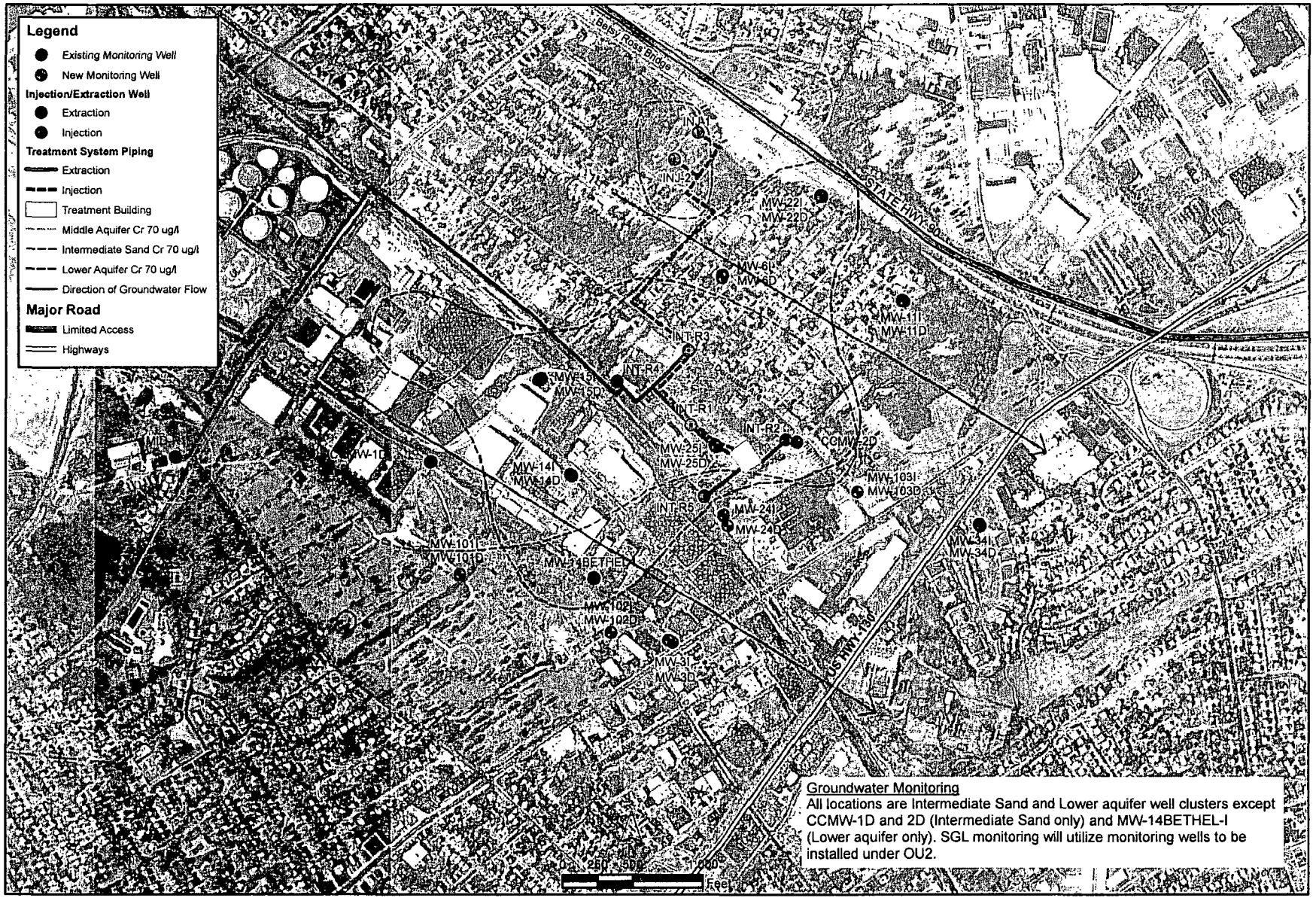
Figure 4-4
Alternative 3B
In Situ Treatment (Geochemical Fixation)
for Chromium Plume > 1000 ug/l



CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Figure 4-5
Alternative 3C
In Situ Treatment (Geochemical Fixation)
for Chromium Plume > 70 ug/l



CDM

Puchack Well Field Superfund Site
Pennsauken Township, New Jersey

Figure 4-6
Alternative 4
Groundwater Extraction/Treatment/Offsite Disposal

400156

5 Section Five

400157

Section 5
References

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Appendix A

400160

Appendix A

Calculations of Aquifer Reductive Capacity and Quantity of Chromium in Plumes

Purpose: 1) Calculate the time that a given volume of the Intermediate and Lower Aquifers are effective in attenuating/removing Cr from the Groundwater.

2) Calculate the total attenuating capacity of the Intermediate and Lower Aquifers for a given volume of aquifer material.

For Item 1

Method:

Time (yr) = (Comp Zone distance)(1/GW velocity)(R)(Reduction Capacity)

Comp Zone Distance (ft) = Distance perpendicular to ground water flow over which reduction and Cr removal will occur (use 100 ft as an example)
Compliance Zone

GW Velocity = ground water velocity (ft/yr)
= 310 ft/yr for both aquifers
(Frank Tsang email of 1/4/06) - attached pg 10

R = Retardation Factor for Cr^{6+} ($HCrO_4^-$)
(depends on aquifer material, pH and sulfate concentration)

Reduction Capacity (# of pore volume) = the capacity of the aquifer material to reduce Cr^{6+} to Cr^{3+} .. resulting in attenuation (precipitation) of the Cr.

For Item 2

Method:

Mass of Cr Removed (Precipitated) (Kg) =

(Comp Zone Distance) (Aquifer Thickness) (length of plume)
(Density of aquifer material) (Adsorption Capacity)

Comp Zone Distance (ft) = see page 1

Aquifer thickness (ft) = 20 ft for Intermediate
= 90 ft for ~~Deep~~ Lower
attached pg 13 → (see Eric Kenney 1/6/06 calc)

length of plume (ft) = distance along downgradient edge of plume
= approx. 3000 ft for Intermediate (Fig 4-14, RI)
= approx. 2500 ft for ~~Deep~~ Lower (Fig 4-15, RI)

Density of Aquifer Material (g/cm^3) = 1.6 g/cm^3

Adsorption Capacity $\left(\frac{mg\ Cr}{kg\ of\ aquifer\ material}\right)$ = $35 \frac{mg\ Cr}{kg}$
(see calc on page 8)

~~Item 1~~

Reference

1) Pacific Northwest National Laboratory (PNNL), Nov 2005, Draft Interim Progress Report, Treatability Study of In Situ Technologies for Remediation of Hexavalent Chromium in Groundwater at the Puchack Well Field Superfund Site, New Jersey = "TS"

2) CDM, June 2002, Draft OU1 Remedial Investigation Report, Puchack Well Field Superfund Site, Pennsauken Township, New Jersey = "RI"

For Item 1 Calculation

Data Used

Unit	Area	Average pH (su)	Average DO (mg/L)	Average Cr (ug/L)
Intermediate	Near Plume Boundary	4.9	2.48	1,704.
Intermediate	Downgradient of Boundary	5.3	4.71	1.7
Lower	Near Plume Boundary	5.47	0.86	374.
Lower	Down gradient of Boundary	5.3	1.48	1.85

See attached email of 1/04/06 from D. Gilroy to R. Olsen giving all data and sources of data (pg 11/13)

"Co-located Samples" were averaged and then used as one value to obtain average values given above.

pH values were converted to concentrations of H^+ before averaging

"Areas"

"Near Plume Boundary" = All data ~~at~~ near downgradient edge of Cr plume boundary (both inside & outside boundary)

"Downgradient of Plume Boundary" = just data downgradient (outside) of plume boundary (shown in RI figures 4-14 and 4-15)

Retardation Factor Calculation

Depends upon both pH and sulfate concentration

Use Figure 4.4-3 from TS.

Use Equation for 3 hour Batch from Fig 4.4-3

$Kd = (1 \times 10^7)\, x^{-8.3321}$ $\quad x = pH$

$R = 1 + \frac{\rho}{n} Kd$ $\quad \rho$ = bulk density = 1.65 g/cm^3

n = porosity = 0.3

Unit	Area	pH	Kd	R
Inter.	Near	4.9	17.8	98.9
Inter.	Downgradient	5.3	9.2	51.6
Lower	Near	5.47	7.1	40.0
Lower	Downgradient	5.3	9.2	51.6

As shown in Figure 4.4-3, use of the 3hr equation will yield conservative low values. However, at a pH value of 4.83, the calculated Kd would be 20. This compares to the

Column study Kd value of 6.58 (see Fig 4.4-1) at pH value of 4.83. So the calculated values above are higher than the column study but lower than the ~~lower~~ longer term batch studies.

The batch study was conducted using DI water. Adjustments must be made for actual site groundwater. In particular, sulfate reduces chromium adsorption/reduction. See Figure 4.2-8 in TS (pg 100 has larger version of this figure).

Using the Equation on Fig. 4.2-8

~~y = -4242 ln(x) + 64.488~~ RR

~~y = -0.377 ln~~

$$y = -0.3077 \ln(x) + 3.1098$$

x = Sulfate conc.

y = Kd

at 100 mg/L sulfate, Kd is reduced by a factor of 1.53 (compared to sulfate at 5 mg/L) $\frac{2.6}{1.67} = 1.53$

100 mg/L sulfate is a conservatively high value at the site: Pg 4.21 (RI) "Concentrations of most samples ~~were~~ (73%) were between 10 - 50 mg/L" (for sulfate)

Adjusting for sulfate yields following values

Unit	Area	Adjusted R
Inter.	Near Boundary	64.6
Inter.	Down gradient	33.7
Lower	Near Boundary	26.1
Lower	Down gradient	33.7

Reduction Capacity Calculation

The average "sediment reductive capacity" was determined in the TS to be 3.49 μmole Fe^{2+}/g or 3.5 μmole Fe^{2+}/g (used in calculations). See Table 4.3-4 and pg 53 of TS. Intermediate and Lower aquifer materials (sediments) were tested. The TS converts this value to the amount of available electron donors in the aquifer material (see pg 53, TS)

Electron donor = 23.2 mmoles e^-/L

This is the amount of electrons in the pore water that can react with the electron acceptors. The major electron acceptors are Cr^{6+} and Dissolved Oxygen (D.O.)

The amount of electron acceptors are calculated as follows:

D.O.

$(X\ mg/L\ O_2)(g/1000mg)(mole\ O_2/32g)(4 mole\ e^-/mole\ O_2)$

$= \underline{A}\ mole\ e^-/L$

Cr^{6+}

$(X\ mg/L\ Cr^{6+})(g/1000mg)(mole\ Cr^{6+}/52g)(3 mole\ e^-/mole\ CrO_4^{2-})$

$= \underline{B}\ mole\ e^-/L$

Total electron acceptor $= A + B = TEA$

Total Reductive Capacity or how long the reductive capacity will be effective (in terms of PVs)

= Total Electron Donor / Total Electron Acceptor

$= (23.2 \times 10^{-3} mole\ e^-/L) / TEA =$ # of Pore volumes (PV)

Results

Unit	Area	D.O (mg/L)	Cr^{6+} (mg/L)	TEA (mole e/L)	Reductive Capacity (PV)
Inter.	Near Boundary	2.48	1.704	4.08×10^{-4}	56.8
Inter.	Downgradient	4.71	0.0017	5.89×10^{-4}	39.4
Lower	Near Boundary	0.86	0.374	1.29×10^{-4}	180
Lower	Downgradient	1.48	0.00185	1.85×10^{-4}	125

The effective Time of a selected aquifer zone to reduce and remove Cr^{6+} can be calculated using the Equation on pg 1 of this document

Effective Time

Time (yr) = (Comp Zone ft)(1/GW velocity)(R)(Reduction Capacity)

Example using 100 ft for Compliance zone

(100 ft)(1/310 ft/yr)(33.7)(39.4 PV)

= 428 yr ≈ 430 yr

Results

Unit	Area	Adjusted R	Reductive Capacity PV	Effective Time (yr)
Inter.	Near Boundary	64.6	56.8	1,180
Inter.	Downgradient	33.7	39.4	430
Lower	Near Boundary	26.1	180	1,520
Lower	Downgradient	33.7	125	1,360

For Item # 2 Calculation

Adsorption capacity of the aquifer material has been evaluated in the TS. The adsorption isotherm is shown in Fig 4.2-5. The Langmuir Adsorption capacity (K) = 3 μmole/g

$$(3\ \mu mole/g)(117\ mg\ HCrO_4^-/mole)\left(\frac{mg}{1000\ \mu g}\right)\left(\frac{1000\ g}{kg}\right)$$

= 351 mg $HCrO_4^-$ / kg aquifer

Total Attenuating Capacity of a 100 ft Compliance Zone

Intermediate

$$(100\ ft)(20\ ft)(3000\ ft)\left(\frac{12''}{ft}\right)^3\left(\frac{2.54\ cm}{in}\right)^3\left(\frac{1.6\ g}{cm^3}\right)\left(\frac{kg}{1000\ g}\right)$$

$$\left(\frac{351\ mg}{kg}\right)\left(\frac{g}{1000\ mg}\right)\left(\frac{kg}{1000\ g}\right) = 95{,}400\ kg\ Cr\ Reduction\ Capacity$$

Lower

$$(100\ ft)(90\ ft)(2500\ ft)\left(\frac{12''}{ft}\right)^3\left(\frac{2.54\ cm}{in}\right)^3\left(\frac{1.6\ g}{cm^3}\right)\left(\frac{kg}{1000\ g}\right)$$

$$\left(\frac{351\ mg}{kg}\right)\left(\frac{g}{1000\ mg}\right)\left(\frac{kg}{1000\ g}\right) = 357{,}800\ kg\ Cr\ Reduction\ Capacity$$

Using Eric Kenney Calculation of Total Cr Mass in plumes (see attached Calc.)

Intermediate

(95,400 kg Capacity)/(1,280 kg Cr) = 74.5 times enough capacity

Lower

(357,800 kg Capacity)/(3,717 kg Cr) = 96.3 times enough capacity

→ A 100 ft compilance zone has 75-96 times enough capacity to remoral all the Cr in the groundwater upgradient of the zone

Date checked: 1/13/06
checked by: JL

10/13
RLOlsen

Olsen, Roger

From: Tsang, Frank
Sent: Wednesday, January 04, 2006 12:50 PM
To: Gilroy, Daniel; Olsen, Roger; Kenney, Eric
Subject: RE: Puchack FS calculations

310 ft/day

There is a typo on that page; the correct groundwater velocity should be 310 feet per year. Velocity = K * gradient / porosity = 150 feet/day * 0.0017 ft/ft / 0.3 = 0.85 ft/day * 365 days/yr = 310 ft/yr

---

From: Gilroy, Daniel
Sent: Wednesday, January 04, 2006 1:12 PM
To: Olsen, Roger; Kenney, Eric
Cc: Tsang, Frank
Subject: RE: Puchack FS calculations

Eric: Use the hand calculation sheet you drafted and create an excel spreadsheet for the calculations, only calculate in English units (not metric), see Roger's comments on calculations. This will be included as a table in the report (or in a separate appendix). Then, redraw your plume area estimate maps on 1 sheet to accompany the calculations

Roger/Frank:

1. The groundwater velocity on Page 5-10 is now much lower at approximately 10 ft/yr than the ones you listed below 620 to 720 ft/year, please verify. Also page 5-10 lists the porosity as 0 3, so perhaps use 0.3. Attached is the final RI report text, the figures appear to be the same, Frank can you confirm?

I checked the data points and have these suggested changes, based on using the same set of wells within each aquifer unit for all of the various parameters.

2 Cr concentrations. I will use total Cr (Cr6+ is the appropriate value to use, however, total Cr values are more conservative) For intermediate aquifer, I used figure 4-14. I will use all values near the southeast edge of the plume (3.3, <2, 0.82, 3570, 6310, 1720 and 320 ug/L). If I only use values downgradient, I will have three values (3 3, 0.82 and <2) For the deep aquifer, I used figure 4-15. For all values near edge of plume 4.9 (and 0.59 collocated), 0.81, 543, 237, 1460 and 2 ug/L. For only those outside: 4.9 (and 0.59 collocated), 0.81 and 2.

3. DO concentrations: For Intermediate, I used figure 5 2. For all values near edge of plume: 0.03, 1.05, 0 43, 1 7, 3.99, 7.13 and 3.0 mg/L For outside the plume: 3.99, 7.13 and 3.0 mg/L. For lower aquifer, I used figure 5 3. For all values near edge of plume 19, .31, .23, 1.29, (and 2.90 and 3.59 collocated) 0 11, and 1.74 mg/L. For outside the plume: 1.29, (and 2.90 and 3 59 collocated) 0.11, and 1.74 The values of 2 9 and 3.59 appear to be from the same well and will be averaged before use.

4 pH values: For intermediate, I used figure 4-27 For all values near the SE plume edge: 4.43, 4 94, 4 64, 4 92, 5.82, 5 9, and 6 18 For values outside the plume: 4.92, 5.82, and 5 9. For the lower aquifer, I used figure 4-28 For all values near SE plume edge: 5.51, 6.15, 6 02, 4 89, (and 4 71 and 4.96 collocated), 6.14, and 6.22. For outside the plume: 6 14, 4.89, (4.71 and 4.96 collocated), and 6.22. 4.71 and 4.96 appear to be from the same well and will be averaged before use (after appropriate conversion from log values).

From: Olsen, Roger
Sent: Monday, January 02, 2006 7:49 PM
To: Kenney, Eric; Gilroy, Daniel
Cc: Tsang, Frank
Subject: RE: Puchack FS calculations

Eric: For mass, general equation if you have a contoured isoconcentration figure: (area between two isoconcentrations lines)x(thickness of aquifer in the area of isoconcentrations lines)x(porosity)x(average concentrations of the two isoconcentration lines)x(appropriate conversion factors). If you only have extent (which is what you probably have), use average concentration or try to estimate various areas of concentration. Do you

Date checked: 1/13/06
Checked by: JL

11/13
RLOlsen

Olsen, Roger

From: Gilroy, Daniel
Sent: Wednesday, January 04, 2006 11:12 AM
To: Olsen, Roger; Kenney, Eric
Cc: Tsang, Frank
Subject: RE: Puchack FS calculations

Eric: Use the hand calculation sheet you drafted and create an excel spreadsheet for the calculations, only calculate in English units (not metric), see Roger's comments on calculations. This will be included as a table in the report (or in a separate appendix). Then, redraw your plume area estimate maps on 1 sheet to accompany the calculations.

Roger/Frank:

1. *The groundwater velocity on Page 5-10 is now much lower at approximately 10 ft/yr than the ones you listed* below 620 to 720 ft/year, please verify. Also page 5-10 lists the porosity as 0.3, so perhaps use 0.3. Attached is the final RI report text, the figures appear to be the same, Frank can you confirm?

I checked the data points and have these suggested changes, based on using the same set of wells within each aquifer unit for all of the various parameters:

Cr

2. Cr concentrations. I will use total Cr (Cr6+ is the appropriate value to use; however, total Cr values are more conservative). For intermediate aquifer, I used figure 4-14. I will use all values near the southeast edge of the plume (3.3, <2, 0.82, 3570, 6310, 1720 and 320 ug/L). If I only use values downgradient, I will have three values (3.3, 0.82 and <2). For the deep aquifer, I used figure 4-15. For all values near edge of plume: 4.9 (and 0.59 collocated), 0.81, 543, 237, 1460 and 2 ug/L. For only those outside: 4.9 (and 0.59 collocated), 0.81 and 2.
(4.9+0.59)/2

3. DO concentrations: For Intermediate, I used figure 5.2. For all values near edge of plume: 0.03, 1.05, 0.43, 1.7, 3.99, 7.13 and 3.0 mg/L. *For outside the plume: 3.99, 7.13 and 3.0 mg/L. For lower aquifer, I used figure* 5.3. For all values near edge of plume: .19, .31, .23, 1.29 (and 2.90 and 3.59 collocated) 0.11, and 1.74 mg/L. For outside the plume: 1.29, (and 2.90 and 3.59 collocated) 0.11, and 1.74. The values of 2.9 and 3.59 appear to be from the same well and will be averaged before use. (1.29+2.9+3.59)/3

pH

4. pH values: For intermediate, I used figure 4-27. For all values near the SE plume edge: 4.43, 4.94, 4.64, 4.92, 5.82, 5.9, and 6.18. For values outside the plume: 4.92, 5.82, and 5.9. For the lower aquifer, I used figure 4-28. For all values near SE plume edge: 5.51, 6.15, 6.02, 4.89, (and 4.71 and 4.96 collocated), 6.14, and 6.22. For outside the plume: 6.14, 4.89 (4.71 and 4.96 collocated), and 6.22. 4.71 and 4.96 appear to be from the same well and will be averaged before use (after appropriate conversion from log values).
(4.89+4.71+4.96)/3

From: Olsen, Roger
Sent: Monday, January 02, 2006 7:49 PM
To: Kenney, Eric; Gilroy, Daniel
Cc: Tsang, Frank
Subject: RE: Puchack FS calculations

Eric: *For mass, general equation if you have a contoured isoconcentration figure: (area between two* isoconcentrations lines)x(thickness of aquifer in the area of isoconcentrations lines)x(porosity)x(average concentrations of the two isoconcentration lines)x(appropriate conversion factors). If you only have extent (which is what you probably have), use average concentration or try to estimate various areas of concentration. Do you have mass values for both the intermediate and lower aquifers? We should have both values.

Eric, Dan and Frank: To do the other calcuations, I need groundwater velocity/porosity, Cr concentrations, DO concentrations and pH values in the area just down gradient (southest) of the plumes for the intermediate and lower aquifers.

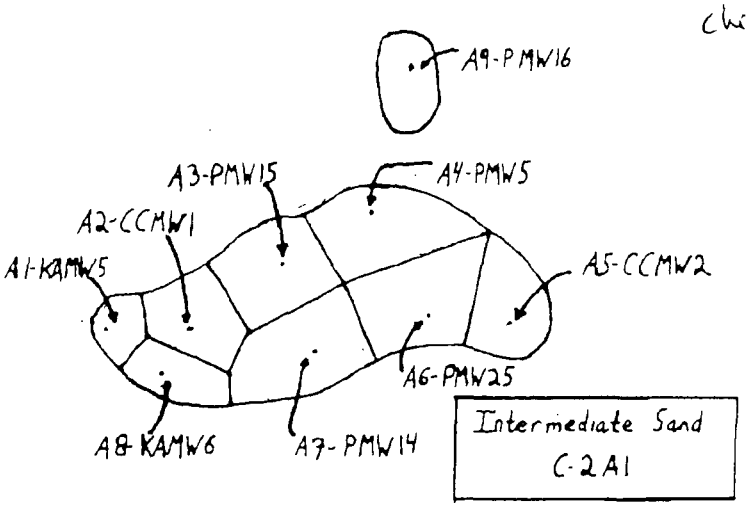
I could not find a new RI on the eRoom RAC2 site (only found FS and HHRA). Therefore, I used the RI that I have (dated 6/14/02) to dervive the following:

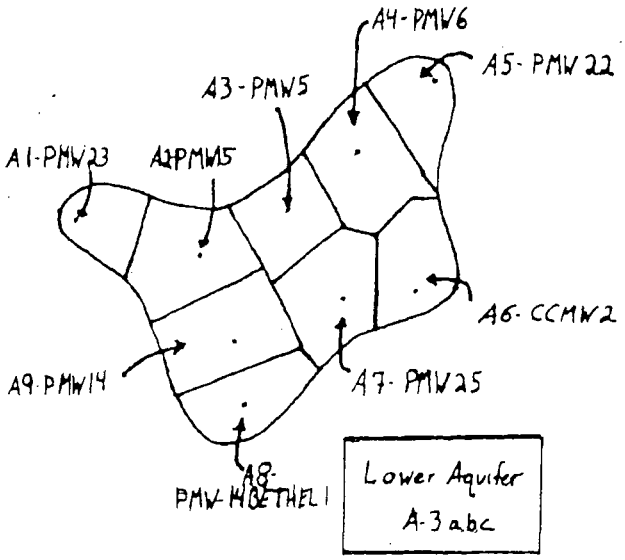
CDM

CLIENT	EPA	JOB NO	3223-102	COMPUTED BY	E. Kenney
PROJECT	Puchack FS	DATE CHECKED	1/6/06	DATE	1/6/06
DETAIL	Plume Areas	CHECKED BY	D. Gilroy	PAGE NO.	1 of 1

Date checked: 1/13/06
checked by: JL

12/13
RLOlsen





400173

CDM 8

Date checked:
Checked by: JL

13/13

Name Estimate of Areal Extent of Plume and Quantity of Chrmium in Groundwater Plumes

Int Sand

Area (sf)	Area (acres)	Volume (soil) (cf)	d=20ft
3,029,745	70	60,594,900	

assume saturated with porosity = 0.316

vol. water (cf)	vol. water (l)	mass of Cr (ug)	kg	lb
19,147,988	541,888,060	1.281023E+12	1281	2823

Lower Aq

Area (sf)	Area (acres)	Volume (soil) (cf)	d=90ft
3,559,215	82	320,329,350	

assume saturated with porosity= 0.283

vol. water (cf)	vol. water (l)	mass of Cr (ug)	kg	lb
90,653,206	2,565,485,731	3.71739E+12	3717	8192

Cr (kg)

1281

3717

Porosity	
Int Sand	0.304
	0.330
	0.308
	0.307
	0.323
	0.348
	0.295
Average	0.316

Porosity	
Lower Aq	0.244
	0.281
	0.307
	0.284
	0.170
	0.224
	0.315
	0.315
	0.268
	0.235
	0.367
	0.644
	0.222
	0.241
	0.381
	0.187
	0.209
	0.347
	0.233
	0.179

Int Sand	Avg. [Cr] Area (sf)	Conc (ug/L)	Product
1	111777	910	1.02E+08
2	317682	1730	5.5E+08
3	400044	766	3.06E+08
4	458874	3010	1.38E+09
5	447108	3570	1.6E+09
6	370629	6310	2.34E+09
7	458874	1720	7.89E+08
8	241203	320	77184960
9	223554	100	22355400
Sum	3029745		7.16E+09
Weighted Avg		2364	

Lower Aq	Avg. [Cr] Area (sf)	Conc (ug/L)	Product
1	247086	129	31874094
2	470640	2220	1.04E+09
3	352980	427	1.51E+08
4	494172	1450	7.17E+08
5	352980	185	65301300
6	400044	543	2.17E+08
7	423576	237	1E+08
8	329448	1460	4.81E+08
9	488289	4810	2.35E+09
Sum	3559215		5.16E+09
Weighted Avg		1449	

CDM

CLIENT EPM
PROJECT Puchack FS
DETAIL in response to NJDEP comment

JOB NO.
DATE CHECKED 5/16/06
CHECKED BY J. Greenberg

COMPUTED BY [illegible]
DATE 5/16/06
PAGE NO. 1

* Sodium Metabisulfite ($Na_2S_2O_5$)

molecular weight = 190.13 g/mol

% Sodium = $\frac{45.92 \text{ g/mol Na}}{190.13 \text{ g/mol } Na_2S_2O_5}$

= 24.2% Na

* Volume of aquifer receiving reagent (from p. 13/13 of backup calculations)

Intermediate Sand = 541,888,060 L GW

Lower Aquifer = 2,565,485,731 L GW

3,107,373,791 L GW

Alternative 3c

from Cost Table → 13,699 Kg reagent

assume factor of safety = 20

∴ 273980 Kg reagent

× 24.2% Na

66303 Kg Na injected into aquifer

concentration of Sodium in GW

= $\frac{66303 \text{ Kg Na}}{3107373791 \text{ L GW}}$

= 2.134×10^{-5} Kg/L $\times 10^6$ mg/Kg

= 21 mg/L Na introduced into Aquifer

NJDEP MCL for Sodium is 50 mg/L

Sodium will not exceed MCL if alternative 3c is selected

400175

CDM

CLIENT EPA
PROJECT Puchack FS
DETAIL in response to NJDEP comment

JOB NO.
DATE CHECKED 5/16/06
CHECKED BY J. Greenberg

COMPUTED BY F. Schwarz
DATE 5/16/06
PAGE NO. 1

* Sodium Metabisulfite ($Na_2S_2O_5$)

molecular weight = 190.13 g/mol

% Sodium = $\frac{45.92 \text{ g/mol Na}}{190.13 \text{ g/mol } Na_2S_2O_5}$

= 24.2% Na

* Volume of aquifer receiving reagent (from p. 13/13 of backup calculations)

Intermediate Sand = 541,888,060 L GW

Lower Aquifer = 2,565,485,731 L GW

3,107,373,791 L GW

Alternative 3C

From Cost Table → 13,699 Kg reagent

assume factor of safety = 20

∴ 273980 Kg reagent

× 24.2% Na

66303 Kg Na injected into aquifer

concentration of Sodium in GW

= $\frac{66303 \text{ Kg Na}}{3107373791 \text{ L GW}}$

= 2.134×10^{-5} Kg/L $\times 10^6$ mg/Kg

= 21 mg/L Na introduced into Aquifer

NJDEP MCL for Sodium is 50 mg/L

Sodium will not exceed MCL if alternative 3C is selected

400176

CDM

CLIENT	EPA	JOB NO.		COMPUTED BY	K. Schwarz
PROJECT	Puchack	DATE CHECKED	5/16/06	DATE	5/16/06
DETAIL		CHECKED BY	S Gromberg	PAGE NO.	2

Alternative 3b

From cost table → 10963 kg reagent

Factor of Safety = 20

∴ 219260 Kg reagent

x 24.2% Na

53061 Kg Na

concentration of Na in GW

$= \frac{53061 \text{ Kg Na}}{3107373791 \text{ L GW}}$

$= 1.708 \times 10^{-5}$ Kg/L $\times 10^{6}$ mg/Kg

= 17.08 mg/L

Alternative 3b will not exceed MCL for Sodium

400177

* Sodium Dithionite ($Na_2S_2O_4$)

molecular weight = 174.1 g/mol

$$\% \ Na = \frac{45.92 \ g/mol \ Na}{174.1 \ g/mol \ Na_2S_2O_4}$$

= 26.4% Sodium

Alternative 3a

from cost table → 20080 Kg Reagent

assume factor of safety = 10

∴ 200800 Kg Reagent

$$\times \frac{26.4\% \ \text{Sodium}}{53011 \ \text{Kg Na}}$$

concentration of Sodium in GW

$$= \frac{53011 \ \text{Kg Na}}{3107373791 \ \text{L GW}}$$

$$= 1.706 \times 10^{-5} \frac{Kg}{L} \ Na \times 10^{6} \ mg/kg$$

= 17.06 mg/L Na

Alternative 3a will not exceed the MCL for Sodium

Alternatives 2a and 2b use less sodium dithionite and sodium metabisulfite than alternatives 3a and 3c, respectively. ∴ The MCL will not be exceeded

Appendix B

400179

Appendix B

USGS Groundwater Modeling Simulations

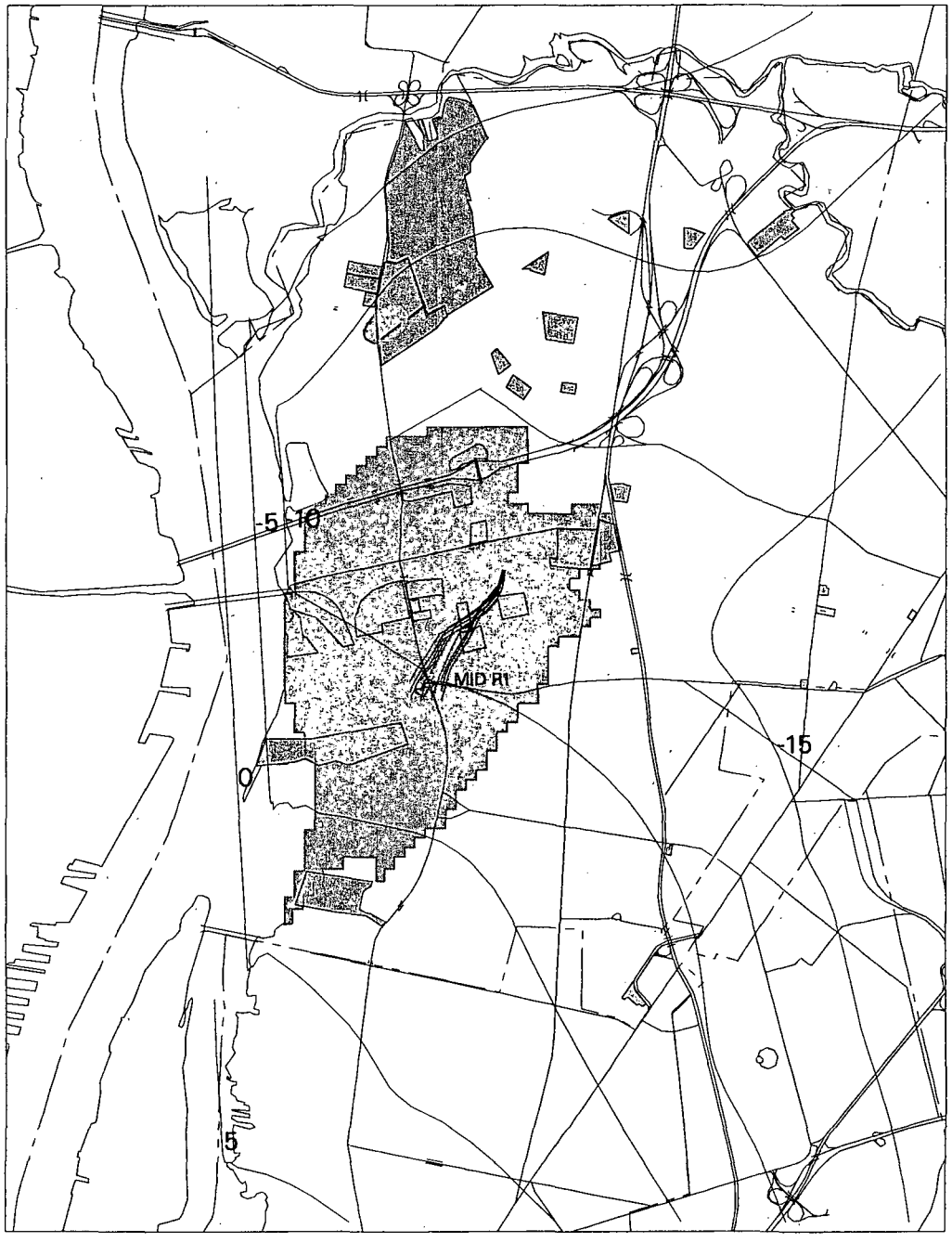
Scenario Ex Situ

Short Name: ex

Water Use: Baseline pumpage data is used. Baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Ex Situ treatment. Most of the remedial pumpage is from the Intermediate Sand. Remedial pumpage rate is 1500 gpm from the Intermediate Sand and 25 gpm from the middle aquifer. The treated water is discharged into the Delaware River.

Results: Particles tracked from chromium areas in the Middle, Intermediate Sand, and Lower aquifers are all captured. The longest travel time was 36 years, however, 95% of the particles in each aquifer had travel times less than 15 years.



Forward tracking and contributing area of remedial wells in the Middle aquifer in scenario EX

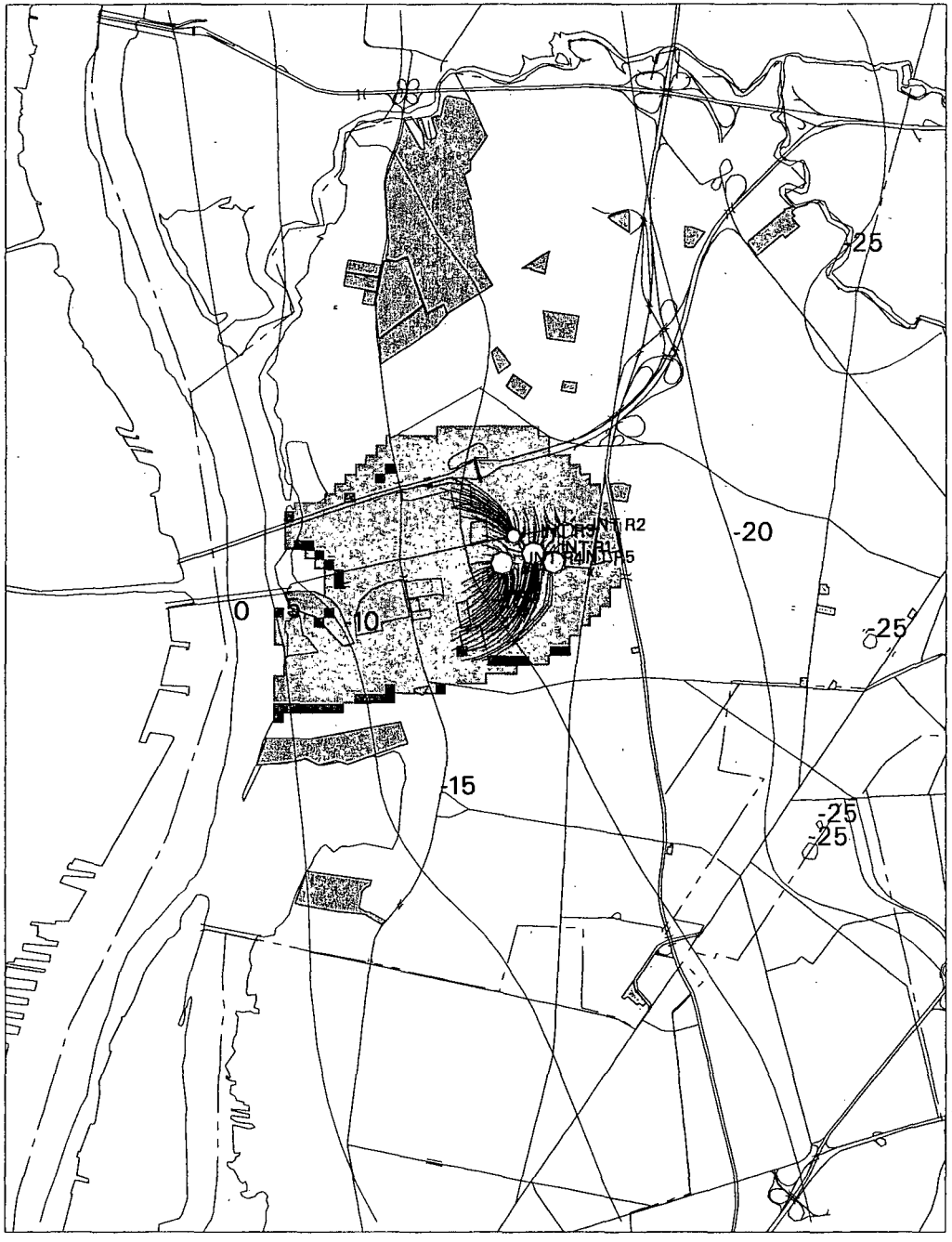
September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
INT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	15	15	15	14
isand	36	4	3	2
lwr	5	3	3	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.



Forward tracking and contributing area of remedial wells in the Intermediate sand in scenario EX

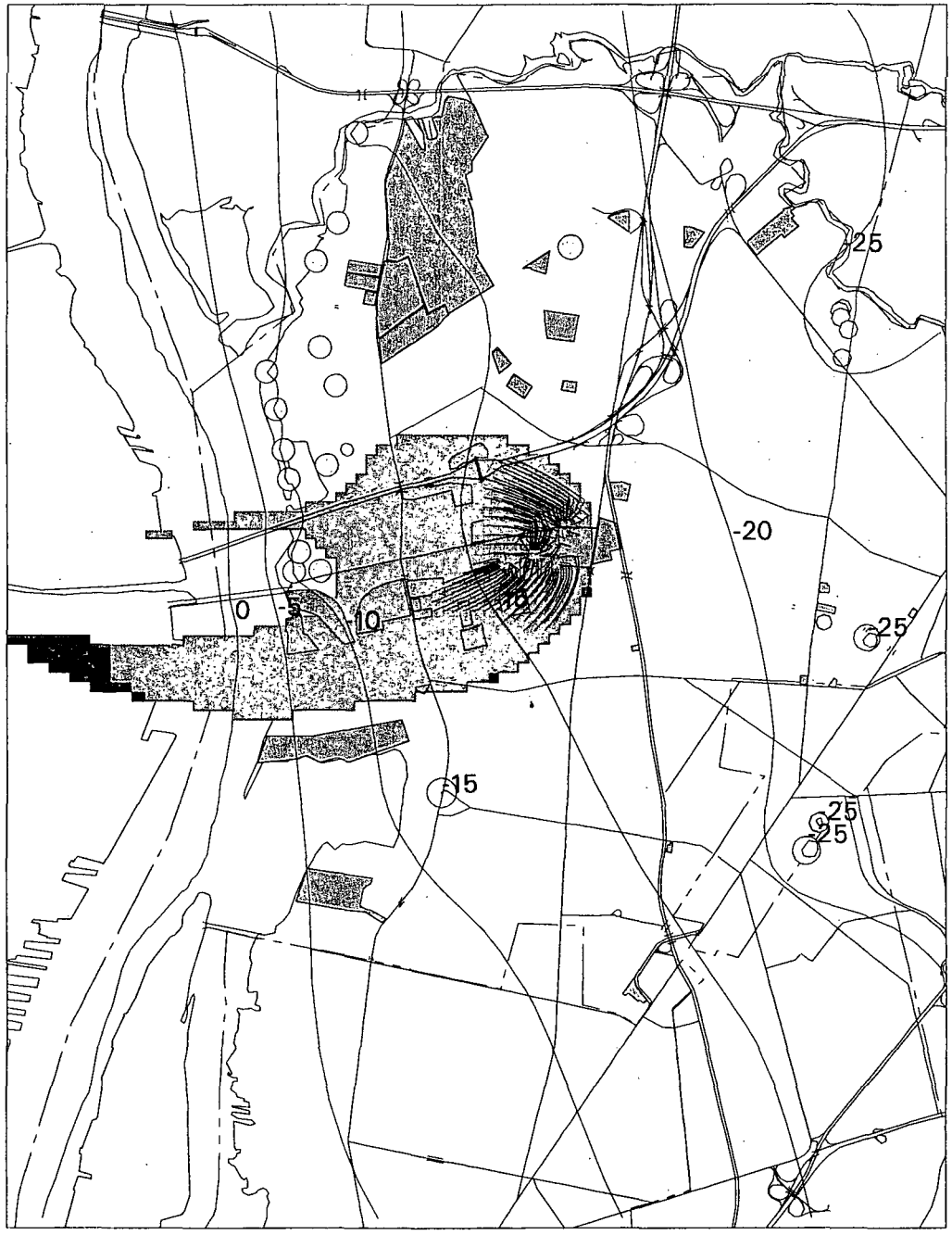
September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
INT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	15	15	15	14
isand	36	4	3	2
lwr	5	3	3	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.



Forward tracking and contributing area of remedial wells in the Lower aquifer in scenario EX

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MI D	R1	25
I NT	R2	200
I NT	R5	350
I NT	R3	150
I NT	R4	400
I NT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	15	15	15	14
isand	36	4	3	2
I wr	5	3	3	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.

400184

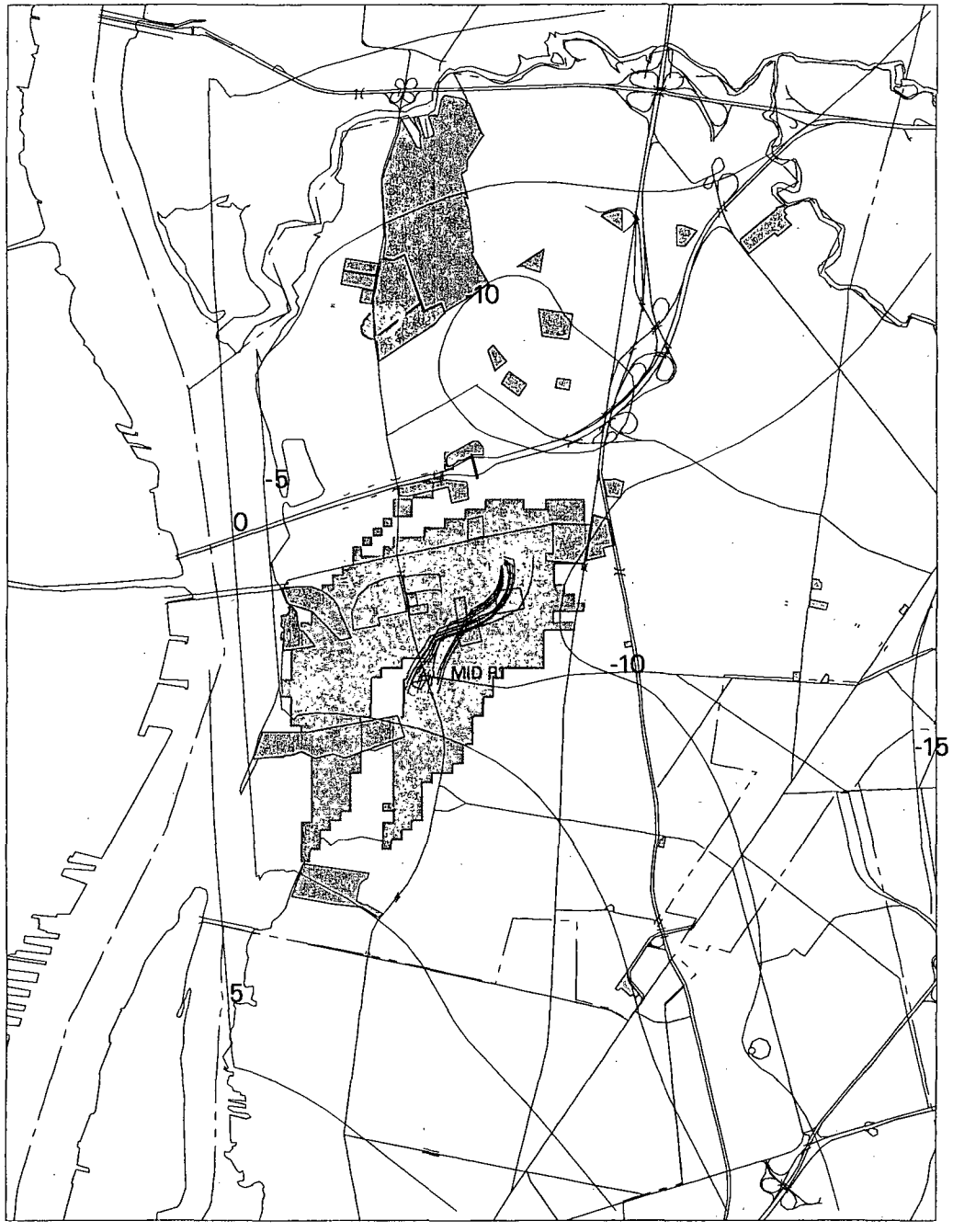
Scenario Ex Situ –I

Short Name: ex-I

Water Use: Baseline pumpage data is used. Baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Ex Situ treatment. Most of the remedial pumpage is from the Intermediate Sand. Remedial pumpage rate is 1500 gpm from the Intermediate Sand and 25 gpm from the middle aquifer. The treated water is reinjected into 2 wells updip of the plume into the Lower aquifer.

Results: All particles from the Middle aquifer are captured. Particles from the Intermediate sand and Lower aquifer both flow downdip to the Park Avenue well field. The longest travel times are in the Middle aquifer where 20 percent of the particles have travel times greater than 30 years. Travel times for 95 percent of the particles from both the Intermediate sand and Lower aquifer were less than 20 years.



Forward tracking and contributing area of remedial wells in the Middle aquifer in scenario EX-1

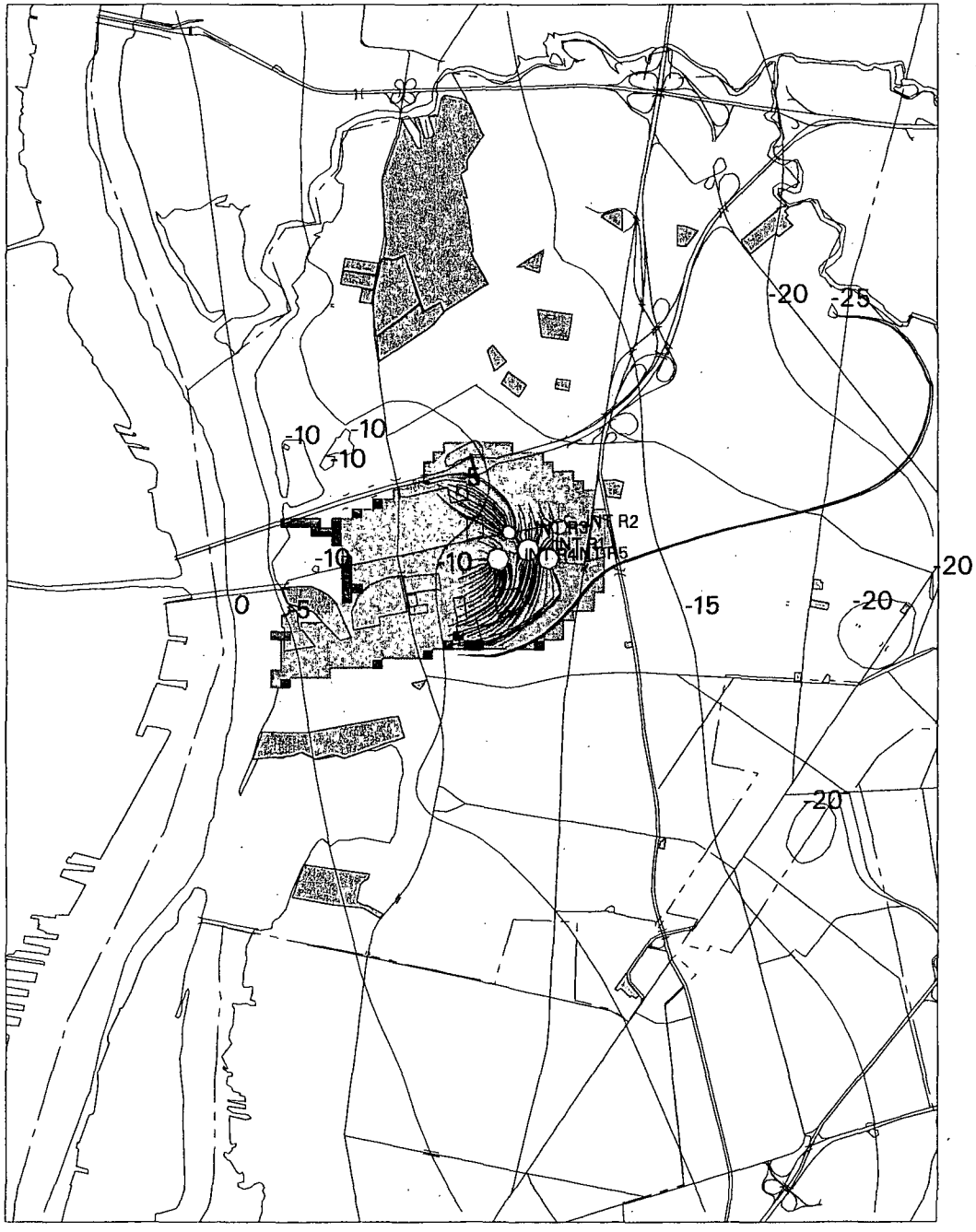
September 05, 2002 DRAFT

Remedial Pumpage in GPM

MI D	R1	25
I NT	R1	400
I NT	R2	200
I NT	R5	350
I NT	R3	150
I NT	R4	400
i nj	2	-750
i nj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	120	120	120	30
isand	51	20	3	2
lwr	28	15	12	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.



Forward tracking and contributing area of remedial wells in the Intermediate sand in scenario EX-I

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R1	400
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
inj	2	-750
inj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	120	120	120	30
isand	51	20	3	2
lwr	28	15	12	2

Extent of Chromium

Extent of VOC plume near Puchack

Travel time to Remedial wells < 20 years

Travel time to Remedial wells > 20 years

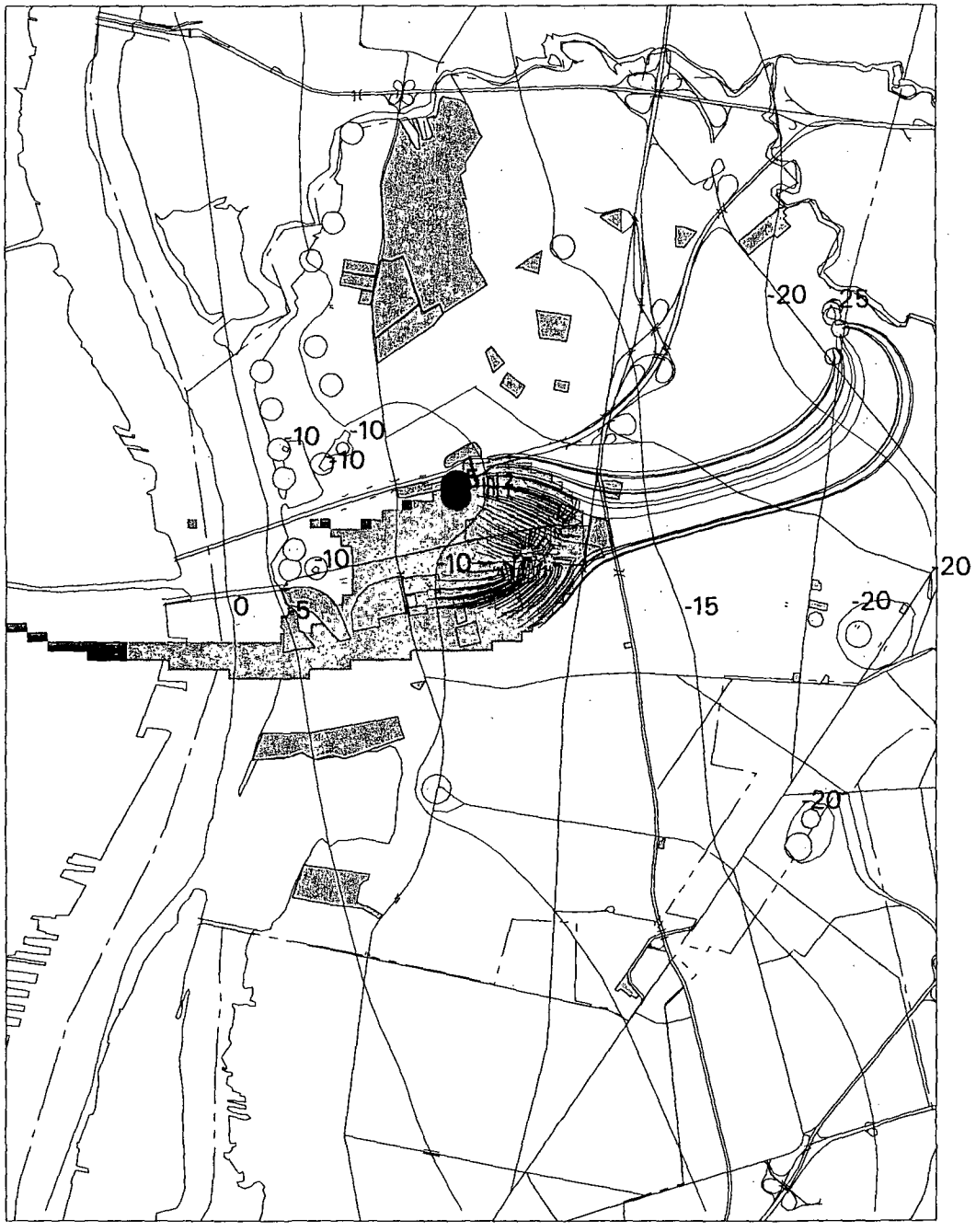
Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400187



Forward tracking and contributing area of remedial wells in the Lower aquifer in scenario EX-I

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R1	400
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
inj	2	-750
inj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	120	120	120	30
isand	51	20	3	2
lwr	28	15	12	2

Extent of Chromium

Extent of VOC plume near Puchack

Travel time to Remedial wells < 20 years

Travel time to Remedial wells > 20 years

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400188

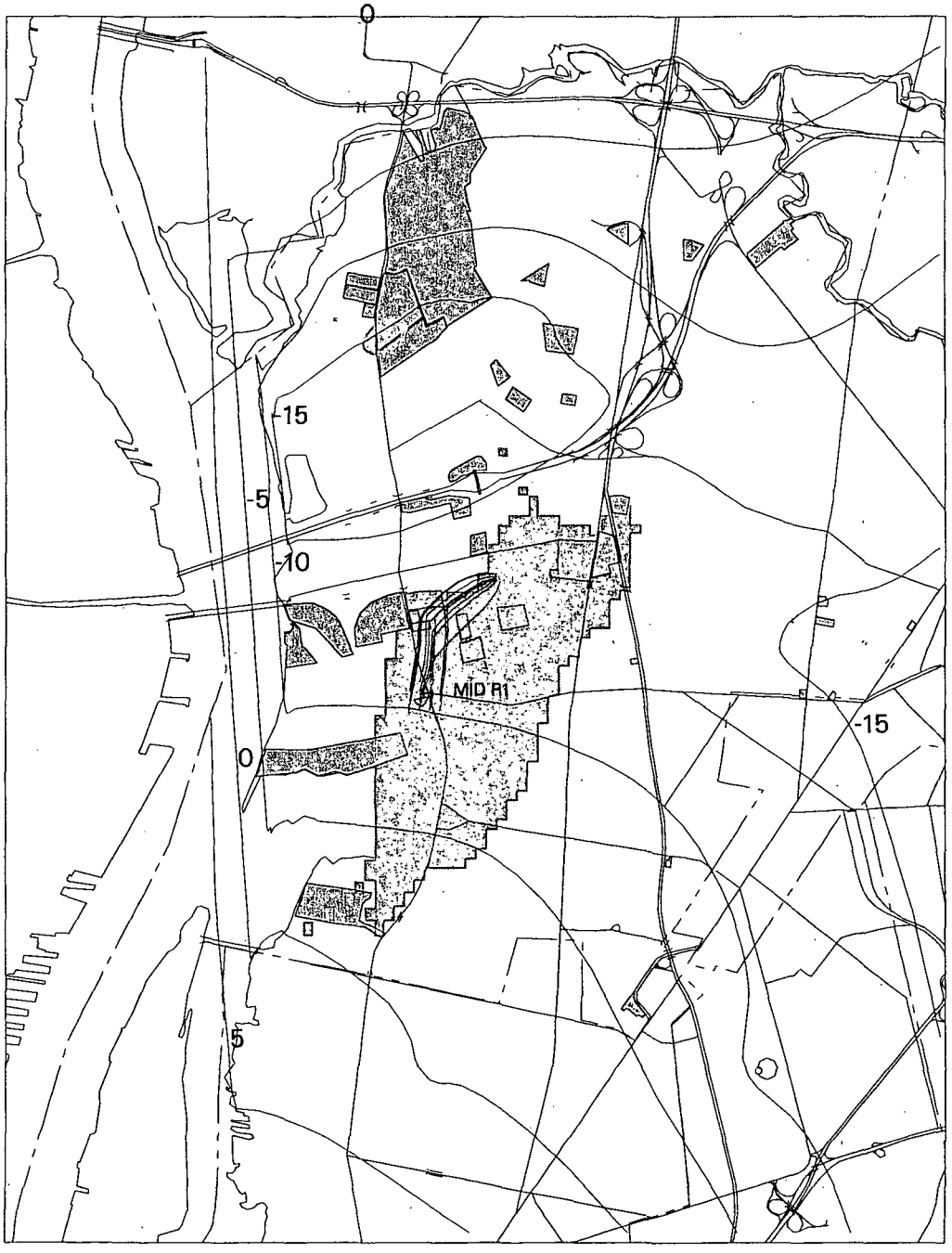
Scenario Ex Situ-Morris – I

Short Name: ex-md-i

Water Use: Water use is the baseline pumpage data except that the Morris well field is pumping at it's allocated 20 MDG. For other users the baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Ex Situ treatment. Most of the remedial pumpage is from the Intermediate Sand. Remedial pumpage rate is 1500 gpm from the Intermediate Sand and 25 gpm from the middle aquifer. The treated water is reinjected into 2 wells updip of the plume into the Lower aquifer.

Results: All particles from the Middle aquifer are captured. Travel times in the Middle aquifer are more than 45 years at 10 percent of the particles. Some of the particles in the Intermediate sand flow to the Morris well field. Travel times 95% of the particles originating in the Intermediate sand are less than 6 years. Some particles originating in the Lower aquifer flow to the Park Ave. well field. Travel times for all of these particles are less than 16 years.



Forward tracking and contributing area of remedial wells in the Middle aquifer in scenario EX-MD-1

September 05, 2002 DRAFT

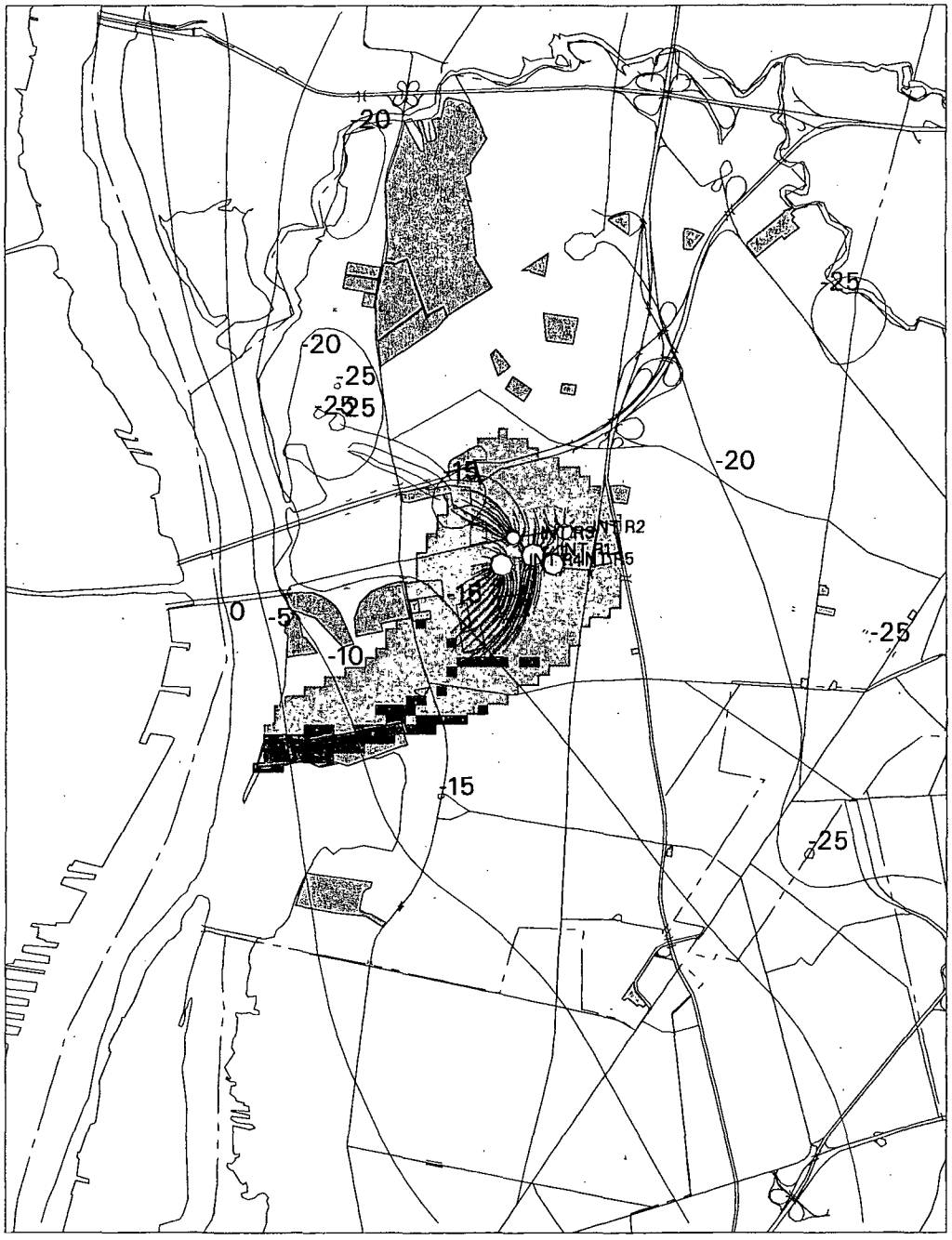
Remedial Pumpage in GPM

MID	R1	25
INT	R1	400
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
inj	2	-750
inj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	45	45	45	15
isand	79	6	3	2
lwr	16	15	3	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.

400190



Forward tracking and contributing area of remedial wells in the Intermediate sand in scenario EX-MD-I

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MI D	R1	25
I NT	R1	400
I NT	R2	200
I NT	R5	350
I NT	R3	150
I NT	R4	400
i nj	2	-750
i nj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	45	45	45	15
i sand	79	6	3	2
l wr	16	15	3	2

Extent of Chromium

Extent of VOC plume near Puchack

Travel time to Remedial wells < 20 years

Travel time to Remedial wells > 20 years

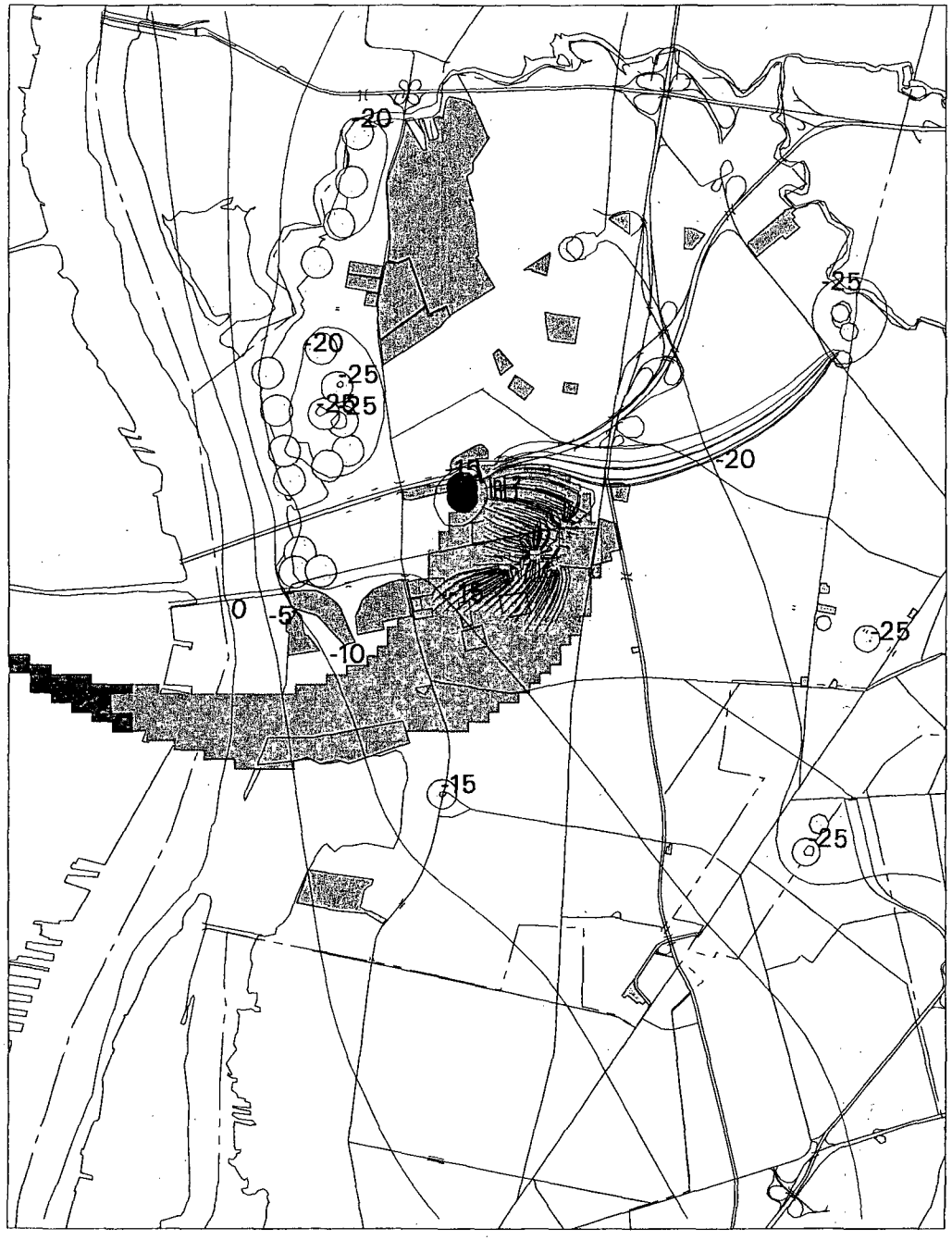
Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400191



Forward tracking and contributing area of remedial wells in the Lower aquifer in scenario EX-MD-I

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R1	400
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
inj	2	-750
inj	1	-750

	Travel time in years			
Layer	Max	95	90	80
mdl	45	45	45	15
isand	79	6	3	2
lwr	16	1.5	3	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.

400192

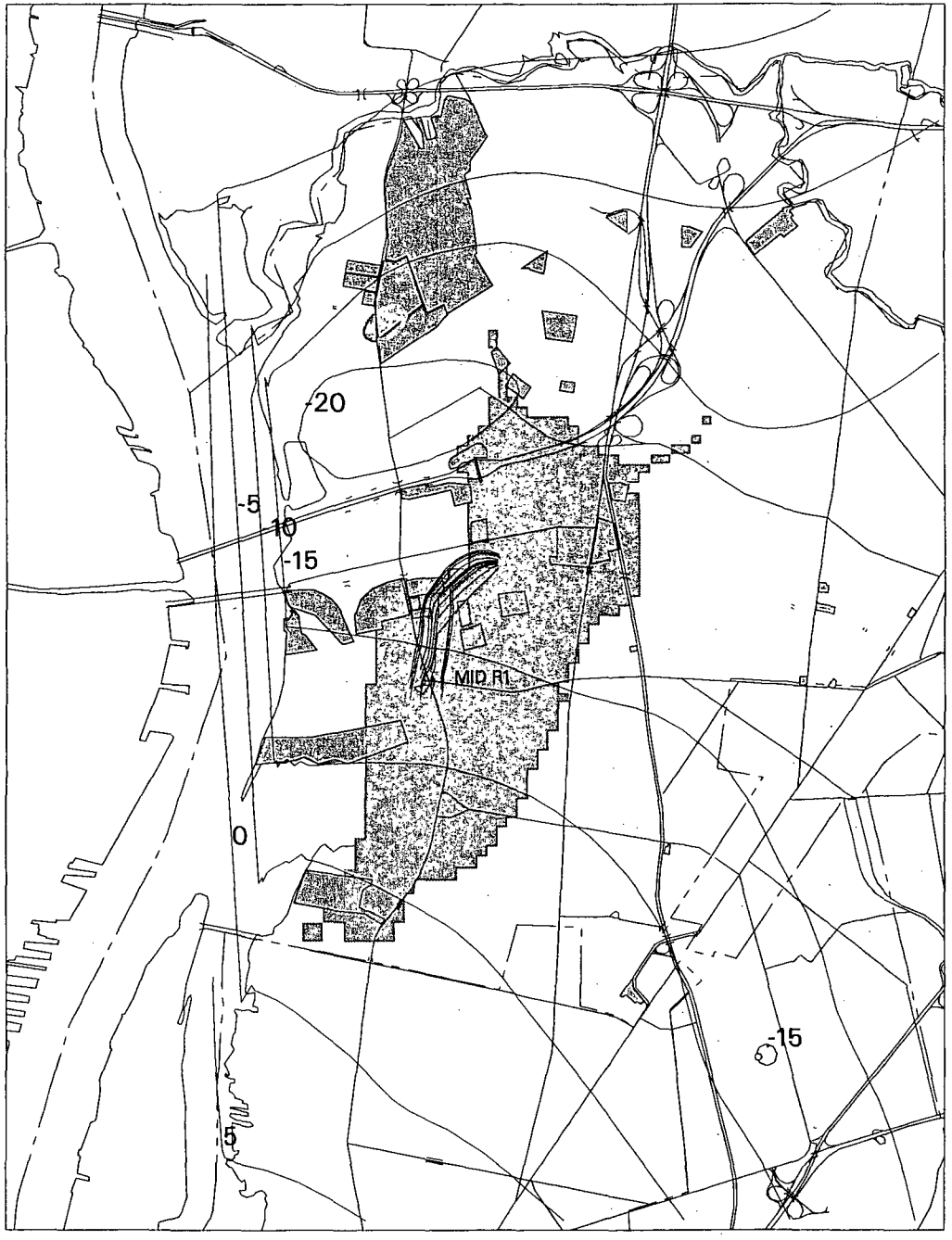
Scenario Ex Situ-Morris – R

Short Name: ex-md-r

Water Use: Water use is the baseline pumpage data except that the Morris well field is pumping at it's allocated 20 MDG. For other users the baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Ex Situ treatment. Most of the remedial pumpage is from the Intermediate Sand. Remedial pumpage rate is 1500 gpm from the Intermediate Sand and 25 gpm from the middle aquifer. The treated water is applied to a recharge basin near the Puchack well field property.

Results: Particles tracked from chromium areas in the Middle, Intermediate Sand, and Lower aquifers are all captured. The longest travel time was 24 years, however, 95% of the particles in each aquifer had travel times less than 13 years.



Forward tracking and contributing area of remedial wells in the Middle aquifer in scenario EX-MD-R

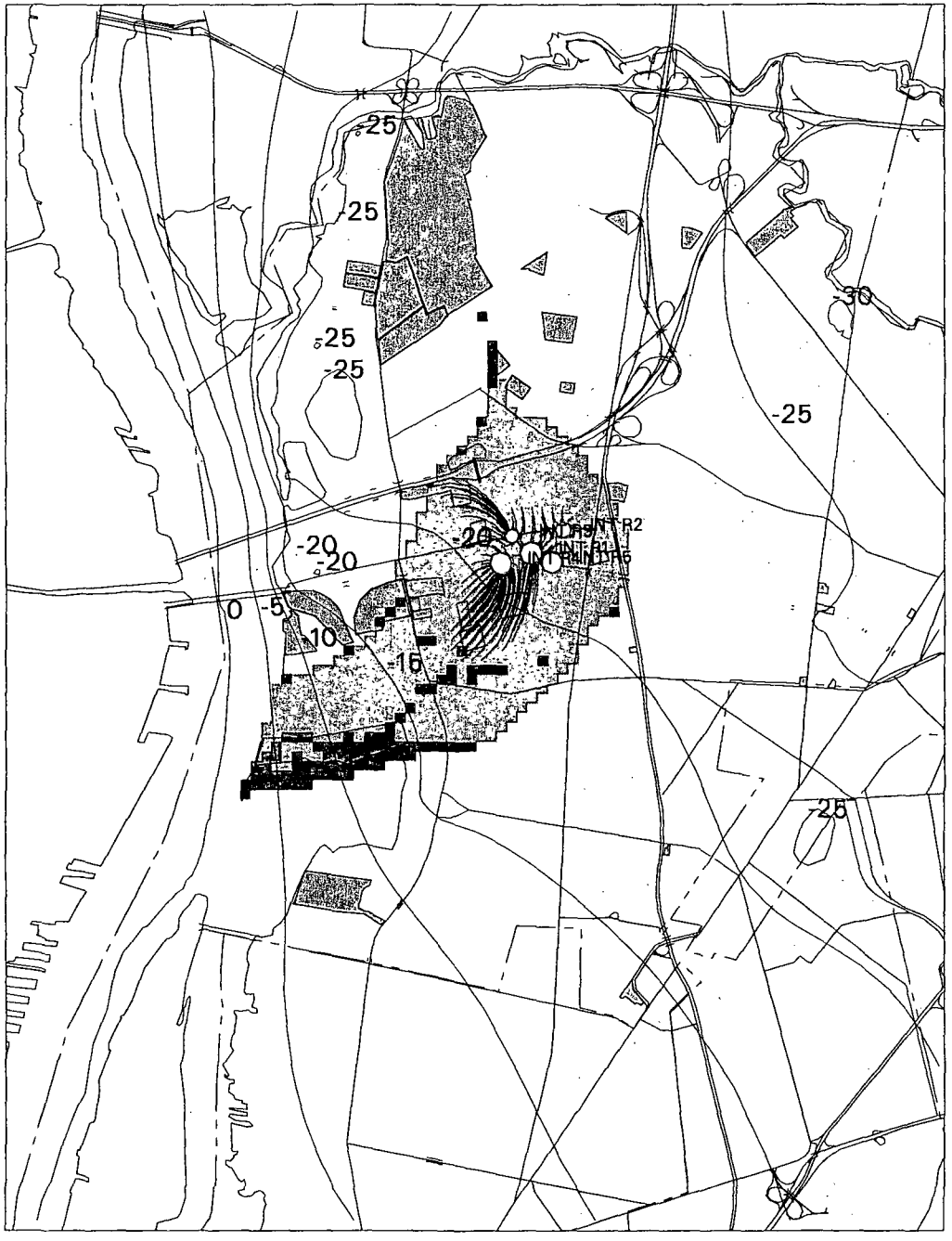
September 05, 2002 DRAFT

Remedial Pumpage in GPM

MI D	R1	25
I NT	R2	200
I NT	R5	350
I NT	R3	150
I NT	R4	400
I NT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	13	13	13	11
isand	24	4	3	2
lwr	8	6	4	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.



Forward tracking and contributing area of remedial wells in the Intermediate sand in scenario EX-MD-R

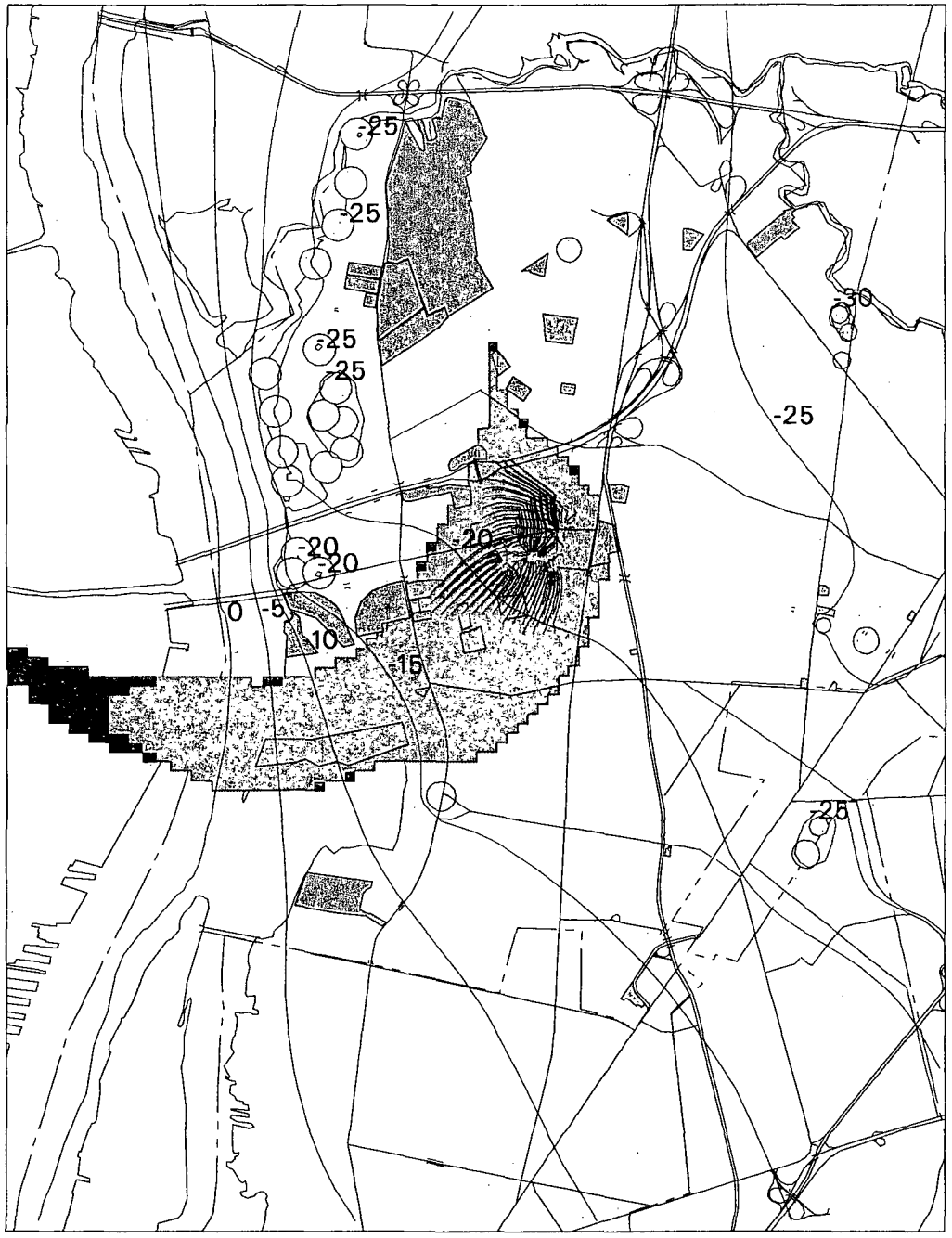
September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
INT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	13	13	13	11
isand	24	4	3	2
lwr	8	6	4	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.



Forward tracking and contributing area of remedial wells in the Lower aquifer in scenario EX-MD-R

September 05, 2002 DRAFT

Remedial Pumpage in GPM

MID	R1	25
INT	R2	200
INT	R5	350
INT	R3	150
INT	R4	400
INT	R1	400

	Travel time in years			
Layer	Max	95	90	80
mdl	13	13	13	11
isand	24	4	3	2
iwr	8	6	4	2

- Extent of Chromium
- Extent of VOC plume near Puchack
- Travel time to Remedial wells < 20 years
- Travel time to Remedial wells > 20 years
- Simulated heads
- Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.
- Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.
- Well location. Size is variable based on pumpage.

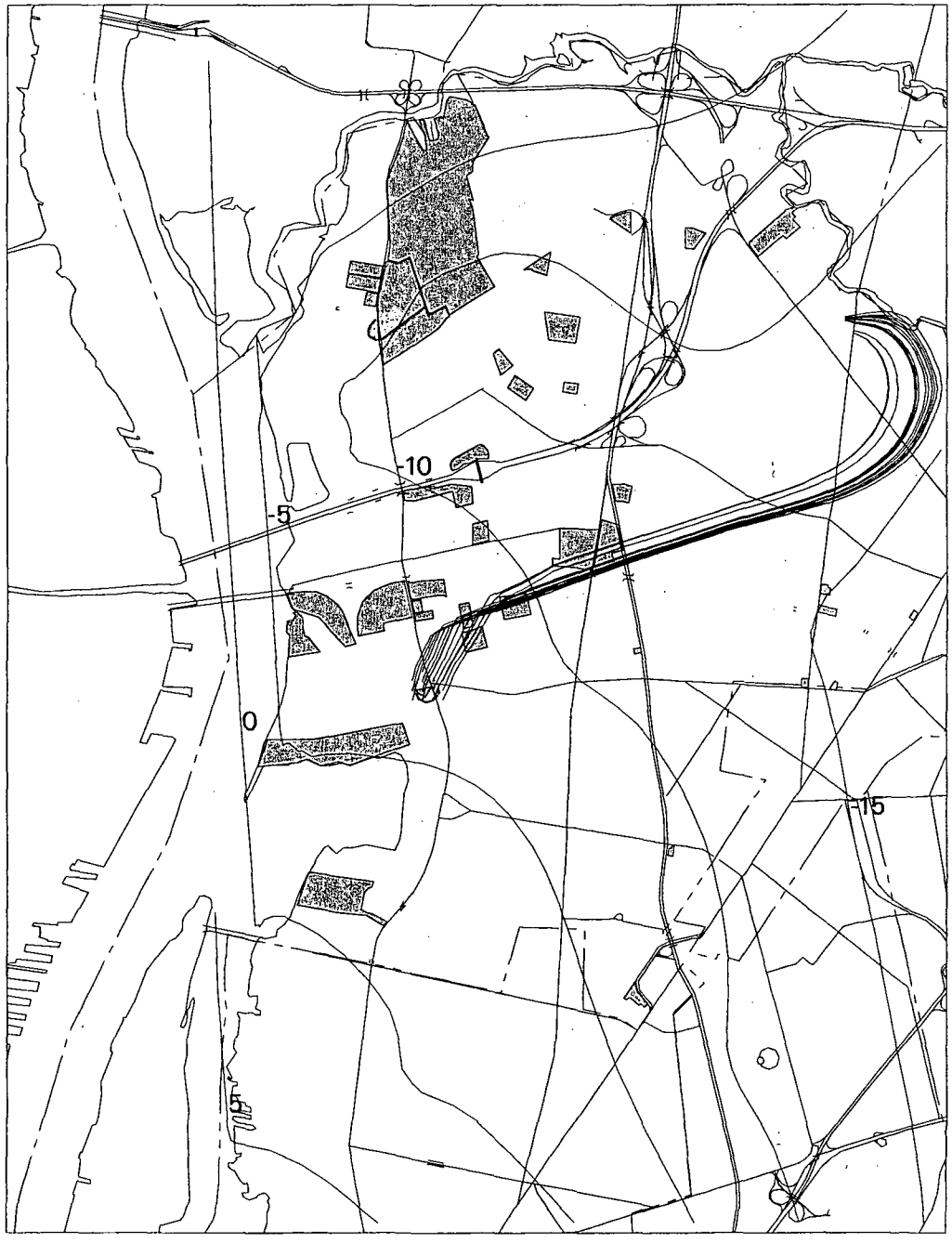
Scenario MNA

Short Name: mna

Water Use: Baseline pumpage data is used. Baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Monitored Natural Attenuation.

Results: All particles from the Middle and Lower aquifer flow to the Park Ave well field. A few particles originating in the Intermediate Sand aquifer flow to the Marion well field. Travel times for 20% of the particles originating in the Middle and Intermediate sand are longer than 46 years, while 20 percent of the particles in the Lower aquifer have travel times longer than 22 years.



Forward tracking in the Middle aquifer in scenario MNA

September 05, 2002 DRAFT

	Travel time in years			
Layer	Max	95	90	80
mdl	47	47	47	47
isand	479	128	118	46
lwr	120	109	104	22

Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

Forward tracking in the Intermediate sand in scenario MNA

September 05, 2002 DRAFT

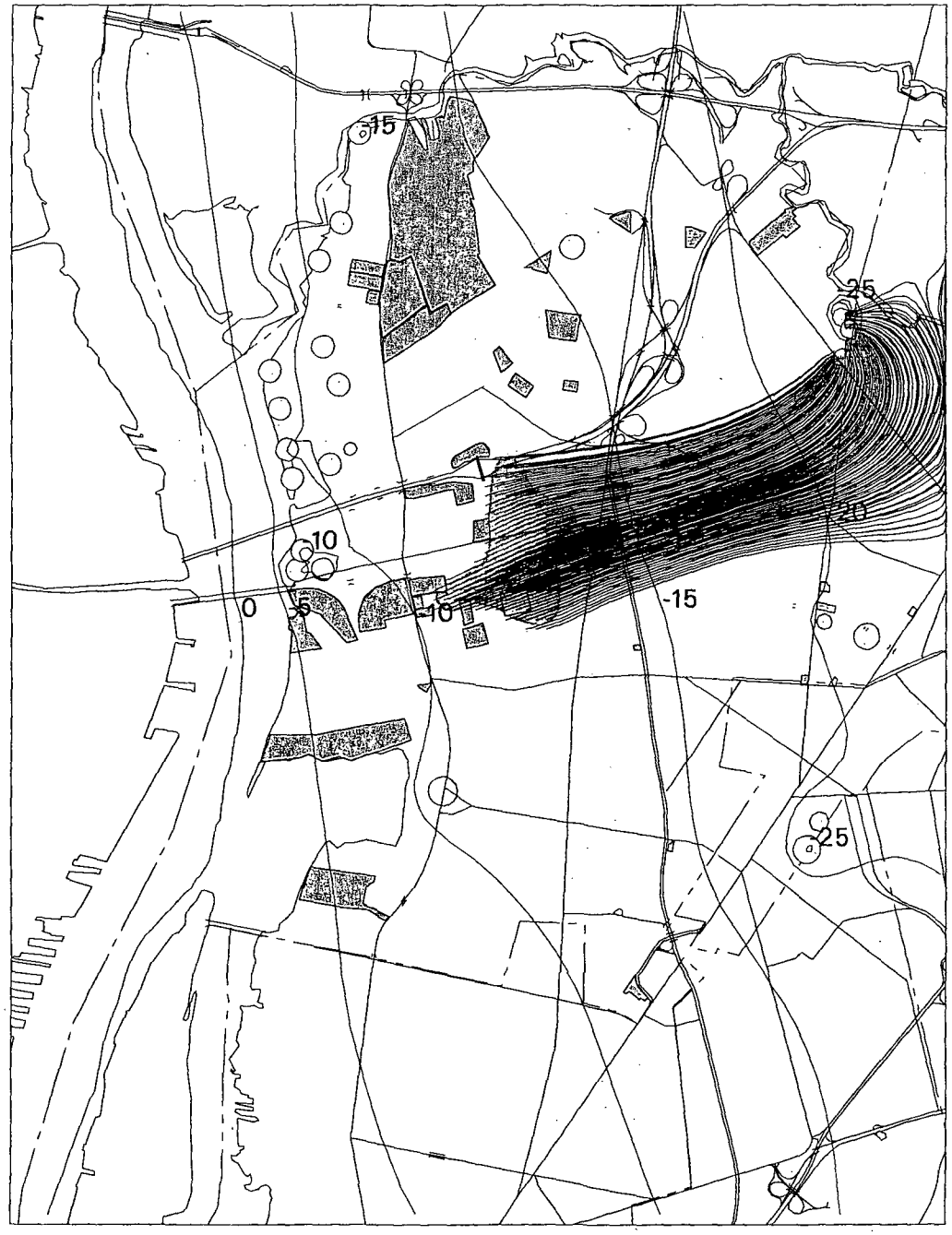
	Travel time in years			
Layer	Max	95	90	80
mdl	47	47	47	47
isand	479	128	118	46
iwr	120	109	104	22

Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.



Forward tracking in the Lower aquifer in scenario MNA

September 05, 2002 DRAFT

Layer	Travel time in years			
	Max	95	90	80
mdl	47	47	47	47
isand	479	128	118	46
lwr	120	109	104	22

Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400200

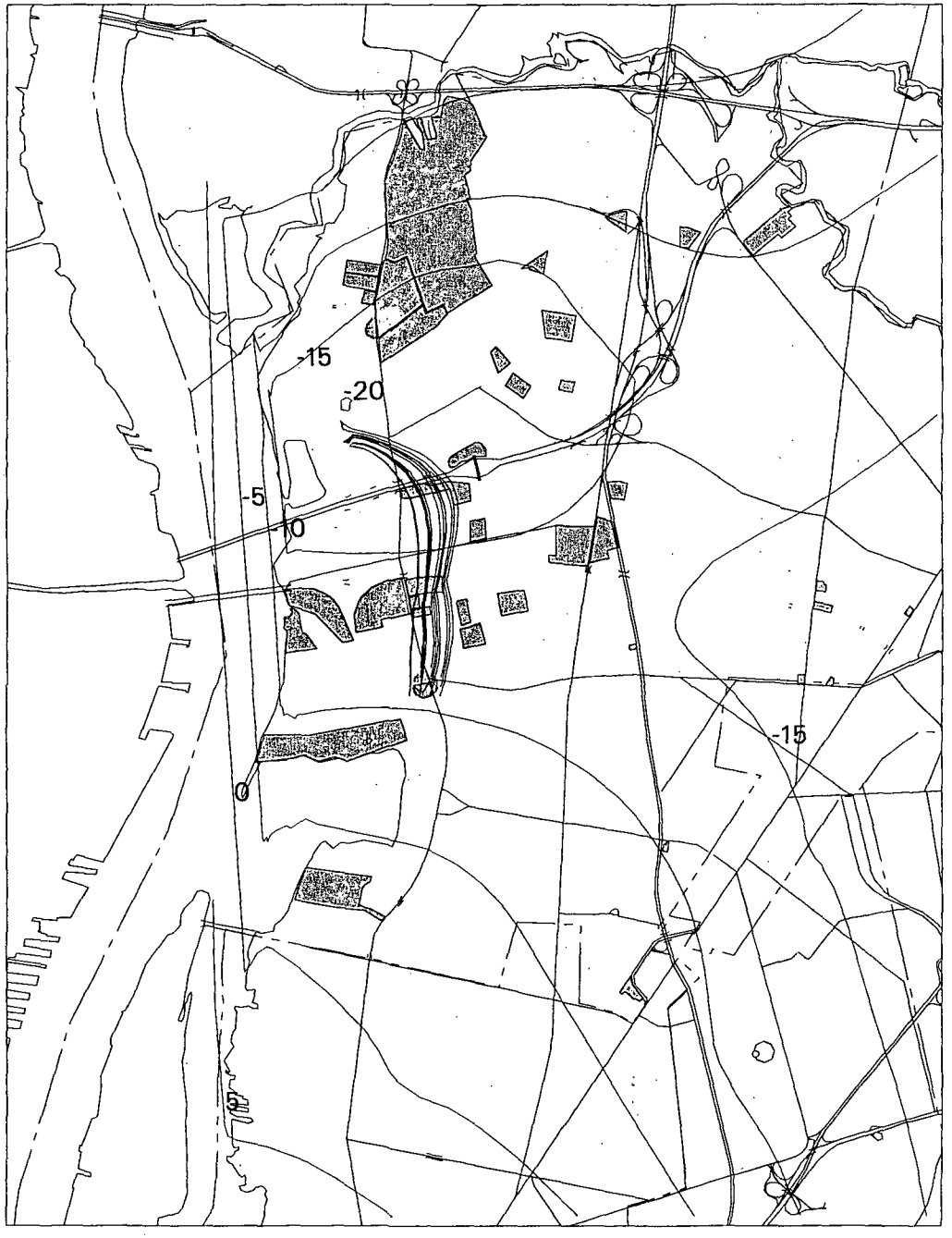
Scenario MNA-Morris

Short Name: mna-md

Water Use: Water use is the baseline pumpage data except that the Morris well field is pumping at it's allocated 20 MDG. For other users the baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Monitored Natural Attenuation.

Results: All of the particles from the Middle aquifer flow to the Morris well field. Travel times for 20 % of these particles are longer than 43 years. Most of the particles originating in both the Intermediate sand and Lower aquifer flow to the Park Ave well field. The remainder of these particles flow to the Morris well field. Twenty percent of the particles in the Intermediate sand have travel times greater than 42 years and twenty percent of the particles in the Lower aquifer had travel times greater than 17 years.



Forward tracking in the Middle aquifer in scenario MNA-MD

September 05, 2002 DRAFT

Layer	Travel time in years Max	95	90	80
mdl	49	49	49	43
isand	79	65	56	42
lwr	27	20	19	17

Extent of Chromium

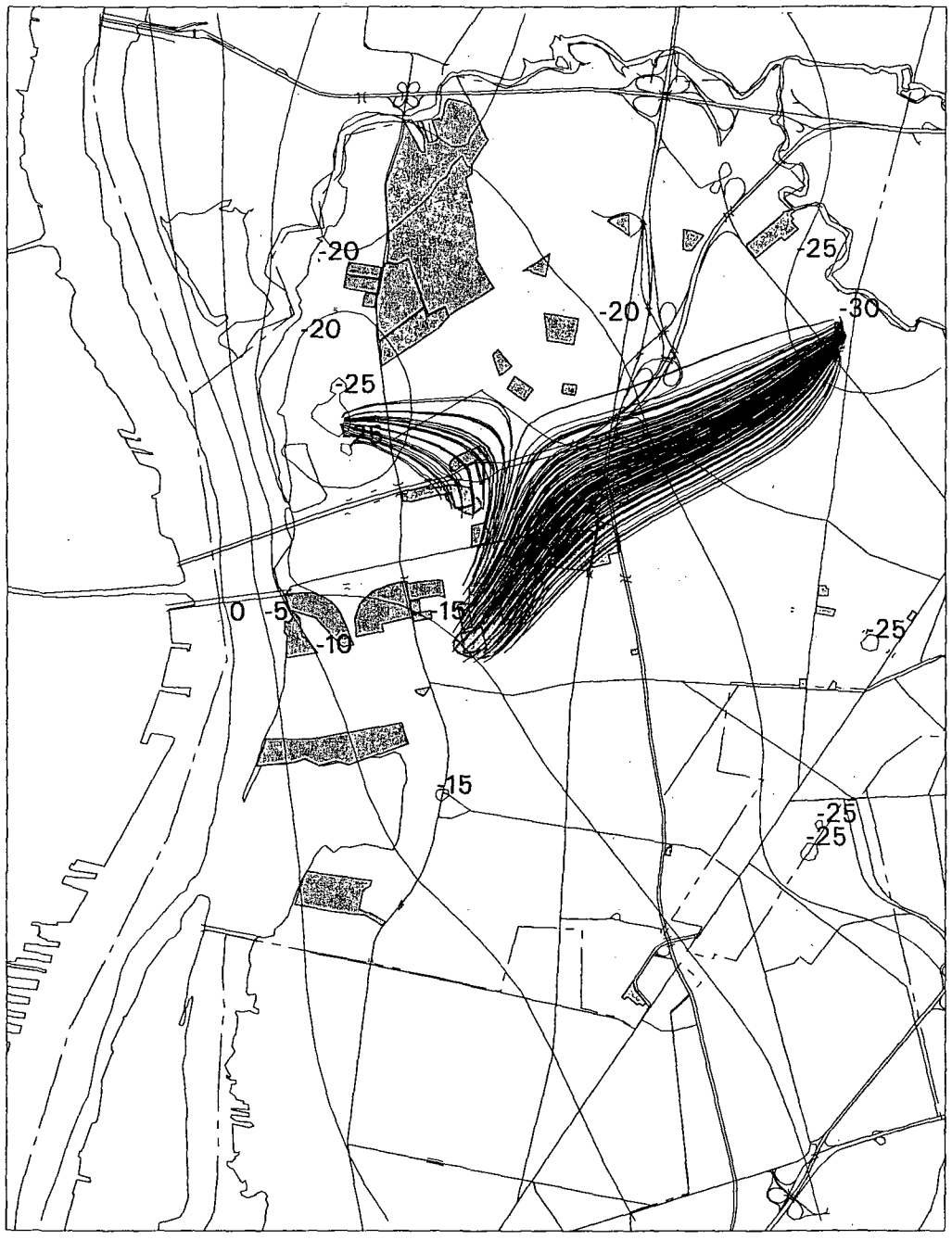
Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400202



Forward tracking in the Intermediate sand in scenario MNA-MD

September 05, 2002 DRAFT

Layer	Travel time in years Max	95	90	80
mdl	49	49	49	43
isand	79	65	56	42
lwr	27	20	19	17

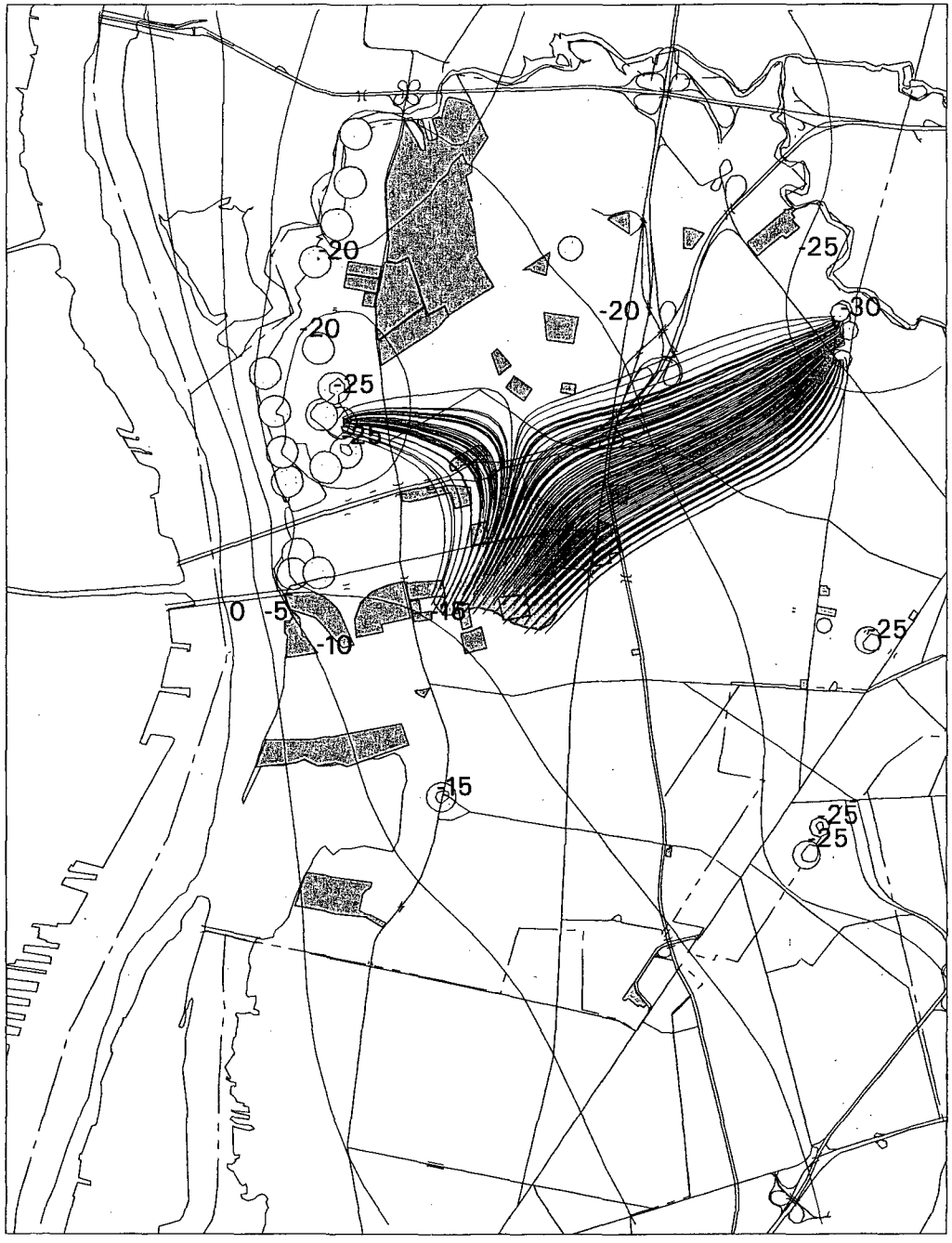
Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

400203



Forward tracking in the Lower aquifer in scenario MNA-MD

September 05, 2002 DRAFT

	Travel time in years			
Layer	Max	95	90	80
mdl	49	49	49	43
isand	79	65	56	42
lwr	27	20	19	17

Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400204

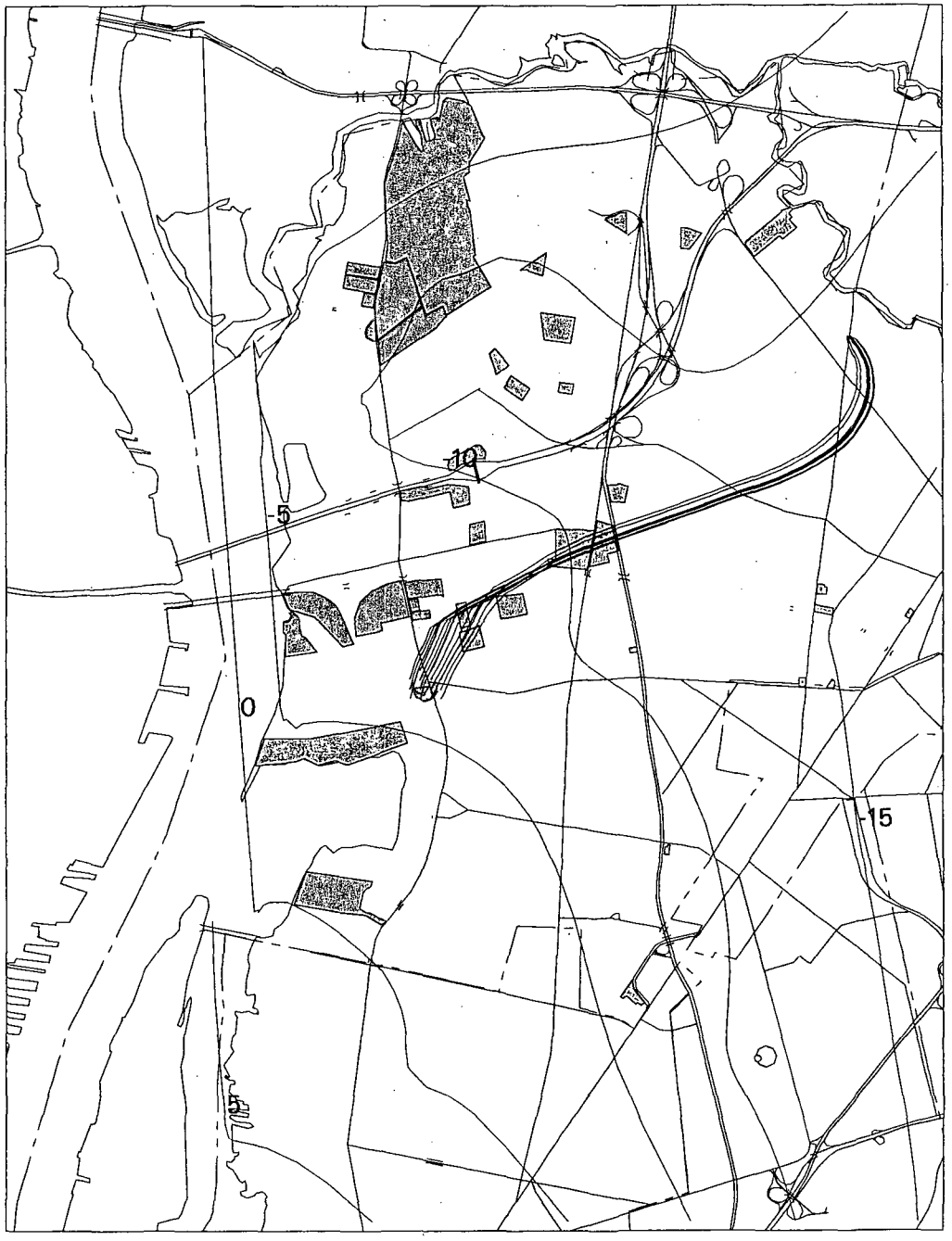
Scenario MNA-DelgardOff

Short Name: mna-nodg

Water Use: Water use is the baseline pumpage data except that the Delaware Gardens well is not pumping. Baseline pumpage is the average 1998-2000 water use plus projected withdrawals from the proposed Delaware Gardens well.

Description: Monitored Natural Attenuation.

Results: All of the particles in the Middle, Intermediate sand, and Lower aquifer flow to the Park Ave well field. Twenty percent of the particles originating in the Middle, Intermediate sand and Lower aquifers have travel times of greater than 40, 53, and 17 years respectively.



Forward tracking in the Middle aquifer in scenario MNA-NODG

September 05, 2002 DRAFT

Layer	Travel time in years			
	Max	95	90	80
mdl	45	45	45	40
isand	367	117	111	53
lwr	102	96	23	17

Extent of Chromium

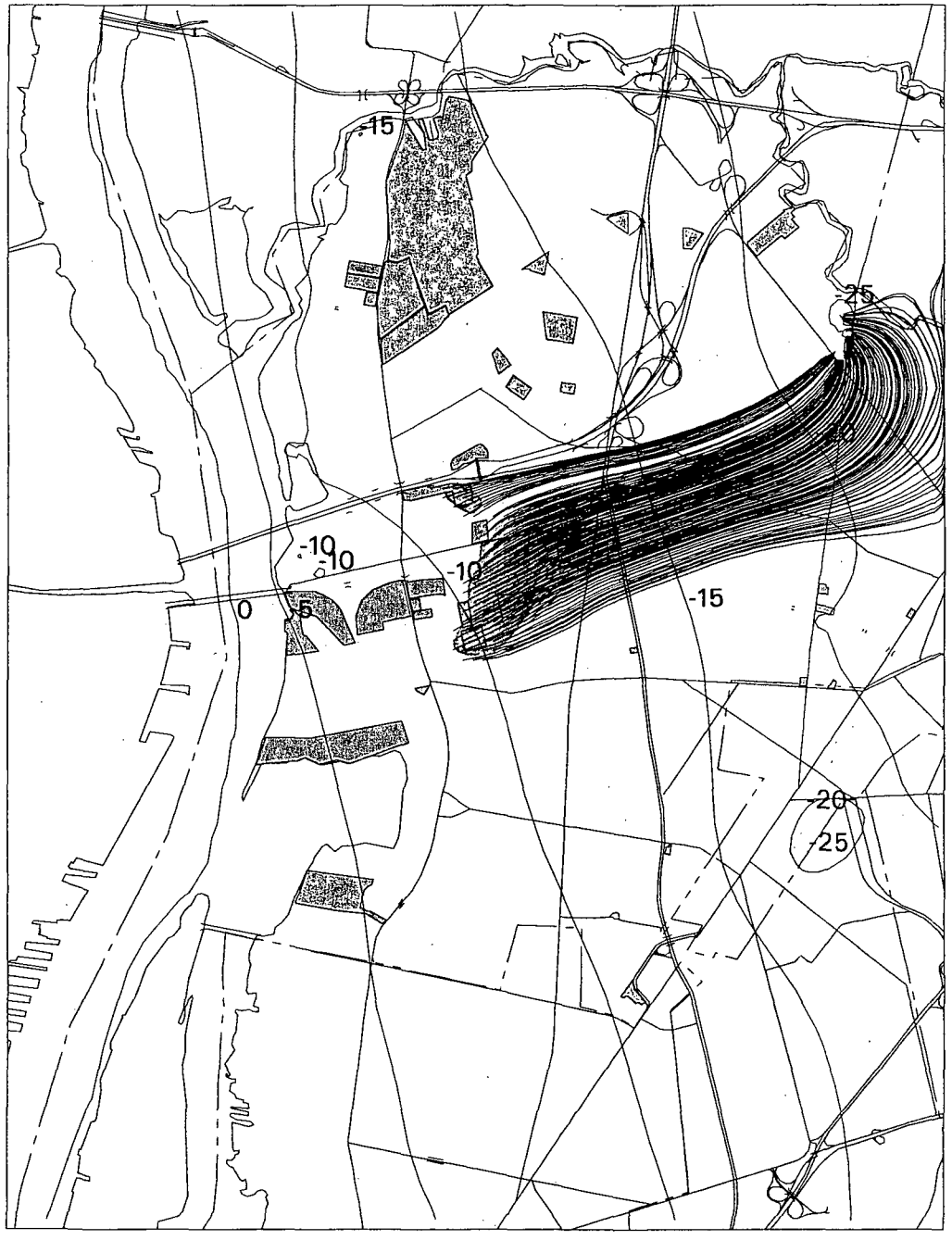
Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400206



Forward tracking in the Intermediate sand in scenario MNA-NODG

September 05, 2002 DRAFT

Layer	Travel time in years			
	Max	95	90	80
mdl	45	45	45	40
isand	367	117	111	53
lwr	102	96	23	17

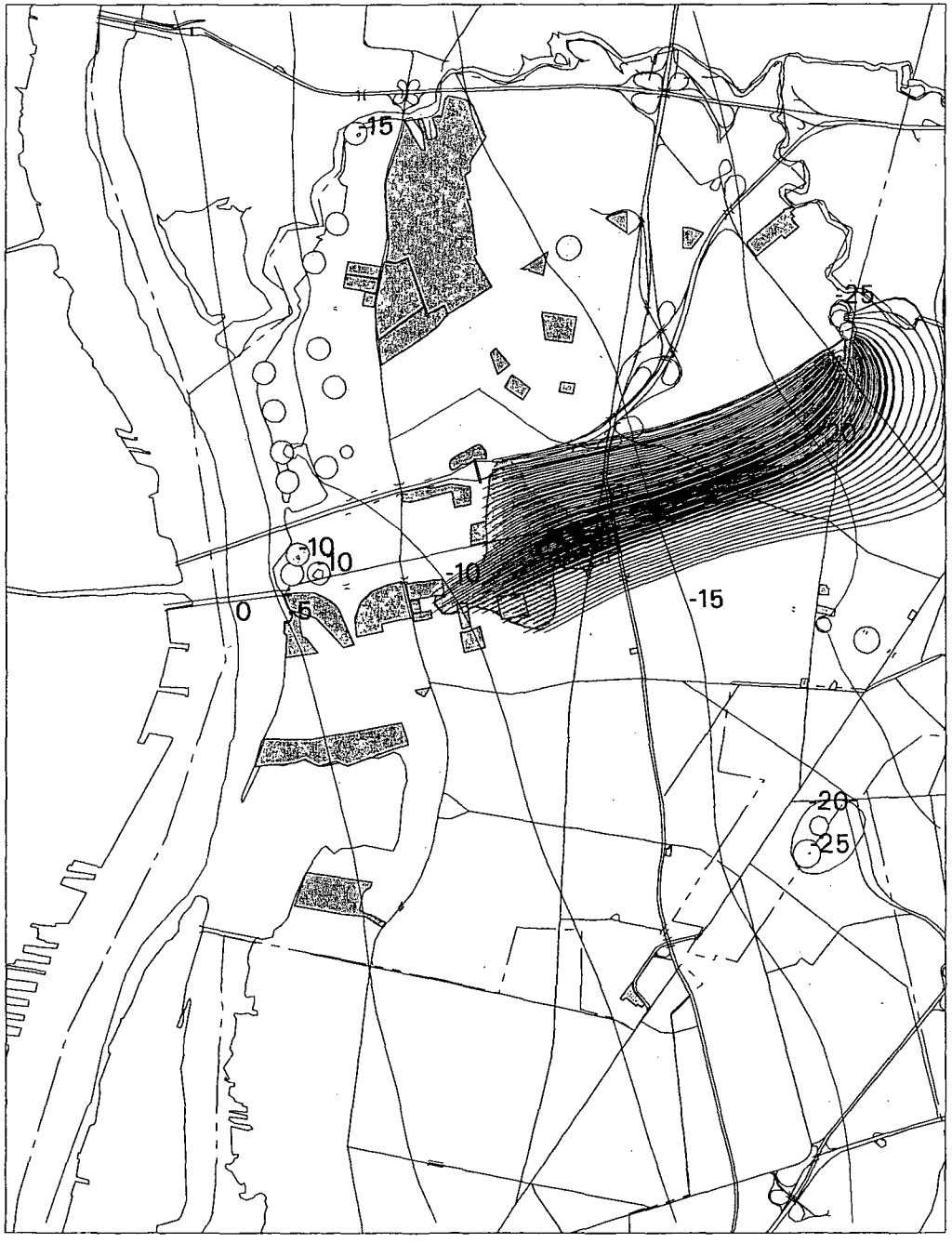
Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

400207



Forward tracking in the Lower aquifer in scenario MNA-NODG

September 05, 2002 DRAFT

	Travel time in years			
Layer	Max	95	90	80
mdl	45	45	45	40
isand	367	117	111	53
lwr	102	96	23	17

Extent of Chromium

Simulated heads

Pathlines from chromium plume to discharge areas. Travel times 0 to 20 years.

Pathlines from chromium plume to discharge areas. Travel times greater than 20 years.

Well location. Size is variable based on pumpage.

400208

Appendix C

400209

Appendix C

Detailed Cost Estimates for Alternatives

Alternative 2A: MNA/ In Situ Treatment (Permeable Reactive Barrier Contingency Remedy)/Institutional Controls
Puchack Well Field Superfund Site

Item No.	Item Description	Quantity	Unit Cost MNA with Contingency	Unit	MNA Cost	Total Cost MNA with Contingency
CAPITAL COSTS						
Construction Costs						
1.	Work Plan Preparation	1	$ 70,600	LS	$17,700	$ 70,600
2.	Mobilization/Demobilization	1	$ 66,000	LS	$5,000	$ 66,000
3.	Construction Management	1	$ 672,765	LS	-	$ 672,765
4.	Construction QC/Chemcial Analysis/H&S	1	$ 672,765	LS	-	$ 672,765
5.	Permeable Reactive Barrier and Monitoring Wells	1	$ 4,485,099	LS	$152,467	$ 4,485,099
6.	Institutional Controls	1	$ 17,700	LS	$17,700	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$192,867	$ 5,984,929
	General Contractor Fee (10% construction)				$19,287	$ 598,493
	Design Engineering				$38,573	500,000
	Bench / Pilot Scale Studies				-	750,000
	Resident Engineering/Inspection				$19,287	$ 400,000
	Contingency (20%)				$38,573	$ 1,196,986
	TOTAL CAPITAL COSTS				$308,587	$ 9,430,408
ANNUAL MONITORING COSTS						
7.	Project Planning and Organization	1	$ 1,700	LS	$1,700	$ 1,700
8.	Sampling Labor	1	$ 32,400	LS	$24,300	$ 32,400
9.	Sampling Equipment	1	$ 18,800	LS	$14,600	$ 18,800
10.	Sample Analysis and Data Validation	1	$ 13,400	LS	$10,200	$ 13,400
11.	Data Evaluation and Reporting	1	$ 16,800	LS	$16,800	$ 16,800
	Total Annual Monitoring Costs				**$67,600**	**$ 83,100**
FIVE YEAR REVIEW						
12.	Five Year Review Report	1	$ 35,300	LS	$35,300	$ 35,300
PRESENT WORTH OF COSTS						
13.	Total Capital Costs				$308,587	$ 9,430,408
14.	Long-term Monitoring (30 year duration)				$838,848	$ 1,031,188
15.	Five-Year Reviews (30 year duration)				$76,171	$ 76,171
	TOTAL PRESENT WORTH				$1,223,607	$ 10,537,767

	$ 1,224,000	$ 10,538,000
Additional Cost of Contingency		$ 9,314,000

Job No. 3223-1Q2
Project Puchack Groundwater FS
Subject Alternative 2A - Cost Backup

Prepared by: EDK
Checked by: DGG

No. 1 Work Plan Preparation (includes WP, HASP, CQC & Chemical QC plans)

Assume 2 persons for 2 months.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4 2 weeks/month x 2 month x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	6 months x	2000 per mo	$	12,000
Utilities during construction	6 months x	2000 per mo	$	12,000
Temp Facilities	6 months x	2000 per mo	$	12,000
Misc.	6 months x	5000 per mo	$	30,000
		Total:	**$**	**66,000**

No. 3 Construction Management

PM at 5% of construction cost	$	224,255
Construction supervision/oversight at 10% of construction cost	$	448,510
Total:	**$**	**672,765**

No. 4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	224,255
Chemical analysis at 5% of construction cost	$	224,255
Health and Safety at 5% of construction cost	$	224,255
Total:	**$**	**672,765**

No. 5 Total Construction Costs

Monitoring Wells	$	354,834	See page 4 for details
Injection Points	$	1,442,467	See page 5 for details
PRB Material and Injection	$	2,687,798	See page 6 for details
Total Construction Cost	$	4,485,099	

No. 6 Institutional Controls

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1 person x		$	35	/hour x	40	hours/week	4.2	weeks/month x	1	month x	3 multiplier
	=	$	17,640								
Assume:		$	17,700								

Job No. 3223-102
Project: Puchack Groundwater FS
Subject: Alternative 2A- Cost Backup

Prepared by: EDK
Checked by: DGG

Monitoring Well Installation

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100	ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50	ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130	ft	x	$	30	per LF	$	3,900
10 slot screen	20	ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1	ea	x	$	118	each	$	118
Bentonite Seal	1	ea	x	$	53	each	$	53
Silica Sand	20	ft	x	$	14	per lf	$	286
5' Steel protective casing	1	LS	x	$	200	each	$	200
Well Development	3	hr	x	$	160	per hr	$	480
Decon of equipment	1	day	x	$	112	per day	$	112
Drum	4	each	x	$	90	each	$	360
Total for One Intermediate Well							$	13,142

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100	ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150	ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160	ft	x	$	30	per LF	$	4,800
10 slot screen	90	ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1	ea	x	$	118	each	$	118
Bentonite Seal	1	ea	x	$	53	each	$	53
Silica Sand	90	ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1	LS	x	$	200	each	$	200
Well Development	3	hr	x	$	160	per hr	$	480
Decon of equipment	1	day	x	$	112	per day	$	112
Drum	6	each	x	$	90	each	$	540
Total for One Deep Well							$	21,720

Misc Items

Drum disposal	100	each	x	$	120	each	$	12,000
Development/Decon Water Disposal	40000	gal	x	$	0.35	gal	$	14,000
Driller oversight	34	day	x	$	600	per day	$	20,400
Driller mobilization	1	LS	x	$	3,899	each	$	3,899
Tank Rental	2	tank (21,000 gal)	x	$	1,225	each	$	2,450
Well Development Equipment	2	week	x	$	236	week	$	472
Contingency	1	LS	x	$	1,000	each	$	1,000
Total misc.							$	54,221

Total Cost for 8 Intermediate and 9 Deep wells **$ 354,834**

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 2A - Cost Backup

Prepared by: EDK
Checked by: DGG

Injection Wells
Intermediate Injection Well
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$ 51	per LF	$	2,562
2-inch Carbon Steel	130 ft	x	$ 30	per LF	$	3,900
10 slot screen	20 ft	x	$ 20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	20 ft	x	$ 14	per lf	$	286
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Decon of equipment	1 day	x	$ 112	per day	$	112
Well Development	3 hr	x	$ 160	per hr	$	480
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Intermediate Injection Well					$	13,622

Deep Injection Well
Assume a depth of 250 ft, with 90 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$ 51	per LF	$	7,686
2-inch Carbon Steel	160 ft	x	$ 30	per LF	$	4,800
10 slot screen	90 ft	x	$ 20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	90 ft	x	$ 14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Decon of equipment	1 day	x	$ 112	per day	$	112
Well Development	3 hr	x	$ 160	per hr	$	480
Drum & Disposal	6 each	x	$ 210	per hr	$	1,260
Total for One Deep Injection Well					$	22,440

For this Alternative, 40 Deep and 40 Intermediate Injection Wells are needed

Total Cost **$ 1,442,467**

Reducing Agent Material Cost (using Sodium Dithionite)

Delivery point spacing and configuration	PRB Length, feet	Spacing btw wells, feet	# of injection wells
Middle aquifer	0	40	0
Intermediate Sand	1600	40	40
Lower aquifer	1600	40	40
	Total Injection Points		80

Total Mass of Chromium in Plume	=	5000 kg	=	96154	moles Chromium
Assume 40% of plume treated	=	2000 kg	=	38462	moles Chromium
Based on stoichiometry 1.5 mole reagent/ mole Cr			=	57700	moles Reagent
@ 174 g/mole		10040 kg	=	11	tons

Factor of Safety of 10, dilution, buffering capacity of aquifer		110	tons reagent
Cost of Reagent	$1000/ton	$110,000	

Water 5,000,000 gallons		$5	per/1000gallon
	=	$25,000	

Total Chemical Cost **$135,000**

Reducing Agent Cost Based on-
Notes on an Engineering Forum Roundtable Dicussion on Permeable Reactive Walls
U.S. EPA Technical Support Project Meeting, January 1997. Adjuxt for inflation

Injection Points Labor

Assume 5 days per injection point, total 400

Crew B23					
1 Foreman		$	358		
4 Laborers		$	1,327		
1 Injection Equipment		$	3,497		
1 3 Ton Truck		$	194		
	Per day	$	5,375	x	400 Days
	=	$	2,149,960		
	Total Cost		**$2,149,960**		

Injection Monitoring

Monitoring points		
10 intermediate sand	$	131,416
10 Lower aquifer	$	217,200
Misc well installation cost	$	54,221
Total monitoring well cost	**$**	**402,838**

Annual O&M
Assume annual monitoring on long-term basis

No. 7 **Project Planning and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +
	$	30	per hour x	8	hours x	3	multiplier +
	$	20	per hour x	8	hours x	3	multiplier
=	$	1,680	per sampling event				
Assume:	**$**	**1,700**	**per sampling event**				

No. 8 **Sampling Labor**
Assume 3 persons for 12 days x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

3	persons x	10	hours/day x	12	days x	$	30	/ h	3 multiplier
=	$	**32,400**	**per sampling event**						

No. 9 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sampling equipment (e.g., bailers and pumps) @ $300 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $100 per day

Shipping	$	200	per day x	12 days =	$	2,400
Sampling Equipment	$	300	per day x	12 days =	$	3,600
Monitoring Equipment	$	*200*	*per day x*	*12 days =*	$	*2,400*
PPE	$	60	$'20 per set/2 set /day x	12 days =	$	720
Vehicle Rental	$	80	per day x	12 days =	$	960
Per Diem	$	120	Per person/day	36 man days =	$	4,320
Misc	$	200	per day x	12 days =	$	2,400
IDW Disposal	$	2,000	each	1 each	$	2,000
	$	**18,800**	**per sampling event**			

No. 10 **Sample Analysis and Validation**
Assume groundwater samples will be collected from 20 monitoring wells + 17 new wells; analyzed for chromium and natural attenuation parameters

Total No. of Samples.	37 samples
	2 field duplicate
	2 MS
	2 MSD
	12 Field Blank
	12 Trip Blanks
	67 Total Samples Per Sampling Event

Assume	$	200	per sample for biodegradation parameters
	$	200	Total sample cost

Analysis Cost:		67	samples x	$	200	
	= $	13,400	per sampling event			

Total Analysis & Validation:		$	13,400
	Assume:	**$**	**13,400**

No. 11 **Data Evaluation and Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

=		2	person x	$	35	per hour x	80	hours x	3 multiplier
=	$	16,800							

No. 12 Five Year Review

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

	2 persons x	$	35	/hour x	40	hours/week	x	4.2	weeks/month x	1	month x	3 multiplier
Assume:	**$**	**35,280**										
					$	**35,300**						

Present Worth Calculations

Assume discount rate is 7%: **0.07**

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

No. 14 **Total Long-term Monitoring Costs**

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 15 **Total 5-year review costs**

This cost occurs every 5 years for 30 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**

Alternative 2B: MNA/ In Situ Treatment (Geochemical Fixation Contingency Remedy)/ Institutional Controls
Puchack Well Field Superfund Site

Item No.	Item Description	Quantity	Unit Cost MNA with Contingency	Unit	MNA Cost	Total Cost MNA with Contingency
CAPITAL COSTS						
Construction Costs						
1.	Work Plan Preparation	1	$ 70,600	LS	$17,700	$ 70,600
2.	Mobilization/Demobilization	1	$ 66,000	LS	$5,000	$ 66,000
3.	Construction Management	1	$ 411,607	LS	-	$ 411,607
4.	Construction QC/Chemical Analysis/H&S	1	$ 411,607	LS	-	$ 411,607
5.	Geochemical Fixation and Monitoring Wells	1	$ 2,744,048	LS	$152,467	$ 2,744,048
6.	Institutional Controls	1	$ 17,700	LS	$17,700	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$192,867	$ 3,721,562
	General Contractor Fee (10% construction)				$19,287	$ 372,156
	Design Engineering				$38,573	$ 500,000
	Bench / Pilot Scale Studies					$ 1,000,000
	Resident Engineering/Inspection				$19,287	$ 400,000
	Contingency (20%)				$38,573	$ 744,312
	TOTAL CAPITAL COSTS				**$308,587**	**$ 6,738,031**
ANNUAL MONITORING COSTS						
7.	Project Planning and Organization	1	$ 1,700	LS	$1,700	$ 1,700
8.	Sampling Labor	1	$ 32,400	LS	$24,300	$ 32,400
9.	Sampling Equipment	1	$ 18,800	LS	$14,600	$ 18,800
10.	Sample Analysis and Data Validation	1	$ 13,400	LS	$10,200	$ 13,400
11.	Data Evaluation and Reporting	1	$ 16,800	LS	$16,800	$ 16,800
	Total Annual Monitoring Costs				**$67,600**	**$ 83,100**
FIVE YEAR REVIEW						
12.	*Five Year Review Report*	1	$ 35,300	LS	**$35,300**	**$ 35,300**
PRESENT WORTH OF COSTS						
13.	Total Capital Costs				$308,587	$ 6,738,031
14.	Long-term Monitoring (30 year duration)				$838,848	$ 1,031,188
15.	Five-Year Reviews (30 year duration)				$76,171	$ 76,171
	TOTAL PRESENT WORTH				**$1,223,607**	**$ 7,845,390**

Assume	$ 1,224,000	$ 7,845,000
Additional Cost of Contingency		$ 6,621,000

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 2B - Cost Backup

Prepared by: EDK
Checked by: DGG

No. 1 Work Plan Preparation (includes WP, HASP, CQC & Chemical QC plans)

Assume 2 persons for 2 months.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 2 month x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	6 months x	2000 per mo	$	12,000
Utilities during construction	6 months x	2000 per mo	$	12,000
Temp Facilities	6 months x	2000 per mo	$	12,000
Misc	6 months x	5000 per mo	$	30,000
		Total:	**$**	**66,000**

No. 3 Construction Management

PM at 5% of construction cost	$	137,202
Construction supervision/oversight at 10% of construction cost	$	274,405
Total:	**$**	**411,607**

No. 4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	137,202
Chemical analysis at 5% of construction cost	$	137,202
Health and Safety at 5% of construction cost	$	137,202
Total:	**$**	**411,607**

No. 5 **Total Construction Cost (labor & material)**

Monitoring Wells	$	354,791	**See page 4 for details**
Injection Points	$	431,397	**See page 5 for details**
Geochemical Fixation and Application	$	1,957,860	**See page 6 for details**
Total Construction Cost	**$**	**2,744,048**	

No. 6 **Institutional Controls**

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1 person x $ 35 /hour x 40 hours/week 4.2 weeks/month x 1 month x 3 multiplier

= $ 17,640
Assume: $ 17,700

Monitoring Well Installation

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130 ft	x	$	30	per LF	$	3,900
10 slot screen	20 ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	4 each	x	$	90	each	$	358
Total for One Intermediate Well						$	13,140

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160 ft	x	$	30	per LF	$	4,800
10 slot screen	90 ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	6 each	x	$	90	each	$	537
Total for One Deep Well						$	21,717

Misc Items

Drum disposal	100 each	x	$	120	each	$	12,000
Development/Decon Water Disposal	40000 gal	x	$	0.35	gal	$	14,000
Driller oversight	34 day	x	$	600	per day	$	20,400
Driller mobilization	1 LS	x	$	3,899	each	$	3,899
Tank Rental	2 tank (21,000 gal)	x	$	1,225	each	$	2,450
Well Development Equipment	2 week	x	$	236	week	$	472
Contingency	1 LS	x	$	1,000	each	$	1,000
Total misc.						$	54,221

Total Cost for 8 Intermediate and 9 Deep wells **$ 354,791**

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 2B - Cost Backup

Prepared by: EDK
Checked by: DGG

Injection Wells
Intermediate Injection Well
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$ 51	per LF	$	2,562
2-inch Carbon Steel	130 ft	x	$ 30	per LF	$	3,900
10 slot screen	20 ft	x	$ 20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	20 ft	x	$ 14	per lf	$	286
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Well Development	3 hr	x	$ 160	per hr	$	480
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Intermediate Injection Well					$	13,510

Deep Injection Well
Assume a depth of 250 ft, with 90 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$ 51	per LF	$	7,686
2-inch Carbon Steel	160 ft	x	$ 30	per LF	$	4,800
10 slot screen	90 ft	x	$ 20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	90 ft	x	$ 14	per lf	$	1,285
Well Development	3 hr	x	$ 160	per hr	$	480
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Decon of equipment	1 day	x	$ 112	per day	$	112
Drum & Disposal	6 each	x	$ 210	each	$	1,260
Total for One Deep Injection Well					$	22,440

For this Alternative, 12 Intermediate and 12 Deep Injection Wells are needed

Total Cost **$ 431,397**

Geochemical Fixation Costs (using sodium metabisulfite)

Delivery point spacing and configuration	Injection Length, feet	Spacing btw wells, feet	# of injection wells
Middle aquifer	0	150	0
Intermediate Sand	1600	150	12
Lower aquifer	1600	150	12
	Total Injection Points		24

Total Mass of Chromium	=	5000 kg	=	96154	moles Chromium
Assume 40% of plume treated	=	2000 kg	=	38462	moles Chromium
Based on stoichiometry 0.75 mole reagent/ mole Cr			=	28800	moles Reagent
@ 190 g/mole		5472 kg	=	6	tons

Factor of safety of 20, dilution, buffering capacity of aquifer		120	tons reagent
Cost of Reagent	$1/lb	$240,000	
Water 5,000,000 gallons		$5	per/1000gallon
	=	$25,000	
Total Cost		**$265,000**	

Reducing Agent Cost Based on - vendor cost for similar injection material

Injection Points Labor

Assume 5 days per injection point, 2 applications. Total 240

Crew B23				
1 Foreman		$ 358		
4 Laborers		$ 1,327		
1 Injection Equipment		$ 3,497		
1 3 Ton Truck		$ 194		
	Per day	$ 5,375	x	240 days
		= $ 1,290,072		
	Total Cost	**$1,290,072**		

Injection Monitoring

Monitoring points	
10 intermediate sand	$ 131,396
10 Lower aquifer	$ 217,170
Misc well installation cost	$ 54,221
Total monitoring well cost	**$ 402,788**

Annual O&M
Assume annual monitoring on long-term basis

No. 7 **Project Planning and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +
	$	30	per hour x	8	hours x	3	multiplier +
	$	20	per hour x	8	hours x	3	multiplier
=	$	1,680	per sampling event				
Assume:	**$**	**1,700**	**per sampling event**				

No. 8 **Sampling Labor**
Assume 3 persons for 12 days x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

3	persons x	10	hours/day x	12	days x	$	30	/ h	3
=	**$ 32,400**	**per sampling event**							

No. 9 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sampling equipment (e.g., bailers and pumps) @ $300 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $200 per day

Shipping	$	200	per day x	12 days =	$	2,400
Sampling Equipment	$	300	per day x	12 days =	$	3,600
Monitoring Equipment	$	200	per day x	12 days =	$	2,400
PPE	$	60	$'20 per set/2 set /day x	12 days =	$	720
Vehicle Rental	$	80	per day x	12 days =	$	960
Per Diem	$	120	Per person/day	36 man days =	$	4,320
Misc	$	200	per day x	12 days =	$	2,400
IDW Disposal	$	2,000	each x	1 each	$	2,000
Assume:	**$**	**18,800**	**per sampling event**			

No. 10 **Sample Analysis and Validation**
Assume groundwater samples will be collected from 20 monitoring wells + 17 new wells; analyzed for chromium and natural attenuation parameters

Total No. of Samples:	37 samples
	2 field duplicate
	2 MS
	2 MSD
	12 Field Blank
	12 Trip Blanks
	67 Total Samples Per Sampling Event

Assume	$	200	per sample for biodegradation parameters
	$	200	Total sample cost

Analysis Cost:		67	samples x	$	200
	= $	13,400	per sampling event		

Total Analysis & Validation:		$	13,400
	Assume:	$	**13,400**

No. 11 **Data Evaluation Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

=	2	person x	$	35	per hour x	80	hours x	3	multiplier
=	**$ 16,800**								

No. 12 **Five Year Review**

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 1 month x 3 multiplier

= $ 35,300

Present Worth Calculations

Assume discount rate is 7%: **0.07**

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

No. 14 **Total Long-term Monitoring Costs**

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 15 **Total 5-year review costs**

This cost occurs every 5 years for 30 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**

Alternative 3A: In Situ Treatment (Permeable Reactive Barrier)/MNA/Institutional Controls
Puchack Well Field Superfund Site
Howell Township, New Jersey

Item No.	Item Description	Quantity	Unit Cost	Unit	Extension
1.	Work Plan Preparation	1	$ 70,600	LS	$ 70,600
2.	Mobilization/Demobilization	1	$ 66,000	LS	$ 66,000
3.	Construction Management	1	$ 1,035,310	LS	$ 1,035,310
4.	QC/Chemical Analysis/H&S	1	$ 1,035,310	LS	$ 1,035,310
5.	Permeable Reactive Barrier and Monitoring Wells	1	$ 6,902,069	LS	$ 6,902,069
6.	Institutional Controls	1	$ 17,700	LS	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$ 9,126,989
	General Contractor Fee (10% construction)				$ 912,699
	Design Engineering				500,000
	Bench / Pilot Scale Studies				750,000
	Resident Engineering/Inspection				$ 500,000
	Contingency (20%)				$ 1,825,398
	TOTAL CAPITAL COSTS				**$ 13,615,086**
ANNUAL MONITORING COSTS					
7.	Project Planning and Organization	1	$ 1,700	LS	$ 1,700
8.	Sampling Labor	1	$ 24,300	LS	$ 24,300
9.	Sampling Equipment	1	$ 14,600	LS	$ 14,600
10.	Sample Analysis and Data Validation	1	$ 10,200	LS	$ 10,200
11.	Data Evaluation and Reporting	1	$ 16,800	LS	$ 16,800
	Total Annual Monitoring Costs				**$ 67,600**
FIVE YEAR REVIEW					
12.	Five Year Review Report	1	$ 35,300	LS	**$ 35,300**
PRESENT WORTH OF COSTS					
13.	Total Capital Costs				$ 13,615,086
14.	Long-term Monitoring (30 year duration)				$ 838,848
15.	Five-Year Reviews (30 year duration)				$ 76,171
	TOTAL PRESENT WORTH				**$ 14,530,106**

Assume $ 14,530,000

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 3A - Cost Backup

Prepared by: __EDK___
Checked by __DGG___

No. 1 Work Plan/CQCP/Chemical QCP/HASP Preparation

Assume 2 persons for 2 months.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 2 month x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	6 mo	x	2000 per mo	$	12,000
Utilities during construction	6 mo	x	2000 per mo	$	12,000
Temp Facilities	6 mo	x	2000 per mo	$	12,000
Misc	6 mo	x	5000 per mo	$	30,000
			Total:	**$**	**66,000**

No. 3 Construction Management

PM at 5% of construction cost	$	345,103
Construction supervision/oversight at 10% of construction cost	$	690,207
Total:	**$**	**1,035,310**

No. 4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	345,103
Chemical analysis at 5% of construction cost	$	345,103
Health and Safety at 5% of construction cost	$	345,103
Total:	**$**	**1,035,310**

No. 5 Total Construction Cost (labor & material)

Monitoring Wells	$	160,828	**See page 5 for details**
Injection Points	$	2,415,574	**See page 4 for details**
PRB Material & Application	$	4,486,494	**See page 6 for details**
Total Construction Cost	**$**	**6,902,069**	

No. 6 Institutional Controls

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1 person x $ 35 /hour x 40 hours/week 4.2 weeks/month x 1 month x 3 multiplier

= $ 17,640
Assume: $ 17,700

Job No. 3232-102
Project Puchack Groundwater FS
Subject Alternative 3A - Cost Backup

Prepared by: EDK
Checked by: DGG

Monitoring Well Installation

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130 ft	x	$	30	per LF	$	3,900
10 slot screen	20 ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drums	4 each	x	$	90	each	$	358
Total for One Intermediate Well						$	13,140

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160 ft	x	$	30	per LF	$	4,800
10 slot screen	90 ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drums	6 each	x	$	90	each	$	537
Total for One Deep Well						$	21,717

Misc Items

Drum disposal	36 each	x	$	120	each	$	4,320
Development/Decon Water Disposal	40000 gal	x	$	0.35	gal	$	14,000
Driller oversight	14 day	x	$	600	per day	$	8,400
Driller mobilization	1 LS	x	$	3,899	each	$	3,899
Tank Rental	2 tank (21,000 gal)	x	$	1,225	each	$	2,450
Well Development Equipment	2 week	x	$	236	week	$	472
Contingency	1 LS	x	$	1,000	each	$	1,000
Total misc.						$	34,541

Total Cost for 3 Intermediate and 4 Deep wells **$ 160,828**

Injection Wells

Shallow Injection Well
Assume a depth of 100 ft, with 25 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
2-inch Carbon Steel	75 ft	x	$ 30	per LF	$	2,250
10 slot screen	25 ft	x	$ 20	per LF	$	491
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	25 ft	x	$ 14	per lf	$	357
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Well Development	3 hr	x	$ 160	per hr	$	480
Decon of equipment	1 day	x	$ 112	per day	$	112
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Middle Aquifer Injection Well					$	9,579

Intermediate Injection Well
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$ 51	per LF	$	2,562
2-inch Carbon Steel	130 ft	x	$ 30	per LF	$	3,900
10 slot screen	20 ft	x	$ 20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	20 ft	x	$ 14	per lf	$	286
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Well Development	3 hr	x	$ 160	per hr	$	480
Decon of equipment	1 day	x	$ 112	per day	$	112
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Intermediate Injection Well					$	13,622

Deep Injection Well
Assume a depth of 250 ft, with 90 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$ 51	per LF	$	7,686
2-inch Carbon Steel	160 ft	x	$ 30	per LF	$	4,800
10 slot screen	90 ft	x	$ 20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	90 ft	x	$ 14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Well Development	3 hr	x	$ 160	per hr	$	480
Decon of equipment	1 day	x	$ 112	per day	$	112
Drum & Disposal	6 each	x	$ 210	each	$	1,260
Total for One Deep Injection Well					$	22,440

For this Alternative, 15 Middle, 63 Intermediate and 63 Deep Injection Wells are needed

Total Cost $ **2,415,574**

Reducing Agent Material Cost (using Sodium Dithionite)

Delivery point spacing and configuration	PRB Length, feet	Spacing btw wells, feet	# of injection wells
Middle aquifer	600	40	15
Intermediate Sand	2500	40	63
Lower aquifer	2500	40	63
	Total Injection Points		141

Total Mass of Chromium in Plume	=	5000 kg	=	96154	moles Chromium
Assume 80% of plume treated	=	4000 kg	=	76923	moles Chromium
Based on stoichiometry 1.5 mole reagent/ mole Cr			=	115400	moles Reagent
@ 174 g/mole		20080 kg	=	22	tons

Factor of Safety of 10, dilution, buffering capacity of aquif		220	tons reagent
Cost of Reagent	$1000/ton	$220,000	
Water 5,000,000 gallons		$5	per/1000gallon
	=	$25,000	
Total Chemical Cost		**$245,000**	

Reducing Agent Cost Based on-
Notes on an Engineering Forum Roundtable Dicussion on Permeable Reactive Walls
U.S. EPA Technical Support Project Meeting, January 1997. Adjust for inflation

Injection Points Labor

Assume 5 days per injection point, total 705 days

Crew B23					
1 Foreman		$	358		
4 Laborers		$	1,327		
1 Injection Equipment		$	3,497		
1 3 Ton Truck		$	194		
	Per day	$	5,375	x	705 days
		= $	3,789,305		
Total Labor Cost			**$3,789,305**		

Injection Monitoring

Monitoring points		
10 intermediate sand	$	131,396
10 Lower aquifer	$	217,170
Misc well installation cost	$	103,623
Total monitoring well cost	**$**	**452,190**

Annual O&M
Assume annual monitoring on long-term basis

No. 7 **Project Planing and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +	
	$	30	per hour x	8	hours x	3	multiplier +	
	$	20	per hour x	8	hours x	3	multiplier	
=	$	1,680	per sampling event					
Assume:	**$**	**1,700**	**per sampling event**					

No. 8 **Sampling Labor**
Assume 3 persons for 9 days x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

3	persons x	10	hours/day x	9	days x	$	30	/ h	3 multiplier
=	$	**24,300**	**per sampling event**						

No. 9 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sampling equipment (e.g., bailers and pumps) @ $300 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $200 per day

Shipping	$	200	per day x	9 days =	$	1,800
Sampling Equipment	$	300	per day x	9 days =	$	2,700
Monitoring Equipment	$	200	per day x	9 days =	$	1,800
PPE	$	60	$20 per set/2 set /day x	9 days =	$	540
Vehicle Rental	$	80	per day x	9 days =	$	720
Per Diem	$	120	Per person/day x	27 man days =	$	3,240
Misc	$	200	per day x	9 days =	$	1,800
IDW Disposal	$	2,000	each x	1 each	$	2,000
Assume:	**$**	**14,600**	**per sampling event**			

No. 10 **Sample Analysis and Data Validation**
Assume groundwater samples will be collected from 20 monitoring wells + 7 new wells; analyzed for chromium and natural attenuation parameters

Total No. of Samples:	27 samples
	2 field duplicate
	2 MS
	2 MSD
	9 Field Blank
	9 Trip Blanks
	51 Total Samples Per Sampling Event

Assume	$	200	per sample for biodegradation parameters
	$	200	Total sample cost

Analysis Cost:		51	samples x	$	200
	= $	10,200	per sampling event		

Total Analysis & Validation:	$	10,200
Assume:	**$**	**10,200**

No. 11 **Data Evaluation & Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

=	2	person x	$	35	per hour x	80	hours x	3 multiplier
= $	16,800							

No. 12 Five Year Review

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

	2 persons x	$	35	/hour x	40 hours/week	x	4.2 weeks/month x	1 month x	3 multiplier
	$ 35,280								
Assume:	**$ 35,300**								

Present Worth Calculations

Assume discount rate is 7%: **0.07**

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

No. 14 **Total Long-term Monitoring Costs**

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 15 **Total 5-year review costs**

This cost occurs every 5 years for 30 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**

Alternative 3B: In Situ Treatment (Geochemical Fixation)/MNA/Institutional Controls
Puchack Well Field Superfund Site

Item No.	Item Description	Quantity	Unit Cost	Unit	Extension
CAPITAL COSTS					
Construction Costs					
1.	Work Plan Preparation	1	$ 70,600	LS	$ 70,600
2.	Mobilization/Demobilization	1	$ 66,000	LS	$ 66,000
3.	Construction Management	1	$ 789,544	LS	$ 789,544
4.	Construction QC/Chemical Analysis/H&S	1	$ 789,544	LS	$ 789,544
5.	Geochemical Fixation and Monitoring Wells	1	$ 5,263,624	LS	$ 5,263,624
6.	Institutional Controls	1	$ 17,700	LS	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$ 6,997,011
	General Contractor Fee (10% construction)				$ 699,701
	Design Engineering				500,000
	Bench / Pilot Scale Studies				1,000,000
	Resident Engineering/Inspection				$ 500,000
	Contingency (20%)				$ 1,399,402
	TOTAL CAPITAL COSTS				**$ 11,096,114**
ANNUAL MONITORING COSTS					
7.	Project Planning and Organization	1	$ 1,700	LS	$ 1,700
8.	Sampling Labor	1	$ 24,300	LS	$ 24,300
9.	Sampling Equipment	1	$ 14,600	LS	$ 14,600
10.	Sample Analysis and Data Validation	1	$ 10,200	LS	$ 10,200
11.	Data Evaluation and Reporting	1	$ 16,800	LS	$ 16,800
	Total Annual Monitoring Costs				**$ 67,600**
FIVE YEAR REVIEW					
12.	Five Year Review Report	1	$ 35,300	LS	$ 35,300
PRESENT WORTH OF COSTS					
13.	Total Capital Costs				$ 11,096,114
14.	Long-term Monitoring (30 year duration)				$ 838,848
15.	Five-Year Reviews (30 year duration)				$ 76,171
	TOTAL PRESENT WORTH				**$ 12,011,134**

Assume $ 12,011,000

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 3B - Cost Backup

Prepared by: EDK
Checked by: DGG

No. 1 Work Plan Preparation

Assume 2 persons for 2 months.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 2 mo x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	6 mo	x	2000 per mo	$	12,000
Utilities during construct	6 mo	x	2000 per mo	$	12,000
Temp Facilities	6 mo	x	2000 per mo	$	12,000
Misc	6 mo	x	5000 per mo	$	30,000
			Total:	**$**	**66,000**

No. 3 Construction Management

PM at 5% of construction cost	$	263,181
Construction supervision/oversight at 10% of construction cost	$	526,362
Total:	**$**	**789,544**

4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	263,181
Chemical analysis at 5% of construction cost	$	263,181
Health and Safety at 5% of construction cost	$	263,181
Total:	**$**	**789,544**

No. 4 **Total Construction Cost (labor & material)**

Monitoring Wells	$	160,828	See page 4 for details
Injection Points	$	1,003,164	See page 5 for details
Geochemical Fixation and Application	$	4,099,632	See page 6 for details
Total Construction Cost	$	5,263,624	

No. 5 **Bench / Pilot Scale Studies**

Assume: $ 750,000

No. 6 **Institutional Controls**

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1 person x $ 35 /hour x 40 hours/week 4.2 weeks/month x 1 month x 3 multiplier

= $ 17,640
Assume: $ 17,700

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 3B - Cost Backup
Monitoring Well Installation

Prepared by: EDK
Checked by: DGG

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130 ft	x	$	30	per LF	$	3,900
10 slot screen	20 ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	4 each	x	$	90	each	$	358
Total for One Intermediate Well						$	13,140

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160 ft	x	$	30	per LF	$	4,800
10 slot screen	90 ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	6 each	x	$	90	each	$	537
Total for One Deep Well						$	21,717

Misc Items

Drum disposal	36 each	x	$	120	each	$	4,320
Development/Decon Water Disposal	40000 gal	x	$	0.35	gal	$	14,000
Driller oversight	14 day	x	$	600	per day	$	8,400
Driller mobilization	1 LS	x	$	3,899	each	$	3,899
Tank Rental	2 tank (21,000 gal)	x	$	1,225	each	$	2,450
Well Development Equipment	2 week	x	$	236	week	$	472
Contingency	1 LS	x	$	1,000	each	$	1,000
Total misc.						$	34,541

Total Cost for 3 Intermediate and 4 Deep wells **$ 160,828**

Injection Wells

Shallow Injection Well
Assume a depth of 100 ft, with 25 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$ 4,678
2-inch Carbon Steel	75 ft	x	$ 30	per LF	$ 2,250
10 slot screen	25 ft	x	$ 20	per LF	$ 491
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$ 118
Bentonite Seal	1 ea	x	$ 53	each	$ 53
Silica Sand	25 ft	x	$ 14	per lf	$ 357
5' Steel protective casing	1 LS	x	$ 200	each	$ 200
Well Development	3 hr	x	$ 160	per hr	$ 480
Decon of equipment	1 day	x	$ 112	per day	$ 112
Drum & Disposal	4 each	x	$ 210	each	$ 840
Total for One Middle Aquifer Injection Well					$ 9,579

Intermediate Injection Well
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$ 4,678
Mud Drilling, 4" Dia	50 ft	x	$ 51	per LF	$ 2,562
2-inch Carbon Steel	130 ft	x	$ 30	per LF	$ 3,900
10 slot screen	20 ft	x	$ 20	per LF	$ 393
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$ 118
Bentonite Seal	1 ea	x	$ 53	each	$ 53
Silica Sand	20 ft	x	$ 14	per lf	$ 286
5' Steel protective casing	1 LS	x	$ 200	each	$ 200
Well Development	3 hr	x	$ 160	per hr	$ 480
Decon of equipment	1 day	x	$ 112	per day	$ 112
Drum & Disposal	4 each	x	$ 210	each	$ 840
Total for One Intermediate Injection Well					$ 13,622

Deep Injection Well
Assume a depth of 250 ft, with 90 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$ 4,678
Mud Drilling, 4" Dia	150 ft	x	$ 51	per LF	$ 7,686
2-inch Carbon Steel	160 ft	x	$ 30	per LF	$ 4,800
10 slot screen	90 ft	x	$ 20	per LF	$ 1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$ 118
Bentonite Seal	1 ea	x	$ 53	each	$ 53
Silica Sand	90 ft	x	$ 14	per lf	$ 1,285
5' Steel protective casing	1 LS	x	$ 200	each	$ 200
Well Development	3 hr	x	$ 160	per hr	$ 480
Decon of equipment	1 day	x	$ 112	per day	$ 112
Drum & Disposal	6 each	x	$ 210	each	$ 1,260
Total for One Deep Injection Well					$ 22,440

For this Alternative, 4 Shallow, 28 Intermediate and 26 Deep Injection Wells are needed

Total Cost **$ 1,003,164**

Geochemical Fixation Reagent Costs (using sodium metabisulfite)

Delivery point spacing and configuration		150 ft spacing, Middle aquifer = 600 ft, Intermediate sand = 4200 ft, Lower Aquifer = 3700 ft			
Total Injection Points	=	58			
Total Mass of Chromium in Plume	=	5000 kg	=	96154	moles Chromium
Assume 80% of plume treated	=	4000 kg	=	76923	moles Chromium
Based on stoichiometry 0.75 mole reagent/ mole Cr			=	57700	moles Reagent
@ 190 g/mole		10963 kg	=	12	tons
Factor of Safety of 20, dilution, buffering capacity of aquifer		240 tons reagent			
Cost of Reagent	$1/lb	$480,000			
Water 5,000,000 gallons		$5 per/1000gallon			
	=	$50,000			
Total Cost		**$530,000**			

Reducing Agent Cost Based on - vendor cost for similar injection material

Chemical Injection Labor

App Crew B23		$ 358			
1 Foreman		$ 1,327			
4 Laborers		$ 3,497			
1 Injection Equipment		$ 194			
1 3 Ton Truck	Per day	$ 5,375	x		580 days
		=	$ 3,117,442		
	Total Cost		**$3,117,442**		

Injection Monitoring

Monitoring points	
10 intermediate sand	$ 131,396
10 Lower aquifer	$ 217,170
Misc well installation cost	$ 103,623
Total monitoring well cost	**$ 452,190**

Annual O&M
Assume annual monitoring on long-term basis

No. 7 **Project Planning and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +
	$	30	per hour x	8	hours x	3	multiplier +
	$	20	per hour x	8	hours x	3	multiplier
=	$	1,680	per sampling event				
Assume:	**$**	**1,700**	**per sampling event**				

No. 8 **Sampling Labor**
Assume 3 persons for 10 x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

3 persons x 10 hours/day x 9 days x $ 30 / hr x 3
= $ 24,300 **per sampling event**

No. 9 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sample equipment (e.g., bailers and pumps) @ $300 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $200 per day

Shipping	$	200	per day x	9 days =	$ 1,800
Sampling Equipment	$	300	per day x	9 days =	$ 2,700
Monitoring Equipment	$	200	per day x	9 days =	$ 1,800
PPE	$	60	$'20 per set/2 set /day x	9 days =	$ 540
Vehicle Rental	$	80	per day x	9 days =	$ 720
Per Diem	$	120	Per person/day	27 man days =	$ 3,240
Misc	$	200	per day x	9 days =	$ 1,800
IDW Disposal	$	2,000	each x	1 each =	$ 2,000

= **$ 14,600 per sampling event**
Assume: $ 14,600 per sampling event

No. 10 **Sample Analysis and Validation**
Assume groundwater samples will be collected from 20 monitoring wells + 7 new wells; analyzed for chromium and natural attenuation parameters

Total No. of Samples:
27 samples
2 field duplicate
2 MS
2 MSD
9 Field Blank
9 Trip Blanks
51 Total Samples Per Sampling Event

Assume $ 200 per sample for biodegradation parameters
$ 200 Total sample cost

Analysis Cost: 51 samples x $ 200
= $ 10,200 per sampling event

Total Analysis & Validation: $ 10,200
Assume: $ 10,200

No. 11 **Data Evaluation and Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

= 2 person x $ 35 per hour x 80 hours x 3 multiplier
= $ 16,800

No. 12 **Five Year Review**

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

	2	persons x	$	35	/hour x	40	hours/week	x	4.2	weeks/month x	1	month x	3	multiplier
Total	$	35,280												
Assume	$	35,300												

Present Worth Calculations

Assume discount rate is 7%: **0.07**

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

No. 14 **Total Long-term Monitoring Costs**

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 15 **Total 5-year review costs**

This cost occurs every 5 years for 30 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**

Alternative 3C: In Situ Treatment (Geochemical Fixation)/MNA/Institutional Controls
Puchack Well Field Superfund Site

Item No.	Item Description	Quantity	Unit Cost	Unit	Extension
CAPITAL COSTS					
Construction Costs					
1.	Work Plan Preparation	1	$ 70,600	LS	$ 70,600
2.	Mobilization/Demobilization	1	$ 66,000	LS	$ 66,000
3.	Construction Management	1	$ 1,283,936	LS	$ 1,283,936
4.	Construction QC/Chemical Analysis/H&S	1	$ 1,283,936	LS	$ 1,283,936
5.	Geochemical Fixation and Monitoring Wells	1	$ 8,559,574	LS	$ 8,559,574
6.	Institutional Controls	1	$ 17,700	LS	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$ 11,281,746
	General Contractor Fee (10% construction)				$ 1,128,175
	Design Engineering				500,000
	Bench / Pilot Scale Studies				1,000,000
	Resident Engineering/Inspection				$ 500,000
	Contingency (20%)				$ 2,256,349
	TOTAL CAPITAL COSTS				**$ 16,666,269**
ANNUAL MONITORING COSTS					
7.	Project Planning and Organization	1	$ 1,700	LS	$ 1,700
8.	Sampling Labor	1	$ 24,300	LS	$ 24,300
9.	Sampling Equipment	1	$ 14,600	LS	$ 14,600
10.	Sample Analysis and Data Validation	1	$ 10,200	LS	$ 10,200
11.	Data Evaluation and Reporting	1	$ 16,800	LS	$ 16,800
	Total Annual Monitoring Costs				**$ 67,600**
FIVE YEAR REVIEW					
12.	Five Year Review Report	1	$ 35,300	LS	**$ 35,300**
PRESENT WORTH OF COSTS					
13.	Total Capital Costs				$ 16,666,269
14.	Long-term Monitoring (30 year duration)				$ 838,848
15.	Five-Year Reviews (30 year duration)				$ 76,171
	TOTAL PRESENT WORTH				**$ 17,581,289**

Assume $ 17,581,000

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 3C - Cost Backup

Prepared by: __EDK___
Checked by: __DGG___

No. 1 Work Plan Preparation

Assume 2 persons for 2 months.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 2 mo x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	6 mo	x	2000 per mo	$	12,000
Utilities during construct	6 mo	x	2000 per mo	$	12,000
Temp Facilities	6 mo	x	2000 per mo	$	12,000
Misc	6 mo	x	5000 per mo	$	30,000
			Total:	**$**	**66,000**

No. 3 Construction Management

PM at 5% of construction cost	$	427,979
Construction supervision/oversight at 10% of construction cost	$	855,957
Total:	**$**	**1,283,936**

4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	427,979
Chemical analysis at 5% of construction cost	$	427,979
Health and Safety at 5% of construction cost	$	427,979
Total:	**$**	**1,283,936**

No. 5 **Total Construction Cost (labor & material)**

Monitoring Wells	$	160,828	**See page 4 for details**
Injection Points	$	1,814,158	**See page 5 for details**
Geochemical Fixation	$	6,584,588	**See page 6 for details**
Total Construction Cost	**$**	**8,559,574**	

No. 6 **Institutional Controls**

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1	person x	$	35	/hour x	40	hours/week	4.2	weeks/month x	1	month x	3 multiplier
		= $	17,640								
Assume:		**$**	**17,700**								

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 3C - Cost Backup
Monitoring Well Installation

Prepared by: EDK
Checked by: DGG

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130 ft	x	$	30	per LF	$	3,900
10 slot screen	20 ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	4 each	x	$	90	each	$	358
Total for One Intermediate Well						$	13,140

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160 ft	x	$	30	per LF	$	4,800
10 slot screen	90 ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drum	6 each	x	$	90	each	$	537
Total for One Deep Well						$	21,717

Misc Items

Drum disposal	36 each	x	$	120	each	$	4,320
Development/Decon Water Disposal	40000 gal	x	$	0.35	gal	$	14,000
Driller oversight	14 day	x	$	600	per day	$	8,400
Driller mobilization	1 LS	x	$	3,899	each	$	3,899
Tank Rental	2 tank (21,000 gal)	x	$	1,225	each	$	2,450
Well Development Equipment	2 week	x	$	236	week	$	472
Contingency	1 LS	x	$	1,000	each	$	1,000
Total misc.						$	34,541

Total Cost for 3 Intermediate and 4 Deep wells **$ 160,828**

Injection Wells

Shallow Injection Well
Assume a depth of 100 ft, with 25 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
2-inch Carbon Steel	75 ft	x	$ 30	per LF	$	2,250
10 slot screen	25 ft	x	$ 20	per LF	$	491
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	25 ft	x	$ 14	per lf	$	357
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Decon of equipment	1 day	x	$ 112	per day	$	112
Well Development	3 hr	x	$ 160	per hr	$	480
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Middle Aquifer Injection Well					$	9,579

Intermediate Injection Well
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$ 51	per LF	$	2,562
2-inch Carbon Steel	130 ft	x	$ 30	per LF	$	3,900
10 slot screen	20 ft	x	$ 20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	20 ft	x	$ 14	per lf	$	286
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Decon of equipment	1 day	x	$ 112	per day	$	112
Well Development	3 hr	x	$ 160	per hr	$	480
Drum & Disposal	4 each	x	$ 210	each	$	840
Total for One Intermediate Injection Well					$	13,622

Deep Injection Well
Assume a depth of 250 ft, with 90 ft of screen

Mud Drilling, 4" Dia	100 ft	x	$ 47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$ 51	per LF	$	7,686
2-inch Carbon Steel	160 ft	x	$ 30	per LF	$	4,800
10 slot screen	90 ft	x	$ 20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$ 118	each	$	118
Bentonite Seal	1 ea	x	$ 53	each	$	53
Silica Sand	90 ft	x	$ 14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$ 200	each	$	200
Well Development	3 hr	x	$ 160	per hr	$	480
Decon of equipment	1 day	x	$ 112	per day	$	112
Drum & Disposal	6 each	x	$ 210	each	$	1,260
Total for One Deep Injection Well					$	22,440

For this Alternative, 50 Deep 48 Intermediate and 4 Middle Aquifer Injection Wells are needed

Total Cost **$ 1,814,158**

Geochemical Fixation Reagent Costs (using sodium metabisulfite)

Delivery point spacing and configuration		150 ft spacing, Middle aquifer = 600 ft, Intermediate Sand =7400 ft, Lower Aquifer = 7000 ft			
Total Injection Points	=	102			
Total Mass of Chromium in Plume	=	5000 kg	=	96154	moles Chromium
Assume 100% of plume treated	=	5000 kg	=	96154	moles Chromium
Based on stoichiometry 0.75 mole reagent/ mole Cr			=	72100	moles Reagent
@ 190 g/mole		13699 kg	=	15	tons
Factor of Safety of 20, dilution, buffering capacity of aqui		300	tons reagent		
Cost of Reagent	$1/lb	$600,000			
Water 5,000,000 gallons		$5	per/1000gallon		
	=	$50,000			
Total Chemical Cost		**$650,000**			

Reducing Agent Cost Based on - vendor cost for similar injection material

Chemical Injection Labor

App Crew B23					
1 Foreman		$	358		
4 Laborers		$	1,327		
1 Injection Equipment		$	3,497		
1 3 Ton Truck		$	194		
	Per day	$	5,375	x	1020 days
		=			
Total Labor Cost			**$ 5,482,398**		

Injection Monitoring

Monitoring points	
10 intermediate sand	$ 131,396
10 Lower aquifer	$ 217,170
Misc well installation cost	$ 103,623
Total monitoring well cost	**$ 452,190**

Annual O&M
Assume annual monitoring on long-term basis

No. 7 **Project Planning and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +
	$	30	per hour x	8	hours x	3	multiplier +
	$	20	per hour x	8	hours x	3	multiplier
=	$	1,680	per sampling event				
Assume:	**$**	**1,700**	**per sampling event**				

No. 8 **Sampling Labor**
Assume 3 persons for 10 x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

3 persons x 10 hours/day x 9 days x $ 30 / hr x 3
= **$ 24,300 per sampling event**

No. 9 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sampling equipment (e.g., bailers and pumps) @ $300 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $200 per day

Shipping	$	200	per day x	9 days =	$	1,800
Sampling Equipment	$	300	per day x	9 days =	$	2,700
Monitoring Equipment	$	200	per day x	9 days =	$	1,800
PPE	$	60	$'20 per set/2 set /day x	9 days =	$	540
Vehicle Rental	$	80	per day x	9 days =	$	720
Per Diem	$	120	Per person/day	27 man days =	$	3,240
Misc	$	200	per day x	9 days =	$	1,800
IDW Disposal	$	2,000	each x	1 each =	$	2,000

= **$ 14,600 per sampling event**

No. 10 **Sample Analysis and Validation**
Assume groundwater samples will be collected from 20 monitoring wells + 7 new wells; analyzed for chromium and natural attenuation parameters

Total No. of Samples:
27 samples
2 field duplicate
2 MS
2 MSD
9 Field Blank
9 Trip Blanks
51 *Total Samples Per Sampling Event*

Assume $ 200 per sample for biodegradation parameters
$ 200 *Total sample cost*

Analysis Cost: 51 samples x $ 200
= $ 10,200 per sampling event

Total Analysis & Validation: $ 10,200
Assume: $ 10,200

No. 11 **Data Evaluation and Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

= 2 person x $ 35 per hour x 80 hours x 3 multiplier
= **$ 16,800**

No. 12 **Five Year Review**

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

	2	persons x	$	35	/hour x	40	hours/week	x	4.2	weeks/month x	1	month x	3	multiplier
Total	$	35,280												
Assume	**$**	**35,300**												

Present Worth Calculations

Assume discount rate is 7%: **0.07**

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

No. 14 **Total Long-term Monitoring Costs**

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 15 **Total 5-year review costs**

This cost occurs every 5 years for 30 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**

Alternative 4:
Groundwater Extraction/Treatment/Off-site Disposal/Monitoring/Instutional Controls
Puchack Well Field Superfund Site

Item No.	Item Description	Quantity	Unit Cost	Unit	Extension
CAPITAL COSTS					
Construction Costs					
1.	Work Plan Preparation	1	$ 70,600	LS	$ 70,600
2.	Mobilization/Demobilization	1	$ 132,000	LS	$ 132,000
3.	Construction Management	1	$ 1,087,929	LS	$ 1,087,929
4.	Construction QC/Chemical Analysis/H&S	1	$ 1,087,929	LS	$ 1,087,929
5.	Pump and Treat System	1	$ 7,252,860	LS	$ 7,252,860
6.	*Institutional Controls*	1	$ 17,700	LS	$ 17,700
	SUBTOTAL CONSTRUCTION COSTS				$ 9,649,018
	General Contractor Fee (10% construction)				$ 964,902
	Design Engineering				$ 600,000
	Bench/Pilot Scale Study				-
	Resident Engineering/Inspection				$ 500,000
	Contingency (20%)				$ 1,929,804
	TOTAL CAPITAL COSTS				**$ 13,643,723**
ANNUAL O&M COSTS					
7.	Groundwater Treatment Plant O&M	1	$ 1,395,197	LS	**$ 1,395,197**
ANNUAL MONITORING COSTS					
8.	Project Planning and Organization	1	$ 1,700	LS	$ 1,700
9.	Sampling Labor	1	$ 24,300	LS	$ 24,300
10.	Sampling Equipment	1	$ 14,600	LS	$ 14,600
11.	Sample Analysis and Data Validation	1	$ 10,200	LS	$ 10,200
12.	Data Evaluation and Reporting	1	$ 16,800	LS	$ 16,800
	Total Annual Monitoring Costs				**$ 67,600**
TREATMENT MEDIA REPLACEMENT					
13.	Media Replacement (every year)	1	$ 19,564	EA	**$ 19,564**
FIVE YEAR REVIEW					
14.	Five Year Review Report	1	$ 35,300	LS	**$ 35,300**
PRESENT WORTH OF COSTS					
15.	Total Capital Costs				$ 13,643,723
16.	O&M Costs (30 year duration)				$ 17,313,005
17.	Media Replacement (30 year duration)				$ 242,770
18.	Long-term Monitoring Cost (30 year duration)				$ 838,848
19.	Five-Year Reviews (30 year duration)				$ 76,171
	TOTAL PRESENT WORTH				**$ 32,114,517**

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 4 - Cost Backup

Prepared by: EDK
Checked by: DGG

No. 1 Work Plan/CQCP/Chemical QCP/HASP Preparation

Assume 2 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

2 persons x $ 35 /hour x 40 hours/week x 4.2 weeks/month x 2 month x 3 multiplier

= $ 70,560

Assume: $ 70,600

No. 2 Mobilization/Demobilization

Materials/supplies	12 months	x	2000 per mo	$	24,000
Utilities during construction	12 months	x	2000 per mo	$	24,000
Temp Facility	12 months	x	2000 per mo	$	24,000
Misc	12 months	x	5000 per mo	$	60,000
			Total:	**$**	**132,000**

No. 3 Construction Management

PM at 5% of construction cost	$	362,643
Construction supervision/oversight at 10% of construction cost	$	725,286
Total:	**$**	**1,087,929**

No. 4 QC/Chemical Analysis/Health and Safety

QC at 5% of construction cost	$	362,643
Chemical analysis at 5% of construction cost	$	362,643
Health and Safety at 5% of construction cost	$	362,643
Total:	**$**	**1,087,929**

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 4 - Cost Backup

Prepared by: ____EDK____
Checked by: ____DGG____

No. 5 Total Construction Cost (labor & material)

Monitoring, Extraction, Injection Wells	$	461,923	**See Pages 4 & 5 for details**
Pre-Fabricated Building	$	458,250	**See Page 6 for details**
Treatment System	$	1,426,496	**See Page 7 for details**
Pumps	$	65,051	**See Page 8 for details**
Construction Subtotal	$	2,411,720	
Installation Costs (HVAC, electrical, piping etc) (2 Times Construction Subtotal)	$	4,823,440	
Total Construction Cost	**$**	**7,252,860**	

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 4 - Cost Backup

Prepared by: ____EDK____
Checked by: ____DGG____

Well Installation

Driller Procurement and Statement of Work Preparation

$	30	per hour x	40 hours x	3 multiplier =		$	3,600

Intermediate Monitoring Well
Assume a depth of 150 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	50 ft	x	$	51	per LF	$	2,562
2-inch Stainless Steel	130 ft	x	$	30	per LF	$	3,900
10 slot screen	20 ft	x	$	20	per LF	$	393
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drums	4 each	x	$	90	each	$	358
Total for One Intermediate Well						$	13,140

Deep Monitoring Well
Assume a depth of 250 ft

Mud Drilling, 4" Dia	100 ft	x	$	47	per LF	$	4,678
Mud Drilling, 4" Dia	150 ft	x	$	51	per LF	$	7,686
2-inch Stainless Steel	160 ft	x	$	30	per LF	$	4,800
10 slot screen	90 ft	x	$	20	per LF	$	1,768
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Silica Sand	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Well Development	3 hr	x	$	160	per hr	$	480
Decon of equipment	1 day	x	$	112	per day	$	112
Drums	6 each	x	$	90	each	$	537
Total for One Deep Well						$	21,717

Misc Items

Drum disposal	36 each	x	$	120	each	$	4,320
Development/Decon Water Disposal	40000 gal	x	$	0.35	gal	$	14,000
Driller oversight	14 day	x	$	600	per day	$	8,400
Driller mobilization	1 LS	x	$	3,899	each	$	3,899
Tank Rental	2 tank (2	x	$	1,225	each	$	2,450
Well Development Equipment	2 week	x	$	236	week	$	472
Contingency	1 LS	x	$	1,000	each	$	1,000
Total misc.						$	34,541

Total Cost for 3 Intermediate and 4 Deep wells **$ 164,428**

Job No 3232-102
Project Puchack Groundwater FS
Subject Alternative 4 - Cost Backup

Prepared by: ____EDK____
Checked by: ____DGG____

Injection Well
Assume a depth of 250 ft, with 20 ft of screen

Mud Drilling, 10" Dia	100 ft	x	$	96	per LF	$	9,579
Mud Drilling, 10" Dia	150 ft	x	$	88	per LF	$	13,199
6" Stainless Steel	230 ft	x	$	95	per LF	$	21,850
6" Stainless Steel Screen	20 ft	x	$	145	per LF	$	2,900
Concrete Pad 2' x 2' x 4'	1 each	x	$	118	each	$	118
Bentonite Seal	1 each	x	$	53	each	$	53
Well Development	3 hr	x	$	160	per hr	$	480
Silica Sand Filter	20 ft	x	$	14	per lf	$	286
5' Steel protective casing	1 LS	x	$	200	each	$	200
Decon of equipment	1 day	x	$	112	per day	$	112
Drum & Disposal	12 each	x	$	210	each	$	2,520
					Total Per Well	$	41,717

Extraction Wells
Assume a depth of 150 ft, with 20 ft of screen

Mud Drilling, 10" Dia	100 ft	x	$	96	per LF	$	9,579
Mud Drilling, 10" Dia	50 ft	x	$	88	per LF	$	4,400
6" Stainless Steel	130 ft	x	$	95	per LF	$	12,350
6" Stainless Steel Screen	20 ft	x	$	145	per LF	$	2,900
Concrete Pad 2' x 2' x 4'	1 ea	x	$	118	each	$	118
Bentonite Seal	1 ea	x	$	53	each	$	53
Well Development	3 hr	x	$	160	per hr	$	480
Silica Sand Filter	90 ft	x	$	14	per lf	$	1,285
5' Steel protective casing	1 LS	x	$	200	each	$	200
Decon of equipment	1 day	x	$	112	per day	$	112
Drum & Disposal	20 each	x	$	210	each	$	4,200
					Total Per Well	$	35,677

For this scenario 2 injection wells are needed	Total	$	83,434
For this scenario 6 extraction wells are needed	Total	$	214,062
	Total I/E Wells	$	**297,495**
	Total Monitoring Wells	$	**164,428**
	Total Well Cost	$	**461,923**

Pre-Fabricated Building

Dimensions of building

Length	=	100 ft
Width	=	50 ft
Height	=	20 ft
Floor Area	=	5000 ft^2

Cost per square foot of floor area
RS Means Clear span tapered beam frame, 50 ft wide, 20' eave height

			Note:		RSMeans #
Unit cost per ft^2	=	$ 67.35	Building		13120-700-2400
Unit cost per ft^2	=	$ 4.30	Slab		18-02-0320
Cost of Building		=	$	358,250	
Foundation/driveway			$	100,000	
Total cost of pre-fab building		=	**$**	**458,250**	

Job No. 3223-102
Project Puchack Groundwater FS
Subject Alternative 4 - Cost Backup

Prepared by: EDK
Checked by: DGG

Aboveground Treatment

	Quantity	Unit Cost	Subtotal Cost	Units	RS Means
Chemical Addition/pH Adjustment					
Mixing Tank	2	$ 11,988	$ 23,976	each	19-04-0442
750 gpm transfer pump	2	$ 5,556	$ 11,112	each	33-29-0112
Aeration Tank					
Mixing tank	1	$ 11,988	$ 11,988	each	19-04-0442
750 gpm transfer pump	2	$ 5,556	$ 11,112	each	33-29-0112
Clarifier/Flocculation					
750 gpm transfer pump	2	$ 5,556	$ 11,112	each	33-29-0112
750 gpm clarifier tank	2	$ 309,090	$ 618,180	each	33-13-0408
Structural slab	8000	$ 4	$ 34,400	sf	18-02-0320
Dual Media Filter					
Electric Auto. Pressure Filter Unit	1	$ 17,449	$ 17,449	each	33-13-0104
Off Gas Treatment					
5000 CFM Radial Flow	2	$ 12,601	$ 25,202	each	33-13-1917
Sludge Dewatering					
Dewatering Mechanism	1	$ 47,825	$ 47,825	each	33-13-1105
Sludge Holding Tank					
2000 gal above ground tank	1	$ 3,241	$ 3,241	each	33-10-9658
Piping Wells to Plant					
6" PVC pipe	14900	$ 9	$ 133,951	ft	19-01-0208
Excavation Trench and Backfill for Pipe	9100	$ 20	$ 182,000	ft	610-0050
Disposal of Trench Material	9100	$ 2	$ 18,200	ft	02300-490-1100
Air Stripper					
15000 gal Sump	1	$ 13,766	$ 13,766	each	19-04-0629
Install Tower 10' dia 20' tall	2	$ 6,848	$ 13,696	each	33-13-0747
Internal Components	20	$ 5,155	$ 103,100	ft	33-13-0737
8000 cfm blowers	2	$ 3,868	$ 7,736	each	33-31-0158
Tower Packing	3500	$ 17	$ 57,750	cf	33-13-0738
Tower Shell	40	$ 1,600	$ 64,000	ft	33-13-0797
750 gpm transfer pump	2	$ 5,556	$ 11,112	each	33-29-0112
6" PVC pipe	500	$ 9	$ 4,495	ft	19-01-0208
2" PVC pipe	250	$ 4	$ 1,093	ft	19-01-0204
		Total	**$ 1,426,496**		

Pumps

Pump Costs	Rate	Number	Cost	Total
Extraction Wells	25 gpm	1	$ 2,450	$ 2,450
	150 gpm	1	$ 7,452	$ 7,452
	200 gpm	1	$ 7,452	$ 7,452
	350 gpm	1	$ 12,073	$ 12,073
	400 gpm	2	$ 12,073	$ 24,146
Injection Wells	750 gpm	2	$ 5,739	$ 11,478
			Total	**$ 65,051**

RS Means pumping @ head = 250 ft - Extraction wells
RS Means pumping @ head = 150 ft - Injection wells

No. 6 **Institutional Controls**

Filing of the necessary paperwork to secure groundwater Classification Exemption Area (CEA)

Assume 1 persons for 1 month.
Assume salary rate of $35/hour.
Assume salary multiplier of 3.

1 person x $ 35 /hour x 40 hours/week 4.2 weeks/month x 1 month x 3 multiplier

= $ 17,640
Assume: $ 17,700

No. 7 Groundwater Treatment Plant Annual Operation and Maintenance Cost

Labor Cost:				
Months of Operation	=		12	
Number of Technician	=		1	
Hours per week	=		40	
Hourly Salary of Technician	=	$	22.59	
RS Means E 33-22-0107				
Weekly Labor cost for Technician	=	$	4,066	
w/ labor multiplier of 1.5, 3 FTE				
Supervision at 20%		$	813	
Total Labor Cost	=	$	**253,731**	
Power Cost:				
Unit cost of Power per KW	=	$	0.07	
Hourly consumption of power	=		500	KW/hr
Total power consumption	=		4,380,000	KW
Total Power Cost	=	$	**306,600**	
Maintenance Cost:				
Estimated Maintenance Cost	=	$	**362,643**	/year
(for parts and supplies)		5% of capital costs		
Chemicals				
Ferrous Sulfate		$	**20,000**	/year
Coagulant		$	**20,000**	/year
Acid		$	**12,000**	/year
Sludge Disposal	292		tons @	$72/ton RS Means 33197270
	=	$	**21,024**	/year

Subtotal Operation and Maintenance Cost	$ 995,998
Contingency @ 20%	$ 199,200
Long-term Engineering Support	$ 200,000
Total Annual Operation and Maintenance Cost:	**$ 1,395,197**

Annual O&M
Assume annual monitoring on long-term basis

No. 8 **Project Plannning and Organization**
Assume 1 Project Manager @ $40 per hour for 4 hours
Assume 1 Engineer @ $30 per hour for 8 hours
Assume 1 Technician @ $20 per hour for 8 hours
Assume salary multiplier of 3

=	$	40	per hour x	4	hours x	3	multiplier +
	$	30	per hour x	8	hours x	3	multiplier +
	$	20	per hour x	8	hours x	3	multiplier
=	$	1,680	per sampling event				
Assume:	$	1,700	**per sampling event**				

No. 9 **Sampling Labor**
Assume 3 persons for 9 x 10 hour days @ $30 per hour
Assume 3 wells per day including purging and sampling
Two Sampling personnel and one Sample Management Organizer/Field Team Leader
Assume salary multiplier of 3

=	3	persons x	10	hours/day	9	days x	$ 30	/ hour x	3
	= $	24,300	**per sampling event**						

No. 10 **Sampling Equipment**
Assume sample shipping cost of $200 per day
Assume sampling equipment (e.g., bailers and pumps) @ $100 per day
Assume PPE @ $20 per person per day
Assume miscellaneous materials @ $100 per day

Shipping	$	200	*per day x*	9 days =	$	1,800
Sampling Equipment	$	300	per day x	9 days =	$	2,700
Monitoring Equipment	$	200	per day x	9 days =	$	1,800
PPE	$	60	$'20 per set	9 days =	$	540
Vehicle Rental	$	80	per day x	9 days =	$	720
Per Diem	$	120	Per person/day	27 man days =	$	3,240
Misc	$	200	per day x	9 days =	$	1,800
IDW Disposal	$	2,000	each	1 per event	$	2,000
	= $	14,600	**per sampling event**			

No. 11 **Sample Analysis and Validation**
Groundwater samples will be collected from 20 monitoring wells + 7 new wells; analyzed for chromium and natural attenuation parameters. Influent/Effluent

Total No. of Samples:	27 samples
	2 field duplicate
	2 MS
	2 MSD
	9 Field Blank
	9 Trip Blanks
	51 Total Samples Per Sampling Event

Assume	$	200	per sample for biodegradation parameters/ chromium
	$	200	Total sample cost

Analysis Cost:		51	samples x	$	200
	= $	10,200	per sampling event		

Total Analysis & Validation:	$	10,200
Assume:	$	10,200

No. 12 **Data Evaluation & Reporting (Annual Monitoring)**
Assume 2 senior engineers/chemists at $35 per hour for 80 hours per sampling event
Assume salary multiplier of 3

=		2	person x	$	35	per hour x	80	hours x	3 multiplier
	= $	16,800							

No. 13 Media Repacking/ Replacement

Air Stripper Packing Reconditioning	2 per year	$2,282 each	$4,564
Vapor Phase Carbon Replacement	2 per year	$7,500 each	$15,000

Total Regeneration cost = $ 19,564 per year

No. 14 **Five Year Review**

Assume 5-year reviews will be conducted every 5 years for 30 years.
Work includes: 5-year review of groundwater monitoring data
Preparation of report

Assume 2 person for 1 weeks
Assume salary rate of $35/hour.
assume multiplier of 3

	2 persons x	$ 35 /hour x	40 hours/week	x	4.2 weeks/month x	1 month x	3 multiplier
Total:	$ 35,280						
Assume:	**$ 35,300**						

Present Worth Calculations

Assume discount rate is 7%: 0.07

No. 16 Total Annual O&M Costs

This is a recurring cost every year for 30 years

This is a problem of the from find (P give A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 17 Media Replacement

This is a recurring cost every year for 30 years

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 18 Total Long-term Monitoring Costs

This is a recurring cost every year for 30 years

This is a problem of the form find (P given A, i, n) or (P/A,i,n)

P = Present Worth
A= Annual amount
i = interest rate
Assume 7%

Looking up the interest rate tables for i = 7% and n = 30 years
The multiplier for (P/A) = **12.409**

No. 19 Total 5-year review costs

This cost occurs every 5 years.

nedd to calculate the effective interest rate i_e
Given i = 7% (nominal interest rate) 0.07
m = # of compounding periods = 5 years 5

$i_e = (1+i)^m - 1$ 0.403 = 40% / 5 years

$$P = A^* \frac{(1+i)^n - 1}{i(1+i)^n}$$

in this case there are 6 - 5yr periods
n = 6 6
i = 0.403

The multiplier is = **2.158**