Feasibility Study

Waste Oil Dump

NASA Wallops Flight Facility

Wallops Island, Virginia

National Aeronautics and Space Administration
Goddard Space Flight Center
Wallops Flight Facility

OCTOBER 2005

CERTIFICATION

The enclosed document was prepared, and is being submitted, in accordance with the requirements of the Administrative Agreement On Consent between the United States Environmental Protection Agency and the National Aeronautics and Space Administration [U.S. EPA Docket Number RCRA-03-2004-0201TH].

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FEASIBILITY STUDY
WASTE OIL DUMP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

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LIST OF ACRONYMS AND ABBREVIATIONS

µg/kg	Microgram(s) per kilogram
µg/L	Microgram(s) per liter
ft^2	Square feet
ft^3	Cubic feet
kg	Kilogram
mg/kg	Milligram(s) per kilogram
mg/L	Milligram(s) per liter
AFCEE	Air Force Center for Environmental Excellence
ARAR	Applicable or Relevant and Appropriate Requirement
AS	Air sparging
AS/VE	Air sparging / vapor extraction
AWQC	Ambient Water Quality Criteria (USEPA's)
bgs	Below ground surface
BNP	Bimetallic Nanoscale Particle
BTEX	Benzene, toluene, ethylbenzene, and xylenes
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
CO_2	Carbon Dioxide
COC	Chemical of concern
COPC	Chemical of potential concern
CSF	Cancer Slope Factor (USEPA's)
CRQL	Contract Required Quantitation Limit
CWA	Clean Water Act
DO	Dissolved Oxygen
DPT	Direct push technology
ERA	Ecological risk assessment
FFTA	Former Fire Training Area
FOTW	Federally owned treatment works
FS	Feasibility Study
FUDS	Formerly Used Defense Site
GAC	Granular activated carbon
GSFC	Goddard Space Flight Center
GRA	General Response Action

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

HI	Hazard Index
HRC®	Hydrogen release compound
ICR	Incremental cancer risk
iSOC®	in-situ Submerged Oxygen Curtain
LDRs	Land Disposal Restrictions (USEPA's)
LUC	Land use control
MB	Main Base
MCL	Maximum Contaminant Level (USEPA's)
MCLG	MCL Goal
MNA	Monitored natural attenuation
MTBE	Methyl tert-butyl ether
NA	Not Applicable
NAAQS	National Ambient Air Quality Standards (USEPA's)
NASA	National Aeronautics and Space Administration
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	National Environmental Policy Act
NESHAPs	National Emissions Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NPW	Net present worth
NSPS	New Source Performance Standards (USEPA's)
O&M	Operation and maintenance
ORC®	Oxygen release compound
ORP	Oxidation/Reduction potential
OSHA	Occupational Safety and Health Act
OSWER	Office of Solid Waste and Emergency Response
PA	Preliminary assessment
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated biphenyl
PID	Photoionization detector
POTW	Publicly owned treatment works
PPE	Personal protection equipment
PRG	Preliminary Remediation Goal
RAO	Remedial Action Objective
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

RFA	RCRA Facility Assessment
RfD	Reference Dose (USEPA's)
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROI	Radius of Influence
SDWA	Safe Drinking Water Act
SI	Site investigation
SMCL	Secondary Maximum Contaminant Level (USEPA's)
SVOC	Semivolatile organic compound
SWDA	Solid Waste Disposal Act
SWMUs	Solid Waste Management Units
TAL	Target analyte list
TBC	To Be Considered (criterion)
TCL	Target compound list
TCLP	Toxicity Characteristic Leachate Procedure
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbon
TSDF	Treatment, storage, disposal facility
TtNUS	Tetra Tech NUS, Inc.
UCL	Upper Confidence Limit
UIC	Underground Injection Control
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VAC	Virginia Administrative Code
VADEQ	Virginia Department of Environmental Quality
VOC	Volatile organic compound
WFF	Wallops Flight Facility
WOD	Waste Oil Dump
WWTP	Wastewater treatment plant

EXECUTIVE SUMMARY

E.1 PURPOSE OF THE REPORT

The purpose of this Feasibility Study (FS) Report is to develop and evaluate options for the remediation of contaminated groundwater at the Waste Oil Dump (WOD) at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) Wallops Flight Facility (WFF) located in Accomack County, Virginia.

E.2 SITE DESCRIPTION AND HISTORY

The WOD is located at the northern end of Runway 17-35 on a peninsula-like feature adjacent to Little Mosquito Creek. The southern half of the site is basically flat, with little slope, and is grass covered. The central portion of the site slopes to the north and east, with slopes ranging from 1 to 3 percent. The northern, eastern, and western boundaries of the site are steeply sloped. These slopes direct surface water runoff into low-lying marshes that border an unnamed tributary to Little Mosquito Creek and Little Mosquito Creek. The northern portion of the site was recently clear cut of a large stand of conifer trees. Vegetation currently consists of bushes and tall grasses. Immediately to the west and southwest, the WOD is bordered by two other suspected disposal sites used by the Navy prior to NASA operations. These two sites are referred to as Debris Pile-Site 15 and Abandoned Drum Field-Site 9. Both of these sites have been designated as Formerly Used Defense Sites (FUDS) under federal programs and are under investigation by the United States Army Corps of Engineers (USACE). There are no surface water bodies within or immediately adjacent to the disposal area at the WOD. The closest body of water is a narrow, unnamed tributary to Little Mosquito Creek located about 160 feet west of the site. Approximately 300 feet of marshland to the north and east separate WOD from Little Mosquito Creek.

The WOD was reportedly used for the disposal of waste oils and possibly solvents from the 1940s through the 1950s. Reportedly, the site was used to dispose of excess waste oil that could not be used for fire training activities. No records are available to determine the types and quantities of materials disposed or the duration of this activity at the site. A review of aerial photographs from 1943 through 1994 indicated the presence of ground scarring and possible excavations in the WOD area from 1943 to 1961.

Environmental investigations began at the WOD in 1986 when the Commonwealth of Virginia conducted an inspection of the WOD and identified the presence of waste (reported as waste oils) on the surface of the site. Following further inspection and consultation, NASA conducted a removal action in the area in December 1986 including the excavation and removal of approximately 180 cubic yards of impacted soils

in four separate areas of the site. A Preliminary Assessment (PA) and Site Investigation (SI) of the WOD were conducted from 1988 through 1992. In 1997, a monitoring well (WFF15-GW7) was installed and sampled within the WOD as part of a Remedial Investigation (RI) being conducted at an adjacent site (Site 15). The analytical results from the well sample revealed the presence of volatile organic and petroleum compounds. In response to this finding, NASA conducted an inspection of the WOD and identified an area of stained soil and stressed vegetation surrounding the newly installed well. An RI was conducted at the WOD from 1998 through 2000. The RI focused on the area of stained soil and did not investigate the remaining portions of the WOD. Surface soil samples collected from within the stained area indicated the presence of elevated concentrations of polynuclear aromatic hydrocarbons (PAHs), primarily benzo(a)pyrene. Subsurface soils collected at the soil/water interface from immediately beneath the stain contained elevated concentrations of benzene, toluene, ethylbenzene, and xylene (BTEX) compounds and PAHs. Analytical results indicated BTEX, PAH, and metals contamination in the groundwater immediately beneath the stained soils.

Based on historical records and the available analytical and groundwater level results, it was concluded in the RI that past waste oil disposal activities at the WOD were the source of a limited groundwater contamination plume. Groundwater in the area occurs in an unconfined water table aquifer within the Columbia Group that is assumed to be isolated by an aquitard from the lower Yorktown Formation. A groundwater divide was interpreted to exist at the WOD, and groundwater was projected to flow in a northwesterly and northeasterly direction from the crest of the site. Groundwater measurements and subsequently projected groundwater contours indicated that the water table mimicked the ground surface topography. The groundwater plume, consisting of organic and metal contaminants, appeared to be fairly stable and located immediately beneath and/or slightly downgradient of the stained soil area.

A Supplemental RI of the WOD site was completed in 2003 to confirm the nature and extent of contamination and the human health and ecological risks associated with the contamination. The results of the Supplemental RI showed that contamination at the WOD existed in both the soil and groundwater medium, but the extent of contamination was localized and concentrated in one distinct area. The localized area of contamination, in the vicinity of monitoring well WFF15-GW7, exists beneath the stained soil area identified in the 2001 RI. Subsurface soil samples collected from the soil/groundwater interface (approximately 23 feet below the ground surface) contained elevated concentrations of some metals and many organic compounds, primarily PAHs and BTEX compounds. Relatively low levels of contamination were encountered at the surface, and the intervening soil horizons were relatively free of contamination. Similarly, soil samples and borings from upgradient and nearby areas were relatively free of contamination. The contamination pattern suggests that waste materials may have been buried at this location.

Groundwater contamination at the WOD was found to be very localized and centered in the vicinity of monitoring well WFF15-GW7. The Supplemental RI and historical sampling of this well indicated that significant metals, BTEX compounds, and PAH contamination exists at this location. In addition, a floating layer of petroleum product (0.4 foot thick) was measured in this well at the start of the Supplemental RI field activities. The presence of a free-phase product and the high concentrations of contamination detected in the dissolved phase within the groundwater indicated that the contaminant source occurs at or near the water table in the immediate vicinity of WFF15-GW7. However, the contaminated groundwater in the vicinity of well WFF15-GW7 does not appear to be migrating for significant distances from the apparent source. Available data indicate that the groundwater plume emanating from this source area migrates downward within the aquifer but attenuates rapidly in the downgradient direction. Very low concentrations of a few volatile organic compounds were detected in a downgradient deep well, and no organic compounds were detected in other downgradient shallow wells.

The baseline human health risk assessment evaluated potential carcinogenic and non-carcinogenic risks to current and future industrial workers, future construction workers and hypothetical future residents. Because the WOD is located at the end of an active runway, access to the area is heavily restricted. The residential scenario was developed as a baseline for comparison purposes in accordance with EPA guidelines. It should also be noted that for the hypothetical future resident exposure scenario it was assumed that the shallow WOD groundwater (Columbia Aquifer) would be used for residential purposes. The use of the shallow aquifer (Columbia aquifer) as a water supply is highly unlikely in that the lower Yorktown aquifer is more productive. In addition the WOD is located within a designated Groundwater Management Area. Groundwater use in the area is managed and controlled through a permit application and review process administered by DEQ, the Virginia Department of Health, and the Accomack County Health Department. These agencies operate in consultation with the Accomack-Northampton Planning District Committee and the Eastern Shore of Virginia Groundwater Committee who administer the Groundwater Supply Protection and Management Plan adopted by the county. In addition, the WOD Site is located at the end of an active airfield and current use plans for the facility indicate that maintaining the airfield is an integral part of the future mission of WFF.

The estimated noncarcinogenic risks did not exceed a hazard index (HI) of 1.0 for any target organ group for receptors potentially exposed to surface soils or total soils, including the industrial worker, construction worker, residential child, or residential adult. Similarly, noncarcinogenic risks did not exceed an HI of 1.0 for any target organic group for the construction worker potentially exposed to groundwater. Target organ group HIs greater than 1.0 were estimated for potential domestic use of the shallow groundwater by hypothetical future child and adult residents. The non-carcinogenic risk drivers included arsenic, iron, manganese, aluminum, chromium, benzene, 4-methylphenol, xylene, 1,2,4-trimethylbenzene, and naphthalene.

Carcinogenic risks were within or less than the acceptable risk range ($1x10^{-4}$ to $1x10^{-6}$) for the current and future industrial worker, future construction worker, future child resident, future adult resident, and future lifetime resident with potential exposure to surface soils and total soils. Carcinogenic risks associated with potential future construction workers exposed to groundwater were less than the acceptable risk range. The risk for hypothetical future child and adult residents exposed to groundwater for domestic purposes, slightly exceeded the acceptable risk range ($1.9x10^{-4}$ and $2.4x10^{-4}$, respectively), which resulted in an unacceptable lifetime estimated carcinogenic risk. The primary risk drivers were arsenic, benzene, tetrachloroethene, and bis(2-ethylhexyl) phthalate. The most significant risks were associated with the potential ingestion of untreated shallow groundwater and the arsenic levels detected in the groundwater. Risks associated with arsenic were the only risks greater than $1x10^{-4}$. In conclusion, unacceptable carcinogenic and noncarcinogenic risks were associated with only hypothetical future residential use of groundwater.

An ecological risk assessment (ERA) was performed to determine whether adverse ecological impacts are present as a result of exposure to contaminants released to the environment at the WOD. The habitat, contaminants present, migration pathways, and the routes that receptors may be exposed to contaminants at the WOD were defined and evaluated as part of the assessment. The WOD is a terrestrial habitat and the receptors evaluated for the terrestrial environment were plants, soil invertebrates, and herbivorous and insectivorous birds and mammals. In addition to considering the terrestrial environment, the ERA also evaluated the risks to benthic invertebrates (aquatic life) that may be exposed to contaminants that migrated from the WOD to marsh soils or sediments in the surrounding area. The contaminant concentrations, occurrence, distribution and potential effects data were evaluated to determine whether adverse effects to growth, survival, and reproduction were likely to occur in these receptors due to exposure to contaminants identified at the WOD. Overall, risks to plant, terrestrial wildlife, and terrestrial and benthic invertebrates from chemicals detected at the WOD were found to be low to negligible.

E.3 REMEDIAL ACTION OBJECTIVES AND CLEANUP GOALS

Groundwater was determined to be the only media of concern for the WOD. The Remedial Action Objectives (RAOs) identified for the WOD groundwater are as follows:

- Prevent the exposure to and use of the WOD-contaminated groundwater, which presents an unacceptable risk.

- Restore WOD-impacted groundwater to usable standards and attain cleanup goals established in this FS and the Record of Decision.

In order to be considered for implementation, a remedy must achieve these RAOs. In addition, implementation and maintenance of the remedy must have minimal impact on NASA's mission at WFF.

The chemicals of concern (COCs) for the WOD groundwater were determined to be arsenic and benzene. The cleanup goals for these WOD groundwater chemicals of concern are as follows:

Chemical of Concern [1]	Frequency of Detection	Range of Concentrations	Cleanup Goal[2]
INORGANICS (µg/L)			
Arsenic	1 / 8	21.4	10
VOCs (µg/L)			
Benzene	2 / 12	8 – 11	5

NOTES:

1 Future monitoring programs will include these COCs as well as tetrachloroethene, naphthalene, 4-methylphenol, xylene, and 1,2,4-trimethylbenzene.

2 United States Environmental Protection Agency Drinking Water Maximum Contaminant Levels (US EPA, 2004a).

E.4 SCREENING OF GENERAL RESPONSE ACTIONS, REMEDIATION TECHNOLOGIES, AND PROCESS OPTIONS

General Response Actions (GRAs) and the remediation technologies and process options associated to these GRAs were screened for effectiveness, implementability, and cost. Remediation technologies that were determined to be ineffective or too difficult to implement were eliminated from further consideration.

The following technologies and process options were retained for the WOD groundwater:

General Response Action	Technology	Process Options
No Action	None	Not Applicable
Limited Action	Monitoring	Sampling & Analysis
	Institutional Controls	Deed Restrictions/Groundwater Use Restrictions/Facility Master Plan
	Natural Attenuation	Naturally-Occurring Biodegradation and Dilution
In-situ Treatment	Biological – Biostimulation	Aerobic biological treatment Oxygen release compounds (ORC®), Bioventing, Air Diffusion
	Biological – Bioaugmentation	Aerobic biological treatment microbes, inoculum, and/or bacterium

General Response Action	Technology	Process Options
	Physical	Air Sparging (AS)

E.5 DEVELOPMENT OF REMEDIAL ALTERNATIVES

Based upon the results of the detailed screening of remediation technologies, the following remedial alternatives were developed for the WOD groundwater:

- **Alternative 1: No Action**. No action would be taken. Retained as a baseline for comparison with other alternatives.

- **Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring**. Natural attenuation would consist of allowing benzene concentrations in groundwater and the petroleum contamination in the subsurface soil at the water table to decrease through naturally-occurring processes such as biodegradation, dilution, and dispersion. The arsenic contamination is most likely associated with the reducing environment (created by the degradation of the organic contaminants) and will transform to insoluble oxidized compounds when the site returns to an oxic environment. Institutional controls would consist of preventing the use of groundwater for drinking purposes until the cleanup goals have been met. Annual site inspections would be performed to verify implementation of the institutional controls. Monitoring would consist of regularly collecting and analyzing groundwater samples both from within the contaminant plumes to assess natural attenuation and downgradient of the leading edge of the plume to evaluate potential contaminant migration.

- **Alternative 3: In-Situ Biological Treatment (Biostimulation), Institutional Controls, and Monitoring**. In-situ biostimulation treatment would consist of injecting oxygen release compound (ORC®) in the groundwater to accelerate biodegradation of benzene and the petroleum contamination in the subsurface soil at the water table. ORC® would be used to promote the aerobic biodegradation of the benzene and the petroleum contamination at the WOD. The treatment would consist of injecting approximately 5,700 pounds of ORC® through 12 direct push technology (DPT) injection points located throughout the plume. The in-situ aerobic biological treatment may also be effective in the treatment of the dissolved arsenic contamination (most likely associated with the reducing environment created by the degradation organic contaminants). In-situ aerobic treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds. Institutional controls and monitoring would be similar to those of Alternative 2.

- **Alternative 4: In-Situ Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring**. In-situ bioaugmentation treatment would consist of using SSWM/U.S. Microbics

nutrients and microbes to provide microorganisms and augment natural biodegradation processes in the contaminant plume to accelerate biodegradation of benzene and the petroleum contamination in the subsurface soil at the water table. The treatment would consist of an initial injection of microbes and nutrients through 12 DPT injection points. The arsenic contamination is most likely associated with the reducing environment (created by the degradation of the organic contaminants) and will transform to insoluble oxidized compounds when the site returns to an oxic environment. Institutional controls and monitoring would be similar to those of Alternative 2.

- **Alternative 5: In-Situ Air Sparging Treatment, Institutional Controls, and Monitoring**. In-situ AS treatment would consist of injecting air in the groundwater to promote the volatilization of benzene and the petroleum contamination in the subsurface soil at the water table. The entire contaminant plume would feature 12 sparging wells and one 150 cubic feet per minute (cfm) blower. The in-situ AS treatment may also be effective in the treatment of the dissolved arsenic contamination (most likely associated with the reducing environment created by the degradation of organic contaminants). AS treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds. Institutional controls and monitoring (without the monitoring of the natural attenuation parameters) would be similar to those of Alternative 2.

E.6 ANALYSIS OF REMEDIAL ALTERNATIVES

The remedial alternatives were analyzed in detail and compared to each other using seven of the nine criteria provided in the National Oil and Hazardous Substance Pollution Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). These seven criteria are as follows:

- Overall Protection of Human Health and the Environment,
- Compliance with Applicable or Relevant and Appropriate Requirements (ARARs) and To-Be-Considered (TBCs) guidance criteria,
- Long-term Effectiveness and Permanence,
- Reduction of Contaminant Toxicity, Mobility, or Volume through Treatment,
- Short-term Effectiveness,
- Implementability, and
- Cost.

Two other criteria, State and Community Acceptance were not evaluated in this report. They will be evaluated after regulatory and public comments are available.

The following is a summary of these comparisons:

- **Overall Protection of Human Health and Environment**

Alternative 1 would not provide protection of human health and the environment because contaminants would remain in groundwater, and potential use of groundwater for drinking purpose could result in unacceptable risk to human receptors. Also under this alternative, no warning would be provided of the potential for migration of COCs because no monitoring would occur.

The natural attenuation component of Alternative 2 would be protective of human health and the environment because it would eventually reduce the concentrations of COCs to the PRGs over a reasonable timeframe. The institutional controls component of Alternative 2 would be protective of human health and the environment as it would reduce exposure to contaminated groundwater by prohibiting use of the Columbia Aquifer for drinking purposes until the PRGs are met. The monitoring component of Alternative 2 would be protective of human health and the environment by evaluating the progress of remediation and detecting potential migration of COCs so that appropriate contingency measures can be taken.

Alternatives 3, 4, and 5 would be more protective than Alternative 2 because, in addition to the same institutional controls and monitoring components, these three alternatives would also include an active treatment component that would remove the groundwater COC benzene and the petroleum contamination in the subsurface soil at the water table. Although Alternative 5 could result in fugitive emissions, the operation of the AS system would be controlled so that the rate of these emissions would remain well under the VADEQ's allowable de minimis of 15 pounds of VOCs per day. Alternatives 3, 4, and 5 would be more protective than Alternative 2 because they would achieve complete protection in a shorter time.

- **Compliance with ARARs and TBCs**

Alternative 1 would not comply with chemical- and location-specific ARARs. Action-specific ARARs or TBCs would not apply.

Alternatives 2, 3, 4, and 5 would comply with location- and action-specific ARARs and TBCs. Alternatives 2, 3, 4, and 5 would not immediately comply with chemical-specific ARARs and TBCs, but these four alternatives would eventually achieve compliance as they attain Preliminary Remediation Goals (PRGs)

either through natural attenuation alone (Alternative 2) or through active treatment (Alternatives 3, 4, and 5). First to achieve compliance would be Alternatives 3, 4, and 5, followed by Alternative 2.

- **Long-term Effectiveness and Permanence**

Alternative 1 would have very limited long-term effectiveness and permanence because no contaminant removal or reduction would occur through treatment although, over time, some contaminant reduction would occur through natural attenuation. As there would be no institutional controls to restrict residential development or use of the Columbia Aquifer groundwater for drinking water purposes, the potential would also exist for unacceptable risk to develop due to direct exposure of human or ecological receptors to contamination. Because there would be no monitoring, potential migration of COCs would remain undetected.

Given that source control activities have been implemented, the natural attenuation component of Alternative 2 would effectively and permanently reduce concentrations of groundwater COCs to PRGs. The institutional controls component of Alternative 2 would effectively prevent the use of the Columbia Aquifer as a drinking water source until the PRGs have been achieved. The long-term monitoring component of Alternative 2 would provide an effective means of evaluating the progress of remediation and verifying that no COC migration is occurring.

Alternatives 3, 4, and 5 would be more effective than Alternative 2 because in addition to the same institutional controls and monitoring components, these three alternatives would also include an active treatment component that accelerates the removal of the VOC COC benzene and the petroleum contamination in the subsurface soil at the water table. Alternative 3, 4, and 5 would all meet the PRGs at roughly the same time. Alternatives 3 and 4 would be slightly less effective than Alternative 5 because the in-situ biological application for these alternatives would use technologies that would require treatability testing compared to AS which is a well-proven technology.

- **Reduction of Contaminant Toxicity, Mobility, or Volume through Treatment**

Alternatives 1 and 2 would not achieve any reduction of toxicity, mobility, or volume of COCs through treatment. Both alternatives would achieve reduction of contaminant toxicity and volume through natural attenuation; however, under Alternative 1, this reduction would neither be verified nor quantified. The contaminant reduction achieved through biodegradation and verified by monitoring in Alternative 2 would be irreversible.

Alternatives 3, 4, and 5 would irreversibly remove an estimated 31 pounds (less than 1 pound of soluble COCs from groundwater and 31 pounds of residual/smeared petroleum on the soil) contamination through either in-situ biological or AS treatment. Alternatives 3, 4, and 5 would generate some residues during the installation of the treatment systems and the groundwater monitoring. However, Alternatives 3, 4, and 5 would not generate treatment residues.

- **Short-term Effectiveness**

Implementation of Alternative 1 would not result in risks to site workers or adversely impact the surrounding community or environment because no remedial activities would be performed. Alternative 1 would not achieve the groundwater RAOs and although the groundwater cleanup goals might eventually be attained through natural processes, this would not be verified.

Implementation of Alternative 2 would result in a slight possibility of exposing site workers to contaminated groundwater during the installation, maintenance, and sampling of new and existing monitoring wells. However, these risks of exposure would be effectively controlled by wearing appropriate personal protective equipment (PPE) and compliance with proper site-specific health and safety procedures. Implementation of Alternative 2 would not adversely impact the surrounding community or environment. Alternative 2 would achieve the first RAO immediately upon implementation of institutional controls and monitoring. Based on the results of the modeling presented in Appendix B, the second RAO and the groundwater PRGs would be attained within an estimated 5 years at the WOD site.

Implementation of Alternatives 3, 4, or 5 would result in a significant possibility of exposing construction workers to contaminated groundwater during the construction and operation of the groundwater treatment systems and the sampling of existing wells. However, these risks of exposure would be effectively controlled by wearing appropriate PPE and compliance with proper site-specific health and safety procedures. Implementation of Alternatives 3, 4, and 5 would not adversely impact the surrounding community or environment. Alternatives 3, 4, and 5 would achieve the first RAO immediately upon implementation of institutional controls. It is estimated that the timeframes to achieve the second RAO and the groundwater PRGs at the WOD site would be 3 years for Alternatives 3, 4, and 5.

- **Implementability**

Alternative 1 would be easiest to implement because there would be no activities to implement.

The technical implementation of the natural attenuation, institutional controls, and monitoring components of Alternative 2 would be very simple. The resources, equipment, and material required for the activities associated with these components are readily available.

The technical implementation of Alternatives 3, 4, and 5 would be somewhat more difficult than that of Alternative 2 because each of these alternatives would require the installation and operation and maintenance (O&M) of a groundwater treatment system. Of these three alternatives, Alternatives 3 and 4 would be easiest to implement because it would only require the installation of small diameter injection points and the feeding of chemicals without installation of permanent equipment. However, treatability testing would have to be performed to verify the effectiveness and design parameters for the treatment injection. Alternative 5 would be technically harder to implement than Alternatives 3 and 4 because it would require construction of an AS system with numerous sparging wells, interconnecting piping, and one or more blower systems. However, the resources, equipment, and material necessary to implement these three alternatives are readily available.

Administrative implementation of the institutional controls component of Alternative 2 would be simple because Land Use Controls (LUCs) or a Facility Master Plan, including land and groundwater use restrictions, would be formulated and implemented to prevent the use of the groundwater from the shallow Columbia Aquifer at the WOD site. Administrative implementation of the monitoring component of Alternative 2 would also be simple and it would not require permits.

The administrative implementation of Alternatives 3, 4, and 5 would be slightly more difficult than that of Alternative 2. In addition to the same requirements as Alternative 2, Alternatives 3, 4, and 5 might require a construction permit for installation of DPT injection points, and Alternatives 3 and 4 would need underground injection permits for the delivery of the chemicals. Alternative 5 may also require the preparation and implementation of an erosion and sedimentation plan. However, these permits should be relatively easy to obtain. In addition, Alternative 5 would require the close coordination with and approval of NASA personnel responsible for maintaining the active runway, during the construction phase and for locating the building structure necessary for housing system components.

- **Cost**

The cost to implement (capital) and perform O&M for the remedies were estimated using current dollars. The long-term costs were discounted to provide an estimate of the net present worth (NPW) over the life-cycle of the remedy. The capital and O&M costs and the NPW of the groundwater remedial alternatives were estimated to be as follows:

Groundwater Alternatives	Capital	NPW of O&M (year)	NPW (year)
1	$0	$0	$0
2	$37,000	$187,000 (5 Years)	$224,000 (5 Years)
3	$240,000	$157,000 (5 Years)	$397,000 (5 Years)
4	$175,000	$355,000 (5 Years)	$530,000 (5 Years)
5	$307,000	$186,000 (5 Years)	$493,000 (5 Years)

The above cost figures have been rounded to the nearest $1,000 to reflect the preliminary nature of these estimates.

1.0 INTRODUCTION

This Feasibility Study (FS) report has been prepared for the Waste Oil Dump (WOD) at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) Wallops Flight Facility (WFF) located in Accomack County, Virginia (see Figures 1-1 and 1-2). The FS has been prepared by Tetra Tech NUS, Inc. (TtNUS) for NASA under Contract Task Order 012 issued by the Engineering Field Activity Northeast of the Naval Facilities Engineering Command under the Comprehensive Long-Term Environmental Action Navy contract number N62472-03-D-0057. This FS report describes the formulation and evaluation of remedial alternatives for contaminated groundwater at the WOD site. The Supplemental Remedial Investigation (RI) for this site concluded that no further action is required for the soil (TtNUS, 2004).

This report has been prepared as part of the NASA Environmental Restoration Program in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Guidance for Conducting Remedial Investigations and Feasibility Studies [United States Environmental Protection Agency (USEPA), 1988] and the Virginia Administrative Code (VAC) Hazardous Waste Management Regulations, 9 VAC 20. The FS was conducted to establish Remedial Action Objectives (RAOs) and Cleanup Goals; screen remedial technologies; and assemble, evaluate, and compare remedial alternatives. This FS focuses on the groundwater contamination that has been delineated at the WOD.

1.1 SITE DESCRIPTION AND BACKGROUND

The WOD is located at the northern end of Runway 17-35 on a peninsula-like feature adjacent to Little Mosquito Creek (see Figure 1-3). The southern half of the site is basically flat, with little slope, and is grass covered. The central portion of the site slopes to the north and east, with slopes ranging from 1 to 3 percent. The northern, eastern, and western boundaries of the site are steeply sloped. These slopes direct surface water runoff into low-lying marshes that border an unnamed tributary to Little Mosquito Creek and Little Mosquito Creek. The northern portion of the site was recently clear cut of a large stand of conifer trees. Vegetation currently consists of bushes and tall grasses. Immediately to the west and southwest, the WOD is bordered by two other suspected disposal sites used by the Navy prior to NASA operations. These two sites are referred to as Debris Pile-Site 15 and Abandoned Drum Field-Site 9. Both of these sites have been designated as Formerly Used Defense Sites (FUDS) under federal programs and are under investigation by the United States Army Corps of Engineers (USACE). There are no surface water bodies within or immediately adjacent to the disposal area at the WOD. The closest body of water is a narrow, unnamed tributary to Little Mosquito Creek located about 160 feet west of the site. Approximately 300 feet of marshland to the north and east separate WOD from Little Mosquito Creek.

The soil at the WOD is a well-drained, fine to coarse sandy loam with low organic content. Because the WOD area was built-up during the construction of the adjacent runway, it is likely that the soil at the WOD has been disturbed and reworked.

The geology immediately underlying the study area consists of the lithologic unit called the Columbia Group. Regionally, the Columbia Group is approximately 50 feet thick and is underlain by a 20 to 40 feet thick clay and silt aquitard which isolates the Columbia from the underlying Yorktown Aquifer. The geologic materials encountered at the site consist of fine-to medium-grained quartz sand with some silt, and the lithology did not differ significantly throughout the site. A sandy clay layer was consistently encountered at depths ranging from 10 to 27 feet below ground surface (bgs), or (considering the differences in site topography) at an elevation near sea level. The thickness of this clay at the WOD is reported to be as much as 5 feet. Based on the local and regional stratigraphy, this clay is not believed to represent the upper Yorktown aquitard, which at the nearby Former Fire Training Area (FFTA) was encountered at an elevation of about 25 feet below sea level (Metcalf & Eddy, Inc., 1996). It is suspected that the clay layer is a localized lens within the Columbia Group. Laterally extensive, fine-grained deposits would not be unusual for the paleoenvironmental and depositional conditions of the Columbia Group (i.e., probable channel and overbank sediments deposited in a low-relief, coastal plain setting) that existed during the Pleistocene Era.

The depth to groundwater beneath the WOD is variable and generally mimics the surface topography, which is common for shallow, unconfined aquifers. The depth to groundwater in the southern portion of the site, in areas of higher elevation, is about 23 feet bgs and decreases in depth to about 6 feet bgs at the northern edge of the open field. In the surrounding areas, adjacent to the marsh, groundwater is encountered immediately below the ground surface. The general direction of groundwater flow near the water table is also consistent with and generally mimics the surface topography. Figure 1-4 presents the March 19, 2003 groundwater contour interpretation and indicates that the WOD is basically bisected by a groundwater divide that trends north-to-northeastward through the peninsula. Groundwater to the west of the divide is indicated as flowing in a generally west to northwestward direction and toward the unnamed tributary to Little Mosquito Creek. Based on this interpretation, it was assumed that the groundwater flowing from the western side of the WOD discharges into the unnamed tributary to Little Mosquito Creek that flows through Site 15 and the wetlands adjacent to Little Mosquito Creek. Groundwater east of the divide was assumed to flow in a generally east to northeastward direction and flow toward and discharge into Little Mosquito Creek and its adjacent wetlands. Using an average horizontal hydraulic conductivity of 140 feet per day, which is based on aquifer test results performed at WFF, a measured hydraulic gradient of 0.009, and an estimated porosity of 0.25, the calculated horizontal seepage velocity in the shallow aquifer at the WOD site is approximately 5 feet per day. Vertical groundwater flow in the vicinity

of the WOD is downward in the upland areas, within the site itself, and upward in the lowland areas adjacent to the unnamed tributary to Little Mosquito Creek.

The WOD was reportedly used for the disposal of waste oils and possibly solvents from the 1940s through the 1950s (Versar, Inc., 2001). Reportedly, the site was used to dispose of excess waste oil that could not be used for fire training activities. No records are available to determine the types and quantities of materials disposed or the duration of this activity at the site.

The USACE and the USEPA have both conducted evaluations of historical aerial photographs that were used to assist in defining the nature and timeframe of the use of the WOD (USACE, 2000; USEPA, 1996a). Both studies indicate the area was heavily disturbed and reworked from the 1940's to 1960. Aerial photographic interpretations also identified areas of excavation, dark staining, and possible disposal activities occurring during this same time period.

1.2 SITE INVESTIGATIONS

The following investigations and studies have been conducted at the WOD site:

- Environmental actions began at the WOD in August 1986 when the Commonwealth of Virginia conducted an inspection of the site and identified the presence of waste (reported as waste oils) on the surface of the site. Following further inspection and consultation, NASA conducted a removal action in the area from November 12 to December 30, 1986 that included the excavation and removal of approximately 180 cubic yards of impacted soils in four separate areas of the site (Figure 1-3). No samples were collected for analysis during or after the excavations. The Commonwealth of Virginia provided NASA with a letter indicating that no further investigations were necessary regarding the potential release of petroleum products at the site (Versar, Inc., 2001).

- A preliminary assessment (PA), consisting of interviews, review of historical records, and a site walk-over, was conducted at the WOD in 1988. The PA recommended further investigation and sampling based on the potential for residual contamination and the reported disposal of solvents in the area (Ebasco Services, Inc., 1988). A site investigation (SI) of the WOD was conducted from 1989 through 1992 and included the performance of soil gas surveys, surface and subsurface soil and sediment sampling, and the installation and sampling of groundwater monitoring wells.

- Two separate soil gas surveys were conducted at the WOD. In August/September 1989, a limited soil gas survey consisting of nine sampling points spaced at 100-foot intervals was conducted. Samples were analyzed using a field instrument. One of the soil gas sample results indicated the presence of elevated concentrations of volatile organic compounds (VOCs) (Ebasco Services, Inc.,

1990). A second soil gas survey, consisting of 37 sampling points, was conducted in June 1990. Sampling points were located throughout and between the areas excavated in 1986, and the samples were analyzed using a field instrument. The results indicated a potential for minor VOC contamination in the area, and further soil and groundwater sampling was recommended (Ebasco Services, Inc., 1990).

- Additional sampling activities were conducted in 1990 and 1992. In 1990, two surface and one subsurface soil, two sediment, and two groundwater samples were collected from the WOD and analyzed for target compound list (TCL), VOCs, semi-volatile organic compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), and target analyte list (TAL) metals. In 1992, five borings were installed in and around the areas that had previously been excavated. Five samples were collected from the borings at depths varying from 1 to 15 feet bgs and analyzed for total petroleum hydrocarbon (TPH). The SI compared the 1990 and 1992 analytical results to action levels, background levels, and USEPA guidance criteria and concluded that no further action was required at the WOD (Metcalf & Eddy, Inc., 1992).

- In 1997, monitoring well WFF15-GW7 was installed in the WOD area (see Figure 1-4) as a background well for investigations being conducted at Site 15 (located west of WOD). This well was sampled in 1997 and 1998 as part of the Site 15 RI. The analytical results from these samples indicated the presence of solvent and petroleum compounds (Versar, Inc., 2001). In response to this finding, NASA conducted an inspection of the WOD and identified an area of stained soil and stressed vegetation (see Figure 1-4). The stained soil area is west of the area that was excavated in 1986, and the ground surface is stained with and contains what appears to be weathered petroleum-based materials.

- An RI was conducted at the WOD from 1998 through 2000 and included a review of historical data, the performance of a geophysical survey, the installation and sampling of temporary monitoring wells, sampling of surface and subsurface soils, and the installation and sampling of permanent monitoring wells (Versar, Inc., 2001). The geophysical survey consisted of an electromagnetic survey using an EM-31 ground conductivity meter conducted to identify the presence of buried metal and nonmetal objects. The survey indicated that the WOD did not contain large areas of buried material or a large burial area, but that two small areas of possible buried metal debris were identified. The survey findings were confirmed through the advancement of 31 soil borings throughout the area using direct push methodology. The borings were extended into the water table and ranged in depth from 12 to 30 feet bgs. Twenty-seven of these borings were converted to temporary monitoring wells and were sampled and analyzed. Based on the data collected from the temporary wells, six new permanent monitoring wells were installed in the study area (WFF16-GW1, WFF16-GW-2S, WFF16-GW2D and

WFF16-GW3 through WFF16-GW5, see Figure 1-4). Soil investigations included the collection of 21 surface soil and 4 subsurface soil samples collected from within and immediately around the area of stained soil and stressed vegetation. Surface soil samples were collected from 0 to 6 inches bgs, and subsurface samples were collected at varying depths ranging from 17 to 24 feet bgs (Versar, Inc., 2001).

- A Supplemental RI (TtNUS, 2004a) was conducted at the WOD in February and March 2003. The investigation included collecting and analyzing surface and subsurface soil samples from throughout the WOD site, collecting and analyzing surface soils from the marsh surrounding the site, installing additional monitoring wells, and sampling the new and existing monitoring wells to better define the groundwater flow and contaminant migration pathway. A total of 27 surface and subsurface soil samples were collected from the WOD site and analyzed for VOCs, SVOCs, PCBs, and TAL metals. Additionally, surface soil samples were analyzed for pH, total organic carbon (TOC), and grain size. An additional twelve surface soil samples were collected from the marsh surrounding the WOD site and analyzed for VOCs, SVOCs, PCBs, TAL metals, pH, TOC, and grain size. Three new monitoring wells were also installed at the WOD during the Supplemental RI. The purpose of the new wells was to fill data gaps to provide a more complete delineation of groundwater flow patterns (by providing additional hydraulic head data) and a more complete delineation of the nature and extent of groundwater contamination. The wells were screened across the water table to monitor for the possible presence of floating or free product. The groundwater samples collected from the new and existing wells were analyzed for VOCs plus methyl tert-butyl ether (MTBE), SVOCs, PCBs, TAL total and dissolved metals (field-filtered), and monitored natural attenuation (MNA) parameters. Field parameters [i.e., pH, temperature, dissolved oxygen (DO), oxygen reduction potential (ORP), salinity, conductivity, turbidity, alkalinity, ferrous iron, and hydrogen sulfide] were also measured in each well.

- A focused post-RI groundwater sampling event was conducted in 2004. Samples collected at the WOD site were analyzed for total chromium during the Supplemental RI. Samples collected from wells WFF16-GW1 and WFF16-GW3 contained total chromium results that were significantly higher than levels detected in other well samples and in historical samples collected from these same wells. A review of the Supplemental RI field records indicated that water levels were unusually low in wells WFF16-GW1 and WFF16-GW3 at the time of sampling, which limited the ability to adequately develop and purge the wells prior to sampling. To address the uncertainties associated with the chromium concentrations in the two wells, additional groundwater samples were collected and analyzed for total and hexavalent chromium. Monitoring wells WFF16-GW1, WFF16-GW3, and WFF16-MW3R were purged and sampled on October 5, 2004 in accordance with the Letter Work Plan (TtNUS, 2004b). All samples were analyzed for total chromium (SW-846/6010B) and hexavalent chromium (SW-846/7196A). The results of the supplemental investigation were

consistent with historical findings and total chromium results ranged from non-detect to 13.3 µg/L (TtNUS, 2004c).

1.3 SUMMARY OF INVESTIGATIONS FINDINGS

1.3.1 Nature and Extent of Soil Contamination

Analytical results for surface soil samples collected at the WOD indicated the general lack of contamination above background and human health and ecological screening levels. The highest number and concentration of contaminants, primarily polynuclear aromatic hydrocarbons (PAHs), were contained in samples collected from the stained soil area (Figure 1-4).

Subsurface soil samples identified a primary area of soil contamination located beneath and immediately upgradient of the stained area near monitoring well WFF15-GW7. The primary contaminants consisted of few metals and many organic compounds, primarily PAHs and benzene, toluene, ethylbenzene, and xylene (BTEX) components. The vertical distributions of the organic compounds within the soil [as determined by both the analytical chemistry and the photoionization detector (PID) readings measured during the Supplemental RI] are somewhat atypical. Relatively high concentrations of contamination were encountered at the water table (23 feet bgs), relatively low concentrations were encountered at the surface, and the intervening soil horizons were relatively free of contamination. Conceptually, if the contamination were introduced at or near the surface, then the highest concentrations of soil contamination (especially for the less mobile PAHs) would be expected near the surface or the shallow subsurface horizon. Even if the compounds had migrated with infiltrating precipitation to the water table over time, significant concentrations of residual contamination would be expected in the intervening subsurface soil. The presence of highly contaminated soil at the water table and the lack of contamination in the overlying soil and upgradient subsurface soils leads to the possibility that the compounds were introduced directly into the deeper horizon through excavation and disposal. Logs prepared during the installation of soil borings in this area of the site do not indicate the presence of the clay layer that is present throughout the rest of the site.

1.3.2 Nature and Extent of Groundwater Contamination

Analytical results for groundwater samples collected at the WOD are summarized in Table 1-1 and illustrated on Figure 1-5. Groundwater contamination at the WOD is very localized and is centered in the vicinity of monitoring well WFF15-GW7. The Supplemental RI and historical sampling of this well has indicated that significant concentrations of metals, BTEX compounds, and PAHs exist at this location (see Figure 1-5). In addition, a floating layer of petroleum product (0.4 feet thick) was measured in this well at the start of the Supplemental RI field activities. The presence of a free-phase product and the high

concentrations of contamination detected in the dissolved phase within the groundwater indicate that the contaminant source occurs at or near the water table in the immediate vicinity of WFF15-GW7.

The contaminated groundwater associated with well WFF15-GW7 is not migrating for significant distances from the immediate vicinity of the apparent source. Available data indicate that the groundwater plume emanating from this source area migrates downward within the aquifer but attenuates rapidly in the downgradient direction. Very low concentrations of a few VOCs and no SVOCs were detected in the downgradient deep well (WFF16-GW2D), and no significant levels of organic compounds were detected in the downgradient shallow well (WFF16-GW2S).

The presence of the low-concentration contaminant plume in the deep downgradient well, which is screened below the expected depth of the clay lens, and the absence of the plume in the shallow downgradient well, appear to confirm the observation that the clay lens is not present in the immediate vicinity of the source area (WFF15-GW7).

Contaminant concentrations in Supplemental RI groundwater samples collected from within the localized plume are within the same order of magnitude as seen in historical samples. The Supplemental RI concluded that the available data suggests that the attenuation and limited migration of the contaminant plume is related to the active biodegradation (evidenced by nearly depleted DO concentrations, elevated methane concentrations, and a reduced environment) that is occurring at the source area. In addition, it is likely that the multiple removal actions that have been conducted at the WOD have removed a significant portion of the contaminant source material and reduced the impact on the groundwater. It is also likely that based on the age of the site, many of the remaining contaminants are immobile and less likely to migrate with the groundwater.

1.3.3 Human Health Risk Assessment

A baseline human health risk assessment for the WOD site was completed as part of the Supplemental RI (TtNUS, 2004a). The human health risk assessment evaluated potential risks to current and future industrial workers, future construction workers, and hypothetical future residents. Because the WOD is located at the end of an active runway, access to the area is heavily restricted. These restrictions limit the current activities at the site to periodic mowing and maintenance functions. The future anticipated land use for the WOD is the continued use of the area as an airfield. The development of the area for other uses, especially residential purposes, is extremely unlikely. The residential scenario was developed as a baseline for comparison purposes in accordance with USEPA guidelines. It should also be noted that for the hypothetical future resident exposure scenario it was assumed that the shallow WOD groundwater (Columbia Aquifer) would be used for residential purposes. The use of the shallow aquifer

as a water supply is highly unlikely in that the lower Yorktown aquifer is more productive. In addition, the WOD is located within a designated Groundwater Management Area and groundwater use in the area is managed and controlled through a permit application and review process administered by DEQ, the Virginia Department of Health, and the Accomack County Health Department.

The results of the risk assessment are summarized in Table 1-2. Overall, the risk assessment indicated that hypothetical future residential exposure to groundwater could potentially result in adverse health effects, but no other unacceptable risks were identified for the other exposure scenarios or other media present at the WOD.

The cancer risk associated with the lifetime residential exposure to groundwater was calculated as 4.25×10^{-4}. The primary constituents in groundwater resulting in this risk include arsenic, bis(2-ethylhexyl)phthalate, benzene, and tetrachloroethene. The evaluation of the domestic use of site groundwater resulted in noncancer health hazards (hazard index [HI]) greater than 1.0 based primarily on potential exposure to chromium, arsenic, iron, aluminum, manganese, benzene, 4-methylphenol, xylene, 1,2,4-trimethylbenzene, and naphthalene in untreated drinking water.

As presented in Section 1.2, there was considerable uncertainty associated with the chromium detections. The calculated risk was based on total chromium results from two samples that did not appear to accurately characterize the groundwater at the site and it was conservatively assumed that the chromium was present as hexavalent chromium (Chromium VI). To address the uncertainties associated with the chromium concentrations, additional groundwater samples were collected and analyzed for total and hexavalent chromium. Monitoring wells WFF16-GW1, WFF16-GW3, and WFF16-MW3R were purged and sampled in accordance with the Letter Work Plan on October 5, 2004 (TtNUS, 2004b). A duplicate sample was collected from WFF16-GW3. All samples were analyzed for total chromium (SW-846/6010B) and hexavalent chromium (SW-846/7196A).

The analytical results from the supplemental investigation were validated and presented in a letter report and are summarized in Table 1-3 (TtNUS, 2004b). The samples collected from WFF16-GW1 and WFF16-MW3R contained chromium at 13.3 µg/L and 2.3 µg/L, respectively. The sample from WFF16-GW1 also contained hexavalent chromium at an estimated concentration of 12 µg/L. The results of this supplemental groundwater sampling are consistent with previous findings at the site and for these specific monitoring wells. The chromium results were compared to the health-based screening concentrations used in the risk assessment (100 µg/L, as presented in Table 1-3) and it was concluded that chromium does not present a significant risk in WOD-related groundwater and should not be considered a contributor to unacceptable risks associated with residential exposure to groundwater.

The occurrence and distribution of the groundwater contaminants that contributed significantly to the risks under a future residential groundwater use scenario and site-related and base-wide background concentrations are summarized in Table 1-4. As discussed in the Supplemental RI, there is considerable uncertainty associated with the source and/or risk attributed to most of these compounds. Arsenic was detected in one site-related monitoring well sample at a concentration of 21.4 µg/L (WOD-WFF16-GW2D). Six base-wide background samples contained arsenic, three of which contained arsenic at similarly elevated concentrations. However, a review of the base-wide background data indicates that in subsequent sampling of these wells, arsenic was either not detected or was detected at low estimated concentrations. As discussed in the Supplemental RI, it is not known if the elevated concentration of arsenic detected in the one site-related well is directly associated with waste materials handled at the WOD or if the concentration is associated with the release of arsenic from native materials as a result of the reduced environment created by the degradation of other WOD waste-related contaminants. Arsenic has been found to be present in some refined petroleum products and waste oils and these materials may have been handled at the WOD. However, the extent of the arsenic present at the WOD site is not widespread and is found at only one well (WFF16-GW2D). The groundwater in this well exhibits highly reduced conditions [indicated by the low ORP of -51 mV (see the Supplemental RI)]. Subsurface soil samples from the area indicated the elevated presence of petroleum compounds, but arsenic concentrations were not elevated in these samples or other site samples above base-wide background levels. The low frequency and the groundwater conditions at the location where arsenic was detected in WOD-related groundwater suggest an uncertainty as to the source of the arsenic.

The chemical bis(2-ethylhexyl) phthalate was detected in three site groundwater samples at concentrations of 2, 4, and 18 µg/L. However, bis(2-ethylhexyl) phthalate was not detected in a duplicate sample collected from the well that was reported to contain 18 µg/L, and the 2 and 4 µg/L concentrations were reported as estimated values (J) less than the quantitation limit. This phthalate is a common laboratory contaminant and although its reported presence could not be discounted during data validation, its presence as a site-related contaminant is questionable.

Tetrachloroethene, 4-methylphenol, xylene, and naphthalene were each detected only once in WOD groundwater samples. A single low-concentration detection of these compounds does not constitute a plume and the calculated risk based on the single detections results in an overestimation of actual site risks.

Iron, a naturally occurring element, was detected in all of the site and background samples. Supplemental RI site-related groundwater samples contained iron at concentrations ranging from 50.6 µg/L to 49,900 µg/L. Base-wide groundwater samples contained iron at concentrations ranging from 452 µg/L to 50,000 µg/L. A qualitative review of the site and background data suggests that site

concentrations of iron are not greater than base-wide background concentrations and the calculated risk associated with iron may not be site related. Similarly, aluminum was detected in all site-related groundwater samples at concentrations (831J to 8,220 µg/L) that are within the range of detections reported for base-wide background samples (5,460 to 59,200 µg/L).

Arsenic was detected in only the deep monitoring (WFF16-GW2D) well located immediately downgradient of the source area. As discussed above, data indicate that groundwater conditions in this area reflect a highly reducing environment. Because of the reducing conditions in this area, it is not known if the presence of arsenic in this single sample is indicative of a waste constituent or if the reducing environment has enhanced the dissolution of arsenic from the geologic materials. Tetrachloroethene was also detected in only one monitoring well, WFF15-GW7. The concentration of tetrachloroethene (5 µg/L) in the single sample was equal to the MCL for tetrachloroethene. Benzene was detected in only these same two wells (WFF16-GW2D and WFF15-GW7) located in the source area. Both detections exceeded the MCL for benzene (5 µg/L). Floating petroleum product was present at monitoring well WFF15-GW7 and the sample from this well showed the highest number and levels of contamination at the WOD.

1.3.4 Ecological Risk Assessment

An ecological risk assessment (ERA) was performed to determine whether adverse ecological impacts are present as a result of exposure to contaminants released to the environment at the WOD. The habitat, contaminants present, migration pathways, and the routes that receptors may be exposed to contaminants at the WOD were defined and evaluated as part of the assessment. The WOD is a terrestrial habitat and the receptors evaluated for the terrestrial environment were plants, soil invertebrates, and herbivorous and insectivorous birds and mammals. In addition to considering the terrestrial environment, the ERA also evaluated the risks to benthic invertebrates (aquatic life) that may be exposed to contaminants that migrated from the WOD to marsh soils or sediments in the surrounding area. The contaminant concentrations, occurrence, distribution and potential effects data were evaluated to determine whether adverse effects to growth, survival, and reproduction were likely to occur in these receptors due to exposure to contaminants identified at the WOD. Overall, risks to plant, terrestrial wildlife, and terrestrial and benthic invertebrates from chemicals detected at the WOD were found to be low to negligible (TtNUS, 2004a).

1.4 DOCUMENT ORGANIZATION

This FS Report has been organized with the intent of meeting the general format requirements specified in the RI/FS Guidance Document (USEPA, 1988). This report features the following five sections:

- Section 1.0, Introduction, summarizes the purpose of the report, provides site background information, summarizes findings of the RI, and provides the report outline.

- Section 2.0, RAOs and General Response Actions (GRAs), presents the RAO, identifies Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) criteria, develops cleanup goals and associated GRAs, and provides an estimate of the volume of contaminated media to be remediated.

- Section 3.0, Screening of Remediation Technologies and Process Options, provides a two-tiered screening of potentially applicable groundwater remediation technologies and identifies the technologies that will be assembled into remedial alternatives.

- Section 4.0, Assembly and Detailed Analysis of Remedial Alternatives, assembles the remedial technologies retained from the Section 3.0 screening process into multiple groundwater remedial alternatives, describes these alternatives, and performs a detailed analysis of these alternatives in accordance with seven CERCLA criteria.

- Section 5.0, Comparative Analysis of Remedial Alternatives, compares the groundwater remedial alternatives on a criterion-by-criterion basis, for each of the seven CERCLA analysis criteria used in Section 4.

2.0 REMEDIAL ACTION OBJECTIVES AND GENERAL RESPONSE ACTIONS

This section identifies the media of concern and develops RAOs and derives cleanup or remediation goals for the contaminated media. The regulatory requirements and guidances that may potentially govern remedial activities are presented in this section. In addition, this section presents GRAs that may be suitable to achieve the cleanup goals. Finally, this section presents an estimate of the volumes of contaminated media.

2.1 MEDIA OF CONCERN

Groundwater associated with the WOD site is contaminated with VOCs, SVOCs, and metals (see Section 1). The nature and extent of the contamination, as summarized in Section 1 and presented in the Supplemental RI report (TtNUS, 2004a), have been defined. The level of contamination in groundwater exceeds human health-based benchmarks and presents an unacceptable risk to future potential residential groundwater users.

The Supplemental RI investigated and evaluated contaminant concentrations in surface and subsurface soils at the WOD. Based on the Supplemental RI findings, the concentration of contamination detected in WOD soil at depths of less than 15 feet bgs does not present an unacceptable risk to human health. However, petroleum contamination was identified in the subsurface soil at the water table (approximately 23 feet bgs) and it is likely that this soil contamination is contributing to the groundwater contamination.

The ecological risk assessment conducted as part of the Supplemental RI concluded that risks to the environment from contaminants identified in WOD groundwater and soil were low to negligible and similar to background concentrations.

Based on this information, groundwater is the only medium of concern. The petroleum contamination in the subsurface soil at the water table will be addressed by the actions taken for the contaminated groundwater.

2.2 REMEDIAL ACTION OBJECTIVES

The purpose of this section is to develop RAOs for the WOD site at NASA's WFF in Accomack County, Virginia. Development of RAOs is an important step in the FS process. The RAOs are medium-specific goals that define the objective of conducting remedial actions to protect human health and the environment.

The development of cleanup goals and GRAs to attain the RAOs takes into consideration Federal and state laws that are considered to be ARARs as well as other Federal and state guidelines and criteria TBCs. Section 2.2.1 presents the RAOs, Section 2.2.2 identifies the ARARs and TBCs, and Section 2.2.3 identifies the chemicals of concern (COCs) for remediation.

2.2.1 Statement of Remedial Action Objectives

This FS addresses the groundwater contamination at the WOD site. Contaminated groundwater attributable to the WOD site presents an unacceptable human health risk to potential future residential users. To protect the public from potential current and future health risks, the following RAOs have been developed:

- Prevent the exposure to and use of the WOD-contaminated groundwater, which presents an unacceptable risk.

- Restore WOD-impacted groundwater to usable standards and attain cleanup goals established in this FS.

In addition to these RAOs, remedial actions must also have minimal impact on NASA's ability to perform its mission at WFF.

2.2.2 Applicable or Relevant and Appropriate Requirements and To Be Considered Criteria

ARARs consist of the following:

- Any standard, requirement, criterion, or limitation under Federal environmental law.

- Any promulgated standard, requirement, criteria, or limitation under a state environmental or facility-siting law that is more stringent than the associated Federal standard, requirement, criterion, or limitation.

TBCs are nonpromulgated, nonenforceable guidelines or criteria that may be useful for developing a remedial action or are necessary for determining what is protective to human health and/or the environment. Examples of TBCs include USEPA Drinking Water Health Advisories, Reference Doses (RfDs), and Cancer Slope Factors (CSFs).

One of the primary concerns during the development of remedial action alternatives for hazardous waste sites under CERCLA is the degree of human health and environmental protection offered by a given remedy. Section 121 of CERCLA requires that primary consideration be given to remedial alternatives that attain or exceed ARARs. The purpose of this requirement is to make CERCLA response actions consistent with other pertinent Federal and state environmental requirements.

2.2.2.1 Definitions

The definitions of ARARs are given below:

- Applicable Requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site.

- Relevant and Appropriate Requirements are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law, while not "applicable" to a hazardous substance, pollutant, contaminant, or remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site.

- TBCs are a category created by the USEPA that includes non-promulgated criteria, advisories, and guidance issued by Federal or state government that are not legally binding and do not have the status of potential ARARs. However, pertinent TBCs will be considered along with the ARARs in determining the necessary level of cleanup or technology requirements.

Under CERCLA Section 121(d)(4), the USEPA may waive compliance with an ARAR if one of the following conditions can be demonstrated:

- The remedial action selected is only part of a total remedial action that will attain the ARAR level or standard of control upon completion;

- Compliance with the requirement will result in greater risk to human health and the environment than other alternatives;

- Compliance with the requirement is technically impracticable from an engineering perspective;

- The remedial action selected will attain a standard of performance that is equivalent to that required by the ARAR through the use of another method or approach;

- With respect to a state requirement, the state has not consistently applied the ARAR in similar circumstances at other remedial actions within the state; or

- Compliance with the ARAR will not provide a balance between protecting public health, welfare, and the environment at the facility with the availability of Superfund money for response at other facilities (fund-balancing). This condition only applies to Superfund-financed actions.

The National Oil and Hazardous Substance Pollution Contingency Plan (NCP) has identified three categories of ARARs [40 Code of Federal Regulations (CFR) Section 300.400 (g)]:

- Chemical-Specific: Health-risk-based numerical values or methodologies that establish concentration or discharge limits for particular contaminants. Examples include Maximum Contaminant Levels (MCLs) and Clean Water Act (CWA) Ambient Water Quality Criteria (AWQC).

- Location-Specific: Restrictions on actions or contaminant concentrations in certain environmentally sensitive areas. Examples of these areas regulated under various Federal laws include floodplains, wetlands, and locations where endangered species or historically significant cultural resources are present.

- Action-Specific: Technology- or activity-based requirements, limitations on actions, or conditions involving special substances. Examples of action-specific ARARs include wastewater discharge standards.

The following section discusses contaminant- and location-specific ARARs and TBCs. Action-specific ARARs and TBCs are presented in Section 2.3 along with the discussion of GRAs.

2.2.2.2 Chemical-Specific ARARs and TBCs

Tables 2-1 and 2-2 present summaries of Federal and State of Virginia chemical-specific ARARs and TBCs for this FS. These ARARs and TBCs provide some medium-specific guidance on “acceptable” or “permissible” concentrations of contaminants. These ARARs and TBCs are discussed below.

FEDERAL

The Safe Drinking Water Act (SDWA) promulgated National Primary Drinking Water Standard MCLs (40 CFR Part 141). MCLs are enforceable standards for contaminants in public drinking water supply systems. They consider not only health factors but also the economic and technical feasibility of removing a contaminant from a water supply system. Secondary MCLs (SMCLs) (40 CFR Part 143) are not enforceable but are intended as guidelines for contaminants that may adversely affect the aesthetic quality of drinking water, such as taste, odor, color, and appearance, and may deter public acceptance of drinking water provided by public water systems.

The SDWA also established MCL Goals (MCLGs) for several organic and inorganic compounds in drinking water. MCLGs are set at concentrations of no known or anticipated adverse health effects, with an adequate margin of safety. The NCP [40 CFR Part 300.430(e)(2)(i)] states that MCLGs that are set at concentrations above zero shall be attained by remedial actions for groundwater or surface water that are current or potential sources of drinking water [where the MCLGs are relevant and appropriate under the circumstances of the release based on the factors in Section 300.400(g)(2) of the NCP]. If an MCLG is found not to be relevant and appropriate, the corresponding MCL shall be achieved where relevant and appropriate to the circumstances of the release. For MCLGs that are set at zero, the MCL promulgated for that contaminant under the SDWA shall be attained by the remedial actions. In cases involving multiple contaminants or pathways where attainment of chemical-specific ARARs will result in a cumulative cancer risk in excess of 10^{-4}, criteria in paragraph (e)(2)(i)(A) of Section 300.430 (i.e., risk-based criteria) may be considered when determining the clean-up level to be attained. The NCP explains that clean-up levels set at zero (generally the case for carcinogens) are not appropriate because CERCLA does not require complete elimination of risk and because "true zero" cannot be detected. SDWA requirements may be relevant and appropriate to remedial actions involving groundwater.

USEPA Health Advisories are nonenforceable guidelines (TBCs) developed by the USEPA Office of Drinking Water for chemicals that may be intermittently encountered in public water supply systems. Health advisories are available for short-term, longer-term, and lifetime exposures for a 10-kilogram child and/or a 70-kilogram adult. Health advisories may be pertinent for remedial actions involving groundwater, especially for contaminants that are not regulated under the SDWA.

Cancer Slope Factors (CSFs) are used for estimating the lifetime probability (assumed 70-year lifespan) of human receptors contracting cancer as a result of exposure to known or suspected carcinogens. These factors are generally reported in units of kg-day/mg and are derived through an assumed low-dosage linear relationship and an extrapolation from high to low dose responses determined from human or animal studies. Cancer risk and CSFs are most commonly estimated through the use of a

linearized multistage mathematical extrapolation model applied to animal bioassay results. The value used in reporting the slope factor is the upper 95 percent confidence limit. CSFs are TBCs for WOD groundwater.

Reference Dose (RfD), as defined in the USEPA Integrated Risk Information System, is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. RfDs are developed for chronic and/or subchronic human exposure to hazardous chemicals and are based on the assumption that thresholds exist for certain toxic effects. The RfD is usually expressed as an acceptable dose (mg) per unit body weight (kg) per unit time (day). The RfD is derived by dividing the no-observed-adverse effect level or the lowest-observed-adverse effect level by an uncertainty factor times a modifying factor. The use of uncertainty factors and modifying factors is discussed in the USEPA Office of Research and Development Health Effects and Summary Tables (USEPA, 1997). RfDs are TBCs for WOD groundwater.

The Clean Water Act (CWA) sets USEPA AWQCs that are non-enforceable guidelines developed for pollutants in surface waters pursuant to Section 304(a)(1) of the CWA. Although AWQCs are not legally enforceable, they have been used by many states to develop enforceable water quality standards; they should be considered as potential ARARs, as specified by CERCLA. AWQCs are available for the protection of human health from exposure to contaminants in surface water as well as from ingestion of aquatic biota and for the protection of freshwater and saltwater aquatic life. AWQCs may be considered for actions that involve groundwater treatment and/or discharge to nearby surface waters and may be used as a basis for determining cleanup goals in the absence of State water quality standards.

STATE

Virginia Surface Water Antidegradation Policy (9 VAC 25-260-30) has been established to protect surface waters from activities that have the potential to impact existing surface water quality. This policy establishes, at a minimum, that existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected. This policy does not address specific contaminant levels but is potentially relevant and appropriate for a remedial action that includes discharge of extracted groundwater.

Virginia Numerical Criteria for Dissolved Oxygen, pH, and Maximum Temperature (9 VAC 25-260-50) establishes minimum, daily averages, and maximum numeric criteria for various Classes of surface water. These criteria have been established to protect surface water conditions and are also used to calculate

loading and are used to establish limits for discharges to surface water. These criteria may be applicable for a remedial action that includes discharge of extracted groundwater.

Virginia Criteria for Surface Water (9 VAC 25-260-140) have been established for pollutants in surface water. Instream water conditions shall not be acutely or chronically toxic, except as allowed in mixing zones. Standards are available for freshwater and saltwater aquatic life and human health (both from drinking water and fish consumption and only fish consumption). These criteria are also used to calculate waste load allocations that are used to establish limits for discharges to surface water. These criteria can be used to determine groundwater remediation goals that are protective of surface water. These criteria may be applicable for remedial action that includes discharge of extracted groundwater.

Virginia Groundwater Standards (9 VAC 25-280, Part IV) contain standards that apply statewide and by physiographic province. The standards apply to the groundwater occurring at or below the uppermost seasonal limits of the water table. The NASA WFF is on the eastern shore of the Delmarva Peninsula in the Atlantic Coastal Plain Physiographic Province. The standards may be applicable for developing groundwater remediation goals.

Virginia Water Quality Criteria for Groundwater (9 VAC 25-280, Part V) contain criteria that apply primarily to constituents that occur naturally by physiographic province. Since natural groundwater quality can vary greatly from area to area for these constituents, enforceable standards were not adopted. These criteria are intended to provide guidance in preventing groundwater pollution and are not mandatory. The groundwater quality criteria may be TBC criteria for developing remediation goals for groundwater.

Virginia Voluntary Remediation Regulations, Remediation Levels (9 VAC 20-160) are applicable for sites that are not being remediated under CERCLA, the Virginia Waste Management Act, or the Virginia State Water Control Law. The remediation levels include general and tier-based criteria. For a site with carcinogenic contaminants, the remediation goal for individual carcinogenic contaminants shall be an incremental upper-bound lifetime cancer risk of $1x10^{-6}$. The remediation levels for the site shall not result in an incremental upper-bound lifetime cancer risk exceeding $1x10^{-4}$ considering multiple contaminants and multiple exposure pathways, unless the use of a SDWA MCL results in a cumulative risk of greater than $1x10^{-4}$. For noncarcinogens, the HI shall not exceed a combined value of 1.0. For unrestricted future use, where a contaminant of concern has an MCL, the MCL for that contaminant shall be the remediation level. For unrestricted use, where a contaminant of concern exists for which a surface water quality standard has been adopted, the concentration in other media shall not result in a concentration that exceeds the water quality standard in adjacent surface water bodies. If the concentration of a contaminant is below the Practical Quantitation Limit, the Practical Quantitation Limit may be considered as the remediation level. Tier-based criteria may be based on background levels, MCLs, RBCs, and/or a

site-specific risk assessment conducted in accordance with CERCLA guidance. The voluntary remediation levels may be relevant and appropriate for developing remediation goals for groundwater.

Virginia Department of Health Waterworks Regulations (12 VAC 5-590-10) contain both MCLs and SMCLs. Cleanup levels for potential drinking water sources are typically based on MCLs or SMCLs if these are enforceable requirements. In the absence of MCLs/SMCLs, other health-based standards or criteria, or best professional judgment based on risk assessment, may be employed. The standards may be applicable for developing groundwater remediation goals.

2.2.2.3 Location-Specific ARARs and TBCs

Tables 2-3 and 2-4 present a summary of Federal and State of Virginia location-specific ARARs and TBCs for this FS. This section presents a summary of Federal and state location-specific ARARs and TBCs. These ARARs and TBCs place restrictions on concentrations of contaminants or the conduct of activities based upon the site's particular characteristics or location.

FEDERAL

The Endangered Species Act of 1973 provides for consideration of the impacts on endangered and threatened species and their critical habitats. This act requires federal agencies, in consultation with the Secretary of the Interior, to make sure that any action authorized, funded, or carried out by the agency is not likely to jeopardize the continued existence of any endangered or threatened species or adversely affect its critical habitat. A review of the available information indicates that no state or federally listed endangered or threatened species are known to permanently or seasonally reside in the vicinity of the WOD site. For this reason, the Endangered Species Act would not be applicable or relevant and appropriate to actions taken at the site.

The Archaeological and Historic Preservation Act (36 CFR Part 62 and 65) establishes requirements relating to potential loss or destruction of significant scientific, historical, or archaeological data as a result of any proposed remedy. The Act also requires Federal agencies to consider the existence and location of landmarks on the National Registry of Natural Landmarks to avoid undesirable impacts on such landmarks. The Secretary of the Interior must be notified if a federal agency finds that its activities, in connection with any federal construction project, might cause loss or destruction of such data. The land surrounding the WOD site is not classified as a potential significant scientific, historical, archaeological, or Natural Landmark. For this reason, the Archaeological and Historic Preservation Act is not applicable or relevant and appropriate to actions taken at the site.

The Fish and Wildlife Coordination Act (33 CFR Subsection 320.3) was enacted to protect fish and wildlife when federal actions result in the control or structural modification of a natural stream or body of water. The types of actions that would fall under the jurisdiction of this act include (1) discharges of pollutants including industrial, mining, and municipal wastes or dredge and fill material into a body of water or wetlands and (2) projects involving construction of dams, levees, impoundments, stream relocation, and water diversion structures. This act requires the federal agency to consult with the United States Fish and Wildlife Service (USFWS) or National Marine Fisheries Service and appropriate state agencies if the above actions would occur as a result of off-site remedial alternatives.

Federal Protection of Wetlands Executive Order (E.O. 11990) and National Environmental Policy Act (NEPA) Regulations 40 CFR 6.302 [a] requires federal agencies, in carrying out their responsibilities, to take action to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands. According to the published definition of national wetlands, Federal Register 40 CFR Appendix C, wetlands are present at WFF and along its boundaries. Because wetlands exist nearby the WOD, this ARAR has been retained in the event that wetland areas may be affected.

Federal Floodplain Management Executive Order (E.O. 11988) and NEPA Regulations 40 CFR 6 provides consideration of floodplains during remedial actions. E.O. 11988 requires federal agencies to avoid long-term and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid support of floodplain development wherever there is a practicable alternative. If no practicable alternative exists to performing cleanup in a floodplain, potential harm must be mitigated and actions taken to preserve the natural and beneficial values of the floodplain. 40 CFR 6 Appendix A contains USEPA policy for implementing the provisions of E.O. 11988. If the treatment system associated with remedial alternatives is constructed, it would be located outside the floodplain.

The Fish and Wildlife Coordination Act (40 CFR Section 6.302) provides for consideration of the impacts on wetlands and protected habitats. The act requires that federal agencies, before issuing a permit or undertaking federal action for the modification of any body of water, consult with the appropriate state agency exercising jurisdiction over wildlife resources to conserve those resources. Consultation with the USFWS is also required. This ARAR has been retained in the event that wetland areas or wildlife resources may be affected.

STATE

Wetlands Mitigation Compensation Policy (4 VAC 20-390-10) regulates activities in wetlands. An activity that impacts a wetland is required to meet the provisions of this act. Wetlands of primary ecological

significance must not be altered so that ecological systems in the wetland are unreasonably disturbed. Anticipated public and private benefit resulting from the activities occurring in a wetland should exceed the public and private detriment. Wetlands are present at WFF and adjacent to the WOD boundaries. This ARAR has been retained in the event that wetland areas may be affected. Remedial actions for groundwater would not be expected to adversely affect wetlands.

Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10) establishes criteria for use by local governments in granting, denying or modifying requests to rezone, subdivide, or to use and develop land in Chesapeake Bay Preservation Areas. The purpose of the criteria is to protect and improve the water quality of the Chesapeake Bay, its tributaries, and other state waters by minimizing the effects of human activity upon these waters and implementing the Act. The location of the WOD site is along the Atlantic Ocean coast line which is not part of the Chesapeake Bay. These regulations are not applicable or relevant and appropriate to the site.

Virginia Natural Areas Preserves Act (Virginia Code §§ 10.1-209) dedicates sites or portions of sites as natural area preserves through the Department of Conservation and Recreation. Dedication under the Act may restrict certain uses of preserve areas. If no such dedication exists, the Act's provisions regarding natural heritage preservation should be classified as TBC. Since the site has not been dedicated as a preserve area, this regulation is not applicable or relevant and appropriate to the site and the Act's provisions should be classified as TBC.

Virginia Endangered Species Act (4 VAC 15-20-130) provides for the consideration of the impacts on endangered and threatened species and their critical habitats. A review of the available information indicates that no state or federally listed endangered or threatened species are known to permanently or seasonally reside in the vicinity of the WOD site. For this reason, this Act would not be applicable or relevant and appropriate to actions taken at the site.

Virginia Endangered Plant and Insect Species Act (2 VAC 5-320-10) prohibit the taking of endangered plant and insect species. A review of the available information indicates that no state listed endangered or threatened species are known to permanently or seasonally reside in the vicinity of the WOD site. For this reason, this Act is not applicable or relevant and appropriate to actions taken at the site.

Virginia Private Well Regulations (12 VAC 5-630) contain standards and prohibitions on groundwater wells. Private wells are prohibited if a source of contamination could adversely affect the well and preventive measures are not available to protect the groundwater. Wells would not be permitted at the WOD site until the groundwater has been remediated and is no longer a source of groundwater contamination.

2.2.3 Chemicals of Concern for Remediation

The Supplemental RI human health risk assessment identified potential unacceptable risks for future residential use of WOD-related groundwater. Section 1 summarizes the results of the risk assessment, identifies the contaminants that contributed to the unacceptable risk, and discusses some of the uncertainties associated with the risk assessment. This section further reviews the WOD-related contaminants, considers the ARARs discussed above, and identifies the COCs that require remediation in WOD-related groundwater. Table 2-5 presents a listing of the contaminants identified as contributing to the WOD groundwater risks, and provides a summary of the primary chemical-specific and location-specific ARARs and TBCs that apply in determining the COCs.

Arsenic was detected in one site-related monitoring well sample at a concentration of 21.4 µg/ (WOD-WFF16-GW2D). This concentration exceeds the MCL for arsenic which is 10 µg/L. As indicated in Section 1, there is uncertainty associated with the source of the arsenic detected in this single sample. The monitoring well sample that contained arsenic also exhibited highly reduced conditions and was collected immediately downgradient of the area that contains the highest level of WOD waste-related organic contamination at the site. As discussed in the Supplemental RI, it is not known if the elevated concentration of arsenic detected in the site-related well is directly associated with waste materials or if the concentration is associated with the release of arsenic from native materials as a result of the reduced environment created by the degradation of other WOD waste-related contaminants. Because the arsenic in the groundwater may be related to site activities it will be retained as a COC for the WOD. The MCL should be considered for establishing the Preliminary Remediation Goal (PRG).

The chemical bis(2-ethylhexyl) phthalate, a common laboratory contaminant, was detected in three site groundwater samples at concentrations of 2J, 4J, and 18 µg/L. The MCL for bis(2-ethylhexyl) phthalate is 6 µg/L. However, as presented in Section 1, bis(2-ethylhexyl) phthalate was not detected in a duplicate sample collected from the well that was reported to contain 18 µg/L, and the other estimated detections were reported as estimated values less than the quantitation limit and the MCL. The poor match in duplicate sample results, the distribution and low-level of the reported concentrations of bis(2-ethylhexyl) phthalate, and the fact that bis(2-ethylhexyl) phthalate is a common laboratory contaminant, do not suggest that its presence is related to waste-handling activities at the site. Based on this evaluation, bis(2-ethylhexyl) phthalate will not be retained as a COC and no PRG will be established for it.

Benzene was detected in two site wells and both detections were at concentrations greater than the MCL (5 µg/L). The monitoring wells that contained benzene (WFF15-GW7 and WFF16-GW2D) have historically shown the highest concentrations of contamination and are located within the area identified as exhibiting evidence of waste disposal. Benzene is a known component of the waste materials handled

at the WOD, and historical and current data indicate that benzene has been released from the WOD. Benzene should be retained as a COC and the MCL should be considered as the PRG for it.

Tetrachloroethene was identified as a contributor to the lifetime incremental cancer risk but was detected in only one sample and at a concentration equal to the MCL of 5 µg/L. No other groundwater sample, including samples collected immediately downgradient of the detection, contained tetrachloroethene. Because one detection does not constitute a plume and because the single detection is at the MCL, no remedial action should be required for this compound. Therefore, tetrachloroethene is not retained as a COC and no PRG is proposed for it. However, because tetrachloroethene was detected at the MCL in a sample from the well exhibiting the highest levels of other contamination, future monitoring programs should include this compound to evaluate its potential impact on achieving the RAOs.

Iron, a naturally occurring element, was detected in all of the site and background samples. The secondary MCL for iron is 300 µg/L. Eleven of the twelve Supplemental RI site-related groundwater samples contained iron at concentrations greater than the secondary MCL (516 µg/L to 49,900 µg/L). This distribution and occurrence of iron is similar to that detected in base-wide background groundwater samples where eleven of twelve samples contained iron at concentrations ranging from 452 µg/L to 55,000 µg/L. Iron is not typically associated with the materials handled at the WOD site. Because iron contamination does not appear to be directly related to waste materials handled at the WOD and because addressing site iron concentrations will not reduce the overall risk presented by iron (due to background concentrations), iron is not retained as a COC and no PRG is proposed for it.

Aluminum was identified as contributing to a potential target organ (central nervous system) HI of 2.9 for a child resident. This HI is marginally greater then the target HI of 1, and aluminum was responsible for 0.7 of the total value. The secondary MCL range for aluminum, established to control odor, taste and staining, is 50 µg/L to 200 µg/L. Aluminum, which is not typically associated with the materials handled at the WOD, was detected in all site-related and site background samples over the recommended secondary MCL. In addition, similar concentrations of aluminum (ranging from 56.3 to 59,200 µg/L) have been detected in 16 of the 17 base-wide background wells. Because all site-related detections of aluminum are within the range of background groundwater concentrations, aluminum will not be retained as a COC and no PRG will be proposed for it.

Similar to aluminum, manganese was identified as contributing to a potential target organ HI of 2.9 for a child resident. This HI is marginally greater than the target HI of 1, and manganese was responsible for 1.8 of the total value. The secondary MCL for manganese, established to control odor, taste and staining, is 50 µg/L. Manganese is not typically associated with the materials handled at the WOD and is a naturally occurring element. It was detected in all site and background samples. Manganese was

detected in four of the site samples (97.1 and 641 µg/L) and eight of base-wide background samples (57 to 3,110 µg/L) at concentrations greater than the secondary MCL. The elevated manganese concentrations detected at the site appear to be associated with anaerobic conditions, which are conducive to the dissolution of manganese from subsurface soils/materials. Although field measurements of general water quality conditions were not available for the majority of the base-wide background samples, they were available for the Supplemental RI site samples. The site wells that contained the highest concentrations of manganese (WFF15-GW1, WFF15-GW7 and WFF16-GW7) exhibited reduced oxygen concentrations (0.68 to 0.79 mg/L). The reduced oxygen in these wells can be attributed to their location or the possible influence of the degradation of site-related contamination. Well WFF16-GW7 and WFF15-GW1, which contained 310 µg/L and 220 µg/L of manganese, respectively, are located in a marshy environment that typically exhibits low DO concentrations due to the degradation of natural materials. Well WFF15-GW7, which contained manganese at 641 µg/L, is located within the disposal area and contained the highest concentrations of petroleum-related compounds and the highest detections of risk-related organic compounds. The active degradation of these compounds may be responsible for the lower DO concentrations found in this well. Manganese concentrations in the disposal area should decrease as the other site-related contamination further degrades and the environment returns to less reductive conditions. However, because of the marsh environment and the degradation of naturally occurring materials, the concentration to which manganese will decrease is unknown and may not be related to the site contaminants. Because manganese is not believed to be a component of the contaminants released at the WOD, because concentrations in the disposal area are anticipated to reduce as other site-related contaminants degrade, and because any action taken to address manganese in this area will not reduce the risk posed by background concentrations, manganese is not retained as a COC and no PRG for manganese is proposed.

4-Methylphenol, detected in one site sample (42 µg/L), was also identified as contributing to a potential target organ HI of 2.9 for a child resident. This HI is marginally greater than the target HI of 1, and 4-methylphenol was responsible for 0.4 of the total value. There is no MCL for 4-methylphenol. The sample that contained 4-methylphenol did not contain any other site-related actionable levels of contaminants. The single detection of 4-methylphenol does not indicate the presence of a plume. Therefore, 4-methylpenol will not be retained as a COC and no PRG will be proposed. However, because it was identified as a potential risk contributor, future monitoring programs should include this compound to evaluate its potential impact on achieving the RAOs.

Similarly, xylene was detected in only one well at the WOD (540 µg/L) and was identified as contributing 0.5 to an adult central nervous system HI of 1.3. This HI is marginally greater than the target HI of 1. The MCL for xylene is 10,000 µg/L. The single detection of xylene at a concentration well below the MCL does not indicate the presence of a plume. Considering its limited presence at the WOD at a

concentration less than the MCL, xylene was not retained as a COC and no PRG will be proposed. However, because it associated with the waste materials at the WOD, future monitoring programs should include this compound to evaluate its potential impact on achieving the RAOs.

The organic compound 1,2,4-trimethylbenzene was detected in one site sample (WFF15-GW7). The single site detection is above the MCL (70 µg/L). One detection does not constitute a plume and therefore no PRG will be developed for 1,2,4-trimethylbenzene. However, because the detection was above the MCL, and considering the location of the detection, future monitoring programs should include this compound to evaluate its potential impact on achieving the RAOs.

Naphthalene was also detected in only one WOD site well (130 µg/L). There is no MCL for naphthalene. The single detection of naphthalene does not indicate the presence of a plume. Naphthalene was not detected in the other groundwater samples, including samples collected immediately downgradient of the single detection at the WOD. Considering its limited presence at the WOD, the lack of a groundwater plume, and the low calculated risk associated with naphthalene (HI of 2.5), the contaminant will not be retained as a COC and no PRG will be proposed for it. However, as with xylene, because naphthalene is associated with the waste materials at the WOD, future monitoring programs should include this compound to evaluate its potential impact on achieving the RAOs.

In summary, based on a review of the Supplemental RI and relevant regulations, standards and criteria, arsenic and benzene are retained as COCs. Also, in consideration of the occurrence and distribution of tetrachloroethene, naphthalene, 4-methylphenol, xylene, and 1,2,4-trimethylbenzene, and in accordance with agreements between NASA and the regulators (TtNUS, 2004b), these compounds will be included in future groundwater monitoring programs at the WOD to evaluate their impact on achieving RAOs.

2.3 REMEDIATION GOALS

A PRG is the target concentration that a COC must be reduced to within a particular medium of concern to achieve one or more of the established RAOs. Cleanup goals are developed to make sure that contaminant concentrations left on site are protective of human and ecological receptors.

For the WOD site, groundwater cleanup goals were established based on the following criteria:

- Protection of human health from residential exposure to contaminated groundwater.
- Compliance with ARARs and TBCs to the extent practicable.

The groundwater cleanup goals can be summarized as follows:

Chemical of Concern (1)	Frequency of Detection	Range of Concentrations	Cleanup Goal(2)
INORGANICS (µg/L)			
Arsenic	1/8	21.4	10
VOCs (µg/L)			
Benzene	2/12	8 – 11	5

NOTES:

1 Future monitoring programs will include these COCs as well as tetrachloroethene, naphthalene, 4-methylphenol, xylene, and 1,2,4-trimethylbenzene.

2 USEPA Drinking Water MCLs (USEPA, 2004a).

For development of groundwater remediation goals, a hierarchy was applied to select the most appropriate regulatory or risk-based criteria. The first priority was to consider adopting the MCL if a MCL was available (SMCLs are not generally used) as the remediation goal. If MCLs were not available, the second approach was to consider risk-based values derived from the human health risk assessment for the WOD.

REMEDIATION GOALS FOR ARSENIC AND BENZENE

MCLs were selected as the PRGs for arsenic and benzene.

2.4 GENERAL RESPONSE ACTIONS AND ACTION-SPECIFIC ARARs

GRAs are broadly defined remedial approaches that may be used (by themselves or in combination with one or more of the others) to attain the RAO. Action-specific ARARs and TBCs are those regulations, criteria, and guidances that must be complied with or taken into consideration during remedial activities on site.

2.4.1 General Response Actions

GRAs describe categories of actions that could be implemented to satisfy or address a component of the RAOs for the site. Remedial action alternatives will then be assembled by identifying types of treatment technologies and process options associated with these technologies according to these GRAs. The technologies and process options will be screened and evaluated using GRAs individually or in combination to develop the remedial action alternatives to be considered for the WOD groundwater.

The following GRAs were considered for groundwater remediation at the WOD site:

- No Action
- Limited Action (Natural Attenuation, Institutional Controls, Monitoring)
- Containment
- Removal
- In-Situ Treatment
- Ex-Situ (On-Site or Off-Base) Treatment
- Disposal

2.4.2 Action-Specific ARARs

Action-specific ARARs and TBCs are technology - or activity-based regulatory requirements or guidance that would control or restrict remedial action. Tables 2-6 and 2-7 present a list of federal and State action-specific ARARs and TBCs that may apply to the screening and selection of technologies for addressing the WOD groundwater.

FEDERAL

Air/Superfund National Technical Guidance [Office of Solid Waste and Emergency Response (OSWER) Directive 9355.0-28, EPA/450/1-89/001 to 004] is a TBC that guides the control of air emissions from remedial actions at Superfund sites. For sites located in areas that are not attaining National Ambient Air Quality Standards (NAAQS) for ozone, add-on emission controls are required for remedial actions with an actual emission rate in excess of 3 pounds per hour, an actual emission rate in excess of 15 pounds per day, or a potential (i.e., calculated) emission rate of 10 tons per year of total VOCs. Generally, the guidelines are suitable for VOC air emissions from other vented extraction techniques (e.g., soil vapor extraction) but not from area sources (e.g., soil excavation). NASA WFF is in a nonattainment area for ozone.

Clean Air Act (CAA) (42 USC 7401) consists of three programs or requirements that may be ARARs: NAAQS (40 CFR Parts 50 and 53), New Source Performance Standards (NSPS) (40 CFR Part 60), and National Emission Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR Part 61). USEPA requires the attainment and maintenance of primary and secondary NAAQS to protect public health and public welfare. These standards are not source specific but rather are national limitations on ambient air quality. States are responsible for assuring compliance with the NAAQS. NSPS are established for new sources of air emissions to make sure that the new stationary sources minimize emissions. These standards are for categories of stationary sources that cause or contribute to air pollution that may

endanger public health or welfare. Standards are based upon the best-demonstrated available technology. NESHAPs, which are emission standards for source types (i.e., industrial categories) that emit hazardous air pollutants, are not likely to be applicable or relevant and appropriate for NASA WFF because they were developed for a specific source. These requirements may be applicable for groundwater remediation systems that would emit air pollutants.

Clean Water Act (CWA) governs point source discharges to surface water through the National Pollutant Discharge Elimination System (NPDES), the discharge of dredged or fill material to surface water, and spills of oil and hazardous substances to surface water. NPDES requirements (40 CFR 122 to 125) are potentially applicable if the direct discharge of pollutants into surface water is part of the remedial action. This includes the discharge of stormwater from construction and other industrial activities. Dredge and fill requirements (40 CFR 230) would not be applicable to a remedial action for groundwater because no fill materials would be discharged into surface water.

National Pretreatment Standards (40 CFR Part 403) control the indirect discharge of pollutants to publicly-owned treatment works (POTWs). The goal of the pretreatment program is to protect municipal wastewater treatment plants and the environment from damage that may occur when hazardous, toxic, or other non-domestic wastes are discharged into a sewer system. The regulations include general and specific prohibitions on discharges to POTWs. The regulations are potentially applicable if treated or untreated groundwater is discharged to a local POTW.

Federal Facilities Compliance Act expands the domestic sewage exclusion policy to federally owned treatment works (FOTW). When wastewater is considered a hazardous waste under RCRA, but is mixed with domestic waste as it flows through the sewer system, the system would not be required to meet the additional regulatory requirements for a RCRA facility.

Occupational Health and Safety Act (OSHA) (29 USC Sections 651 through 678) regulates worker health and safety during implementation of remedial actions.

Resource Conservation and Recovery Act (RCRA) Subtitle C regulates the treatment, storage, and disposal of hazardous waste from its generation until its ultimate disposal. In general, RCRA Subtitle C requirements for the treatment, storage, or disposal of hazardous waste will be applicable if:

- The waste is a listed or characteristic waste under RCRA.

- The waste was treated, stored, or disposed (as defined in 40 CFR 260.10) after the effective date of the RCRA requirements under consideration.

- The activity at the site constitutes current treatment, storage, or disposal as defined by RCRA.

Groundwater from the site would not be classified as a hazardous waste because the concentrations are below toxicity characteristic concentrations (40 CFR 261.24) and are not contaminated with known hazardous wastes. However, residuals generated during groundwater treatment activities would need to be tested to determine whether they exhibit the toxicity characteristic. If groundwater treatment residuals were classified as a hazardous waste, the hazardous waste generator (40 CFR 262) and transportation (40 CFR 263) requirements would be applicable.

RCRA Subtitle C requirements may be relevant and appropriate when the waste is sufficiently similar to a hazardous waste and/or the on-site corrective action constitutes treatment, storage, or disposal and the particular RCRA requirement is well suited to the circumstances of the contaminant release and site. RCRA Subtitle C requirements may also be applicable when the corrective action constitutes generation of a hazardous waste.

The following requirements included in the RCRA Subtitle C regulations may pertain to the NASA WFF:

- Hazardous waste identification and listing regulations (40 CFR Part 261).
- Hazardous waste generator requirements (40 CFR Part 262).
- Transportation requirements (40 CFR Part 263).
- Standards for owners and operators of hazardous waste treatment, storage, and disposal facilities (TSDF) (40 CFR Part 264).
- Interim status standards for owners and operators of hazardous waste TSDF (40 CFR Part 265).
- Land disposal restrictions (LDRs) (40 CFR Part 268).

Hazardous Waste Identification and Listing Regulations (40 CFR Part 261) define those solid wastes that are subject to regulation as hazardous waste under 40 CFR Parts 262 to 265 and Parts 124, 270, and 271.

A generator that treats, stores, or disposes of hazardous waste on site must comply with RCRA Standards Applicable to Generators of Hazardous Waste (40 CFR Part 262). These standards include manifest, pre-transport (i.e., packaging, labeling, and placarding), record keeping, and reporting

requirements. The standards are applicable if actions taken at the WOD site constitute generation of a hazardous waste (e.g., generation of treatment residues that may be hazardous).

Standards Applicable to Transporters of Hazardous Waste (40 CFR Part 263) are applicable to off-site transportation of hazardous waste. These regulations include requirements for compliance with the manifest and record keeping systems and requirements for immediate action and cleanup of hazardous waste discharges (spills) during transportation. The standards are potentially applicable if corrective actions involve off-site transportation of hazardous waste from the WOD site.

Standards and Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (40 CFR Parts 264 and 265) are applicable to corrective actions that may be taken at the WOD site and to off-site facilities that receive hazardous waste from the site for treatment and/or disposal. Standards for TSDFs include requirements for preparedness and prevention, corrective action requirements, closure and post-closure care, use and management of containers, and design and operating standards for tank systems, surface impoundments, waste piles, landfills, and incinerators. These standards are potentially applicable if corrective actions involve the on-site treatment or disposal of hazardous waste at the WOD.

RCRA Land Disposal Restriction (LDR) Requirements (40 CFR Part 268) restrict certain wastes from being placed or disposed on the land unless they meet specific best demonstrated available technology treatment standards (expressed as concentrations, total or in the Toxicity Characteristic Leachate Procedure (TCLP) extract, or as specified technologies). Removal and treatment of a RCRA hazardous waste or movement of the waste outside of a Corrective Action Management Unit, thereby constituting "placement" would trigger the LDR requirements.

Placement of hazardous waste into underground injection wells constitutes "land disposal" under the LDRs. Furthermore, RCRA Section 3020(a) bans hazardous waste disposal by underground injection into or above an underground source of drinking water. RCRA Section 3020(b), however, exempts from the ban reinjection of treated contaminated groundwater into such formations undertaken as part of a RCRA corrective action. The contaminated groundwater must be treated to substantially reduce hazardous constituents before such injection, and the corrective action must be sufficient to protect human health and the environment upon completion. LDRs would be potentially applicable if corrective actions at the WOD site include off-site disposal of wastes in a landfill or reinjection of treated groundwater.

RCRA Subtitle D (40 CFR 258) establishes design and operating criteria for solid waste (nonhazardous) landfills. In general, RCRA Subtitle D establishes minimum design and operating criteria for solid waste landfills that meet any of the following:

- Receive municipal solid waste as defined in 40 CFR 258
- Co-dispose sewage sludge with municipal solid waste
- Receive nonhazardous municipal solid waste combustion
- Are not regulated under RCRA Subtitle C

The closure and post-closure care requirements under RCRA Subtitle D may be relevant and appropriate for the landfill waste. These requirements are intended to minimize the infiltration of water into the landfill and maintain the integrity of the cover during the post-closure care period by minimizing cover erosion. Minimum requirements for a final landfill cover are included; however, states with USEPA-approved programs may approve alternate cover designs. Post-closure care must be conducted for 30 years; however, states with USEPA-approved programs have the authority to lengthen or shorten the post-closure period.

Solid Waste Disposal Act (SWDA) Underground Injection Control Program (40 CFR Parts 144 to 147 and 1000) contains provisions for the control and prevention of pollutant injection into groundwater. Class IV wells are used to inject hazardous waste into or above a formation that, within 1/4 mile of the well, contains an underground drinking water source. Operation or construction of Class IV wells is prohibited and allowed only for the reinjection of treated wastes as part of a CERCLA or RCRA cleanup. The regulations are potentially applicable if groundwater is removed, treated, and reinjected into the formation from which it was withdrawn.

Department of Defense Interim Policy on Integration of Natural Resource Injury Responsibilities and Environmental Restoration Activities (Department of Defense, 2000). It is Department of Defense policy that Components (e.g., Navy) identify natural resource injury and, whenever practicable, redress it as part of the site assessment, investigation, and remedy selection process for clean-up actions. Components determine what is practicable based on factors including cost and cost-effectiveness, ERA fund availability, risk prioritization, and technical and engineering feasibility.

Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (OSWER Directive 9200.4-17P) contains guidelines for the use of monitored natural attenuation for the remediation of contaminated soil and groundwater. This guidance is a TBC criterion if monitored natural attenuation is a component of the corrective action at the WOD site.

STATE

Virginia Solid Waste Management Regulations, Groundwater Protection Levels of Hazardous Constituents (9 VAC 20-80, Appendix 5.3) establish protection levels for groundwater. These levels are used to trigger the need for corrective action for groundwater at solid waste management facilities. The protection levels may be applicable for developing remediation goals for groundwater. However, the state has additional applicable solid waste regulations on action levels (9 VAC 20-80-220) and clean-up standards (9 VAC 20-80-230) and voluntary remediation regulations on remediation levels (9 VAC 20-160-90) that may be more appropriate. These are discussed below.

Virginia Solid Waste Management Regulations, Action Levels (9 VAC 20-80-220) have been established for constituents in groundwater that may have been released from a solid waste management unit. Action levels include SDWA MCLs. For carcinogens for which MCLs have not been promulgated, the action level is a concentration associated with an excess lifetime cancer risk of $1x10^{-6}$. For systemic toxicants for which MCLs have not been promulgated, the action level is a concentration to which the human population (including sensitive subgroups) could be exposed on a daily basis without an appreciable risk of deleterious effects. The action levels may be applicable for developing remediation goals for groundwater.

Virginia Solid Waste Management Regulations, Cleanup Standards (9 VAC 20-80-230) have been established for contaminated media. The clean-up standards shall be concentration levels that protect human health and the environment. For known or suspected carcinogens, clean-up standards shall be established at concentrations that represent an excess upper-bound lifetime risk to an individual of between $1x10^{-4}$ and $1x10^{-6}$. The $1x10^{-6}$ risk level shall be the point of departure in establishing such clean-up levels. For systemic toxicants, clean-up standards shall represent concentration levels to which human populations (including sensitive subgroups) could be exposed on a daily basis without appreciable risk of deleterious effects during a lifetime. For groundwater that is a current or potential source of drinking water, SDWA MCLs will be considered in establishing clean-up standards. In establishing clean-up standards, VDEQ may consider the following: multiple contaminants; exposure threats to sensitive environmental receptors; other site-specific exposure or potential exposure to contaminated media; and the reliability, effectiveness, practicability, or other relevant features of the remedy. If a specific concentration is naturally occurring or from another source, a clean-up level that is not below that specific concentration may be established. For groundwater, the clean-up standards or levels shall be achieved throughout the contaminated groundwater, or, at VDEQs discretion, when waste is left in place, up to the boundary of a waste management area encompassing the original source of release. The clean-up standards may be applicable for developing remediation goals for groundwater.

Virginia Hazardous Waste Management Regulations (9 VAC 20-60) regulate the treatment, storage, and disposal of hazardous waste from its generation to its ultimate disposal. The regulations adopt the federal RCRA Subtitle C regulations by reference, with certain additions, modifications, and exceptions. Groundwater from the site would not be classified as a hazardous waste because the concentrations are below toxicity characteristic concentrations (40 CFR 261.24) and are not contaminated with known hazardous wastes. However, residuals generated during groundwater treatment activities would need to be tested to determine whether they exhibit the toxicity characteristic. If groundwater treatment residuals are classified as a hazardous waste additional requirements would be applicable.

Virginia Pollutant Discharge Elimination System Regulations (9 VAC 25-31, Parts I to IV) govern the direct discharges of pollutants to surface water. Discharges must meet the effluent discharge limits established by these regulations. These limits are established on a case-by-case basis and may be based on the following: technology-based effluent limitations, prevention of discharges that would cause a violation of the surface water quality standards, and prevention of discharges of toxic pollutants in amounts that have a reasonable likelihood of adversely affecting human health or the environment. These regulations are potentially applicable for the discharge of groundwater to surface water. These regulations also govern discharges to POTWs. The regulations require POTWs to establish pretreatment requirements of industrial users to prevent pass-through or upset of the POTW and contain specific limitations on discharges to the POTW for various industrial categories.

Virginia Pollution Abatement Permit Regulations (9 VAC 25-32) govern non-point source discharges to surface water from pollutant management activities. These regulations are not potential ARARs. Remedial actions that involve groundwater extraction would have a point source discharge to surface water or would discharge to a POTW or FOTW.

Virginia Stormwater Management Regulations (4 VAC 3-20) establishes requirements for discharges of stormwater to protect the surface water of the state. This regulation also allows local regulatory agencies to adopt management programs in accordance to the regulations. If a local stormwater management program has been adopted and the response action is not exempt under the local program, the project must comply with program requirements. If a local program has not been adopted, the standards contained in these regulations should be considered to be relevant and appropriate requirements.

Virginia Erosion and Sediment Control Regulations (4 VAC 50-30) establishes requirements for erosion control to protect the surface water of the state. This regulation also allows local regulatory agencies to adopt erosion and sediment control programs in accordance to the regulations. If a local soil and erosion control program has been adopted and the response action is not exempt under the local program, the

project must comply with program requirements. If a local program has not been adopted, the standards contained in the regulations should be considered to be relevant and appropriate requirements.

Virginia Water Protection Permit Regulations (9 VAC 25-210) delineate the procedures and requirements for dredging and filling activities in surface water. These regulations are potentially applicable for remedial activities that occur in the river or wetlands adjacent to a site.

Virginia Air Pollution Control Regulations (9 VAC 5) establish ambient air quality standards and regulate the discharge of pollutants into the atmosphere. Remedial actions that involve groundwater treatment would not be expected to result in the discharge of air pollutants. The concentrations of VOCs in groundwater are low enough that treatment, such as air stripping, would not be required prior to discharge. Therefore, these regulations are not potential ARARs.

2.5 ESTIMATED VOLUME OF CONTAMINATED MEDIA

For remedial action purposes, the volume of contaminated groundwater at the WOD site was estimated based on the location of samples where COCs were detected in excess of cleanup goals. The plume surface area is illustrated on Figure 2-1. Based on the analytical results of the Supplemental RI, the groundwater plume was delineated as the area of groundwater where concentrations of the COCs benzene and arsenic are greater than the remediation goals defined in Section 2.3. The benzene plume extends over an area approximately 8,400 square feet (ft^2) in size (0.19 acres) and to a depth of up to 10 feet below the water table. Based on a porosity of 0.25, the estimated volume of the plume was computed at approximately 157,100 gallons. Assuming an average concentration of 9.5 µg/L, the estimated dissolved mass of benzene within the plume is 0.013 pounds [0.006 kilograms (kg)]. The arsenic plume extends over an area approximately 7,000 ft^2 in size (0.16 acres) and to a depth of up to 10 feet below the water table. Based on a porosity of 0.25, the estimated volume of the plume was computed at approximately 52,400 gallons. Assuming an average concentration of 19.5 µg/L, the estimated dissolved mass of arsenic within the plume was 0.009 pounds (0.004 kg). The extent of the plumes is illustrated on Figure 2-1, and volume computations are presented in Appendix A.

The volume of petroleum contaminated soil present near the water table was also estimated to aid with evaluation of groundwater remedial actions at the WOD site. A thin layer of petroleum product was discovered at the water table surface during the Supplemental RI. It is suspected that the petroleum contamination sorbed to the soil at or below the water table or petroleum product is contributing to the groundwater conditions and contamination. The contaminated soil area is illustrated on Figure 2-2. The area suspected of contributing to the groundwater contamination was delineated using the 2001 RI and 2003 Supplemental RI data that showed significant concentrations of petroleum-related compounds

including BTEX and PAHs. The area extends over 2,500 ft^2 and is assumed to be 5 feet in depth, resulting in a volume of 12,500 cubic feet (ft^3) (460 cubic yards). Mass calculations were completed using a combination of existing soil data and contaminant fate and transport modeling results. The calculations and modeling results are provided in Appendices A and B, respectively. Using this method, it was estimated that there is currently less than 0.11 pounds (0.05 kg) of benzene, 8.82 pounds (4 kg) of BTEX, and 30.9 pounds (14 kg) of petroleum contamination present in the subsurface soil near the water table that is contributing to the groundwater conditions and contamination at the WOD.

3.0 SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS

This section identifies, screens, and evaluates the potential technologies and process options that may be applicable to assemble the remedial alternatives for the WOD site at NASA's WFF. The primary objective of this phase of the FS is to develop an appropriate range of remedial technologies and process options that will be used for developing the remedial alternatives.

The basis for technology identification and screening began in Section 2.0 with a series of discussions that included the following:

- Identification of ARARs,
- Development of RAOs,
- Identification of GRAs, and
- Identification of areas and volumes of contaminated groundwater and contaminated soil that may impact remediation of the groundwater.

Technology screening evaluation is performed in this section with the completion of the following analytical steps:

- Identification and screening of remedial technologies and process options
- Evaluation and selection of representative process options

In this section a variety of technologies and process options are identified under each GRA (discussed in Section 2.3.1) and screened. The selection of technologies and process options for initial screening is based on the "Guidance for Conducting Remedial Investigations/Feasibility Studies under CERCLA" (USEPA, 1988). The screening is first conducted at a preliminary level to focus on relevant technologies and process options. Then the screening is conducted at a more detailed level based on certain evaluation criteria. Finally, process options are selected to represent the technologies that have passed the detailed evaluation and screening.

The evaluation criteria for detailed screening of technologies and process options that have been retained after the preliminary screening are effectiveness, implementability, and cost. The following are descriptions of these evaluation criteria:

- Effectiveness
  - Protection of human health and the environment; reduction in toxicity, mobility, or volume; and permanence of solution.
  - Ability of the technology to address the estimated areas or volumes of contaminated media.
  - Ability of the technology to attain the Cleanup Goals required to meet the RAOs.
  - Technical reliability (innovative versus well-proven) with respect to contaminants and site conditions.

- Implementability
  - Overall technical feasibility at the site.
  - Availability of vendors, mobile units, storage and disposal services, etc.
  - Administrative feasibility.
  - Special long-term maintenance and operation requirements.

- Cost (Qualitative)
  - Capital cost.
  - Operation and maintenance (O&M) costs.

Technologies and process options will be identified in the following sections.

3.1 PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

This section identifies and screens groundwater technologies and process options at a preliminary stage based on implementation with respect to site-specific conditions and COCs. Table 3-1 summarizes the results of this preliminary screening process. It presents the GRAs, identifies the technologies and process options, and provides a brief description of each process option followed by the screening comments.

The following are the groundwater technologies and process options retained for detailed screening:

General Response Action	Technology	Process Options
No Action	None	Not Applicable
Limited Action	Monitoring	Sampling & Analysis
	Institutional Controls	Deed Restrictions/Groundwater Use Restrictions/Facility Master Plan
	Natural Attenuation	Naturally-Occurring Biodegradation and Dilution
Removal	Groundwater Extraction	Extraction Wells
Removal (Continued)	Groundwater Extraction (Continued)	Collection Trench
In-situ Treatment	Biological – Biostimulation	Aerobic biological treatment with Oxygen Release Compound (ORC®), Bioventing, or Air Diffusion
	Biological – Bioaugmentation	Aerobic biological treatment with microbes, inoculum, and/or bacterium
	Physical	Air Sparging (AS) or Air Sparging/ Vapor Extraction (AS/VE)
Ex-situ Treatment	Biological	Aerobic Biodegradation Treatment
	Physical	Filtration, Air Stripping, Granular Activated Carbon (GAC) Adsorption, Dewatering, Equalization, and Sedimentation
	Chemical	Coagulation/Flocculation, Neutralization/pH Adjustment, Precipitation
Disposal	Surface Discharge	POTW or NPDES

3.2 DETAILED SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

3.2.1 No Action

No Action consists of maintaining the status quo at the site. As required under CERCLA regulations, the No Action alternative is carried through the FS to provide a baseline for comparison of alternatives and their effectiveness in mitigating risks posed by site contaminants. Because no remedial actions are conducted under this alternative, there are no costs associated with "walking away from" the site, and there is no reduction in risk through exposure control or treatment.

Effectiveness

No Action would not be effective in meeting the RAOs and remediation goals. No Action would not be effective in evaluating either potential contaminant reduction through natural attenuation or potential contaminant migration off-site because monitoring would not be performed.

Implementability

There would be no implementability concerns because No Action would be implemented.

Cost

There would be no costs associated with No Action.

Conclusion

No Action is retained for comparison to other options.

3.2.2 Limited Action

3.2.2.1 Monitoring

Sampling and analysis of groundwater throughout the area of potential groundwater contamination could be used to evaluate migration of contaminants. Monitoring can also be used to monitor potential natural attenuation or the progress of active groundwater remediation.

Effectiveness

Monitoring would not of itself reduce the toxicity, mobility, or volume of contaminants in the groundwater; but it would allow for the evaluation of potential off-site migration of contaminants and the potential reduction in contaminant concentrations through natural attenuation. By serving as a warning mechanism, periodic groundwater monitoring would enable NASA to manage the area of contamination if concentrations or the plume area increased. Monitoring would also be helpful in measuring and evaluating the effectiveness of natural attenuation or active remediation technologies.

Implementability

A groundwater monitoring program could be readily implemented at the site under consideration.

Cost

Capital and O&M costs of monitoring would be low.

Conclusion

Monitoring is retained for use in combination with other process options for the development of groundwater remedial alternatives.

3.2.2.2 Institutional Controls

Institutional controls would consist of limiting access to groundwater by restricting future land use. Land Use Controls (LUCs) or a Facility Master Plan, including land and groundwater use restrictions, would be formulated and implemented to prevent the use of the groundwater from the shallow Columbia aquifer at the WOD site. As part of institutional controls, regular site inspections would be conducted to verify and enforce the continued application of these controls.

Effectiveness

Groundwater use restrictions would be effective in combination with other remedial activities. These controls would minimize potential human health risks associated with exposure to contaminated groundwater. As such, institutional controls would achieve one of the two groundwater RAOs for the WOD site.

Implementability

Institutional controls would be readily implementable. The Facility Master Plan will document the LUCs while the property is owned by NASA. If the site changes from NASA to private ownership, provisions will be incorporated in property transfer documents (deed restrictions) to ensure the continued implementation of institutional controls. Resources are readily available for the preparation of deed restrictions.

Cost

Costs of institutional controls would be low.

Conclusion

Institutional controls are retained for use in combination with other process options for the development of groundwater remedial alternatives.

3.2.2.3 Natural Attenuation

Natural attenuation would consist of monitoring groundwater quality to determine the extent to which naturally-occurring processes such as biodegradation, abiotic transformation, dispersion, and dilution would break down organic contaminants (VOCs and SVOCs) over time, thereby reducing concentrations of these chemicals below regulatory or risk-based criteria. For this purpose, new groundwater monitoring wells would be installed as required and samples from these new groundwater monitoring wells and existing wells would be regularly collected and analyzed for natural attenuation parameters and COCs. The natural attenuation parameters that groundwater would be analyzed for include ORP, DO, pH, alkalinity, temperature, conductivity, TOC, ferrous and total iron, sulfur compounds (sulfides, sulfates), nitrogen compounds (nitrites, nitrates), orthophosphates, chloride, and metabolic gases [methane, ethane, ethene, and carbon dioxide (CO_2)]. In addition to the natural attenuation parameters (used to evaluate the continued efficiency of this process), the identified COCs would also be collected.

Effectiveness

Naturally occurring processes (physical, chemical and biological) are expected to reduce contaminant concentrations in the aquifer over the long term. A limited evaluation was conducted to determine the potential effectiveness of natural attenuation for benzene as well as the other organic contaminants detected at the WOD site. The evaluation also considered the processes that affect the migration of arsenic. Lines of evidence recommended by USEPA (USEPA, 1999), the Navy [*Technical Guidelines for Evaluating Monitored Natural Attenuation of Petroleum Hydrocarbons and Chlorinated Solvents in Groundwater at Naval and Marine Corps Facilities* (United States Department of the Navy [Navy], 1998)], and Air Force [*Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Air Force Center for Environmental Excellence [AFCEE], 1999)] were considered during the evaluation. Site-specific geologic, hydrogeologic, analytical, and geochemical data and groundwater fate and transport modeling were used to complete the evaluation.

Detailed site-specific geology and hydrogeology was provided in the Supplemental RI report and is summarized in Section 1.1 of this report. Based on water level data collected in 2001 and 2003, the general direction of groundwater flow was consistent and mimicked the surface topography. Figure 1-4 (2003 contours) shows that the WOD is basically bisected by a groundwater divide that trends north-to-northeastward through the peninsula. Groundwater from the western portion of the WOD is expected to discharge to the unnamed tributary to Little Mosquito Creek that flows through Site 15 and the wetlands adjacent to Little Mosquito Creek. Groundwater from the eastern portion of the WOD is expected to discharge into Little Mosquito Creek and its adjacent wetlands. Based on 2003 groundwater data,

downward vertical groundwater gradients are present upgradient in the source area (WWF15-GW7) and upward groundwater gradients are present in the downgradient areas near the unnamed tributary to Little Mosquito Creek. The current distribution of the impacted groundwater and historical groundwater elevations confirm that the groundwater flow regimes present at the WOD have remained relatively constant through time.

Benzene concentration trends, as well as the trends of other fuel-related compounds (i.e., toluene, ethylbenzene, and xylene) in groundwater were evaluated. Figures 3-1 and 3-2 show the trends of BTEX concentrations detected in wells WFF15-GW7 and WFF16-GW2D, respectively. Well WFF15-GW7 is located within the suspected source area and well WFF16-GW2D is located downgradient along the center-line of the contaminant plume. Both figures show decreasing contaminant trends with the most recent sampling results (2003 Supplemental RI) being significantly less than the earliest rounds of data (1997 or 1998). Therefore, contaminant concentrations in the groundwater within the source area and downgradient of the source area are decreasing over time.

The natural attenuation geochemical data collected during the Supplemental RI was also evaluated. The results of the natural attenuation field parameter monitoring conducted at the WOD site is provided on Table 3-2. Figures 3-3 through 3-6 show isoconcentration maps of key geochemical parameters [i.e., ORP, DO, methane, and pH] for the WOD site. Special emphasis was placed on ORP, DO, and methane because they are key factors for interpreting the effectiveness of aerobic and/or anaerobic degradation. ORP and pH were also considered because they provide an indication of the areas where arsenic may be mobile. The solubility of arsenic is dependent on the pH and ORP of the groundwater. Arsenic will typically be soluble and mobile in groundwater with low pH and reduced conditions (low ORP). Conversely, arsenic will typically be insoluble and immobile in groundwater with pH near neutral and oxic conditions (high ORP).

As evident in Figures 3-3 through 3-5 it can be seen that DO and ORP are low and methane concentrations are high in the source area well WFF15-GW7 and the downgradient well WFF16-GW2D. This data indicates that biodegradation has been active in the source area, depleting dissolved oxygen concentrations and causing anaerobic conditions. Anaerobic conditions are conducive to reductive dechlorination of the chlorinated VOCs detected at the WOD, but they are not conducive to the degradation of benzene (COC) or the other petroleum-related compounds detected at the WOD. From Table 3-2 it can be seen that ethane and ethene were detected in wells WFF15-GW7 and WFF16-GW2D. These compounds are near the end of the degradation chain for chlorinated VOCs and their presence indicates that relatively complete degradation of some of the chlorinated VOCs is occurring within the source area.

Benzene (COC) and other petroleum-related compounds are degraded most effectively under aerobic conditions. Figures 3-3 through 3-5 show that DO and ORP generally increase and methane concentrations generally decrease in the downgradient flow direction, indicating that once outside the source area, conditions are aerobic and conducive to degradation of benzene and other petroleum-related compounds. The nature of the contaminant source, the active biodegradation, and the hydrogeologic conditions appear to be playing a role in the limited migration of the contaminant plume at the WOD (see Figure 2-1).

The BIOSCREEN analytical model (Version 1.4, 1997) was used to determine the effectiveness of natural attenuation as a remedial action (see Appendix B). BIOSCREEN is a screening-level tool that is based on a simple analytical model and the assumption that groundwater flow and contaminant transport are horizontal. At the WOD site, transport of contaminants occurs predominantly in a horizontal groundwater flow regime between the uplands and lowlands and although vertical components of groundwater flow occur at the site, the extent is limited and its impact on the transport of contaminants is minimal. Therefore, a simple groundwater flow regime is present at the WOD and the use of the BIOSCREEN model is justified. The BIOSCREEN model was used to evaluate benzene migration and degradation. The analytical model was calibrated to site-specific data from 1997 to 2003 and utilized to predict cleanup times in the source area and through out the contaminant plume. The calibrated model predicted that approximately 4 years will be required for natural attenuation to remediate the groundwater plume to the MCL for benzene (5 µg/L). The model's results are considered approximate, but conservative, based on the assumptions used during development of the model.

These results (contaminant trends and distributions, geochemical data, and modeling) show that there is evidence of an environment favorable to natural attenuation of benzene in the Columbia Aquifer. It also suggests that other organic contaminants at the WOD site (i.e., chlorinated VOCs) are also being degraded through natural attenuation processes.

The single arsenic detection in excess of the MCL (10 µg/L) was detected in well WFF16-GW2D. From Figure 3-6 it can be seen that this well is located downgradient of the region with the lowest pH identified by wells WFF15-GW7 and WFF16-GW3. The groundwater in well WFF16-GW2D also exhibited reduced conditions with an ORP of -51 mv, DO of 2.79 mg/L, and methane of 495.5 µg/L. It is suspected that the aerobic and anaerobic biodegradiation occurring in the source area is creating acids, lowering the pH of the groundwater, and causing arsenic in the soil to be soluble in groundwater. Therefore, it appears that the arsenic contamination in the groundwater at the WOD is most likely associated with the reduced environment created by the degradation of the organic contaminants since the extent of the contamination is not widespread. It is assumed that the geochemical conditions in the source area at the

site will return to an oxic (aerobic) environment after the VOCs and SVOCs have been biodegraded and this should cause the arsenic to transform to insoluble oxidized compounds.

Groundwater monitoring would provide an effective means of evaluating the concentrations of COCs in groundwater and of assessing the rate of decrease of these concentrations. Monitoring of indicator parameters would help to evaluate the effectiveness of natural attenuation in reducing COCs concentrations.

Implementability

Natural attenuation would be easy to implement. Monitoring groundwater quality, restricting groundwater use, and periodic reviewing of site conditions could readily be performed, and the necessary resources are available to provide these services.

Cost

Capital and O&M costs for natural attenuation would be low to moderate depending on the time-frame for remediation.

Conclusion

Natural attenuation is retained in combination with other process options for the development of groundwater remedial alternatives.

3.2.3 Containment/Removal

The only technology considered under this GRA is groundwater extraction. Groundwater extraction uses either a pumping system composed of a series of wells or a collection trench that is used to capture contaminated groundwater and restrict horizontal migration of groundwater and to treat the contaminated groundwater. The wells or trench used in the capture system would be designed and located to provide optimum efficiency in capturing contaminated groundwater while minimizing the collection of uncontaminated groundwater.

Effectiveness

Groundwater extraction is a well-established technology for the removal of contaminated groundwater and the containment of groundwater contaminant plumes. While the initial effectiveness of this

technology for contaminant capture is high, it has often been shown to decrease over time. This decrease is generally due to one or more of several factors including the presence of preferential flow pathways due to aquifer heterogeneity, contaminant adsorption onto aquifer materials, diffusion of contaminants into the pore spaces of low-permeability materials, and creation of stagnation zones due to pumping operations. It should be noted, however, that no such decrease over time is observed in the effectiveness of this technology for containment of contaminant plumes.

The effectiveness of an extraction well system depends largely on the extent of contamination and site-specific geology and hydrogeology. The use of wells to extract groundwater should reduce contaminant concentrations and may attain the cleanup goals over the long term. This technology is reliable, and minimal effects on human health and the environment would be expected during implementation.

The findings from several recent case studies concluded that systems were generally not making adequate progress for contaminant mass removal, and that optimization efforts based on the life cycle design concept were needed to achieve site close out within a reasonable timeframe, particularly for sites that require aquifer restoration to concentrations such as MCLs. The long operating timeframe is a common limitation for extraction operations. The result is a slowdown in contaminant mass removal, also referred to as tailing or asymptotic conditions. This phenomenon strongly limits the extraction system's ability to achieve remediation goals for aquifer restoration in a reasonable timeframe.

Extraction has been unable to achieve "restoration" (i.e., reduction of contaminants to concentrations required by health-based standards) as anticipated in the design phase of projects because of a variety of factors (tailing and rebound). Extraction is useful for providing hydraulic containment (control the movement of contaminated groundwater and prevent the continued expansion of the contaminated zone) of those portions of the plume where contaminant sources are present, or for containing or restoring those plume areas with relatively high concentrations of dissolved contamination ("hot spots"). However, extraction followed by treatment may not be the best method for restoring large areas of the plume with low contaminant concentrations (USEPA, 1996b and 1996c, and Navy, 2003). For the WOD site, hydraulic containment is not required because impacts to downgradient groundwater resources have not been identified.

The effectiveness of a collection trench depends largely on the depth to the water table, the type of contamination, the vertical extent of contamination, and site-specific geology and hydrogeology. The use of trenches to collect groundwater should reduce contaminant concentrations and may attain the cleanup goals over the long term. This technology is reliable, and minimal effects on human health and the

environment would be expected during implementation. This technology would have many of the same limitations as extraction wells.

Implementability

Groundwater extraction through a pumping well system or collection trench could be readily implemented at the WOD site. This technology uses readily available equipment and techniques and has been widely used in similar situations. Implementation of this technology would require long term O&M. Maintenance may require periodic replacement of mechanical components, well flushing to remove fine-grained material that may clog the wells, chemical treatment to remove biofouling, etc.

Cost

The extraction systems require long remediation times, perhaps decades, to achieve cleanup goals. Therefore, closeout costs for the site are expected to be very high as these systems are O&M cost intensive.

Conclusion

A groundwater extraction system (i.e., pumping well system or collection trench) is eliminated from further consideration and evaluation due to effectiveness and cost concerns.

3.2.4 In-Situ Treatment

Biological treatment involves the use of microorganisms, primarily bacteria, actinomycetes, and fungi to breakdown hazardous organic compounds into nontoxic or less toxic forms. This technology would enhance natural attenuation of organic COCs by the injection of an electron donor (food source) to promote degradation activity in the subsurface (biostimulation).

This option would consist of using an ORC® to enhance the growth of indigenous microorganisms and natural biodegradation processes, while monitoring groundwater quality to determine the extent to which these microorganisms and processes would break down contaminants over time. ORC® such as hydrogen or magnesium peroxide could be used to enhance the aerobic biodegradation. This compound would initially be injected into the contaminant plume using direct push technology (DPT), after which a maintenance dosage would be periodically fed into monitoring wells if needed. New monitoring wells would be installed as required, and samples from these new wells and existing wells would be regularly collected and analyzed.

This option could also consist of bioventing or air diffusion [in-situ Submerged Oxygen Curtain (ISOC®)] to enhance the growth of indigenous microorganisms and natural biodegradation processes, while monitoring groundwater quality to determine the extent to which these microorganisms and processes would break down contaminants over time. Bioventing and air diffusion are similar to AS described in Section 3.2.4.2 below but they use low air flow rates to provide enough oxygen to sustain microbial activity. Bioventing generically involves the delivery of oxygen to the subsurface soils either through injection or extraction of air with blowers and wells to increase oxygen concentrations and stimulate biodegradation. A blower and new monitoring wells would be installed as required, and samples from these new wells and existing wells would be regularly collected and analyzed.

Effectiveness

In-situ aerobic biological treatment with ORC® or by bioventing or air diffusion is a well-proven technology that would be effective for the removal of benzene and other organic contaminants from the WOD site and the residual soil contamination. Certain air diffusion technologies,(e.g. ISOC®), are effective for contaminants dissolved in the groundwater and below the vadose zone but have limited or unproven effectiveness in treating contaminants above the water table. A treatability study may be needed in order to fully evaluate the process. In-situ aerobic biological treatment may also be effective in the treatment of the dissolved arsenic contamination. The arsenic contamination is most likely associated with the reduced environment created by the degradation of other WOD organic contaminants since the extent of the contamination is not widespread. In-situ aerobic treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Implementability

In-situ biostimulation aerobic biological treatment processes could be implemented. The DPT application of ORC® would be relatively unobtrusive. The DPT application of bioventing or air diffusion wells would also be relatively easy, the equipment and techniques are readily available, and these treatment processes have been used in similar situations. Implementation of bioventing or air diffusion would require O&M. Several qualified contractors would be available for the implementation of this technology.

Cost

Capital and O&M costs for in-situ biostimulation aerobic biological treatment would be low to moderate, depending on the extent of the area treated and the number of applications required for treatment.

Conclusion

In-situ biostimulation aerobic biological treatment is retained in combination with other processes options for the development of groundwater remedial alternatives.

3.2.4.2 In-Situ Aerobic Biological Treatment - Bioaugmentation

Biological treatment involves the use of microorganisms, primarily bacteria, actinomycetes, and fungi to breakdown hazardous organic compounds into nontoxic or less toxic forms. This technology would enhance natural attenuation of organic COCs by the injection of bacteria with degradation activity into the subsurface (bioaugmentation).

This option would consist of using a microbe, inoculum, and/or bacterium to enhance the existing indigenous microorganisms and natural biodegradation processes, while monitoring groundwater quality to determine the extent to which these microorganisms and processes would break down contaminants over time. The microbe, inoculum, and/or bacterium would initially be injected into the contaminant plume using DPT, after which a maintenance dosage may be periodically fed into monitoring wells if needed. New monitoring wells would be installed as required, and samples from these new wells and existing wells would be regularly collected and analyzed.

Effectiveness

In-situ biological treatment with the injection of bacteria is an innovative technology that is being tested in pilot-scale studies and is starting to be used in full-scale remedial actions. This technology would be effective for the removal of benzene from the WOD site and the residual soil contamination. A treatability study would be needed in order to fully evaluate the process. In-situ aerobic biological treatment may also be effective in the treatment of the dissolved arsenic contamination. The arsenic contamination is most likely associated with the reduced environment created by the degradation of other WOD organic contaminants since the extent of the contamination is not widespread. The in-situ bioaugmentation treatment would degrade the contaminants and the site would return to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Implementability

In-situ bioaugmentation aerobic biological treatment processes could be implemented. The DPT application of microbes, inoculum, and/or bacterium would be relatively unobtrusive. The technology would also be relatively easy, the equipment and techniques are readily available, and the treatment

processes have been used in similar situations. Several suppliers of the microbes, inoculum, and/or bacterium would be available for the implementation of this technology.

Cost

Capital and O&M costs for in-situ bioaugmentation aerobic biological treatment would be low to moderate, depending on the extent of the area treated and the number of applications required for treatment.

Conclusion

In-situ bioaugmentation biological treatment is retained in combination with other processes options for the development of groundwater remedial alternatives.

3.2.4.3 Air Sparging (AS) or Air Sparging/ Vapor Extraction (AS/VE)

AS consists of injecting air in the contaminant plume to induce an air current through the groundwater that promotes short-term stripping of VOCs and long-term biodegradation of organic contaminants (VOCs and SVOCs). Air is injected through a network of vertical or horizontal wells screened at various depths within the contaminant plume. If capture and treatment of vaporized groundwater COCs or if treatment of overlying soil is required, a VE system is added. In this case, a vacuum is applied through a network of vertical or horizontal wells screened in the vadose zone above the contaminant plume and the extracted vapors are collected and treated through vapor-phase GAC adsorption (if needed) prior to venting to atmosphere. When saturated, the GAC is replaced and sent off-site for regeneration or incineration. Groundwater samples are regularly collected and analyzed to monitor the progress of the remedial action and, if a VE system is used, offgas samples are collected and analyzed to evaluate its performance and to verify compliance with regulatory emission requirements.

Effectiveness

AS or AS/VE is a well proven technology that would be effective for the treatment of contaminated groundwater at the WOD site. AS or AS/VE would effectively remove VOCs in the plume, primarily through volatilization and, although probably less so, through enhanced aerobic biodegradation. In addition, AS will also reduce the concentration of VOCs and SVOCs in the contaminated soil (smear zone) that are suspected as contributing to the groundwater conditions and contamination.

However, there are certain limitations associated with AS that should be considered. One of these is that air flow through the saturated zone may not be uniform due to non-homogenous soil conditions. Another

limitation is that there may be some uncontrolled movement of potentially dangerous vapors. Although for the low concentration of contaminants at the WOD site and the absence of occupied buildings or the presence of site workers, these potential limitations are not expected to be significant. Also, because groundwater COC concentrations are relatively low and soil contamination is not a significant concern; no VE system would likely be required.

AS treatment may also be effective in the treatment of the dissolved arsenic contamination. The arsenic contamination is most likely associated with the reduced environment created by the degradation of other WOD organic contaminants since the extent of the contamination is not widespread. AS treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Implementability

AS or AS/VE would be relatively simple to implement at the WOD site. AS and VE wells and piping would have to be designed and located for minimum impact at the site. Several qualified contractors would be available for the implementation of this technology.

Cost

Capital and O&M costs would be low to moderate for AS and moderate for AS/VE.

Conclusion

AS is retained in combination with other process options for the development of groundwater remedial alternatives. The VE system would not be required at the WOD site with the low concentration of contaminants in the groundwater, the absence of occupied buildings, the absence of site workers, and the soil contamination is not of significant concern.

3.2.5 Ex-Situ Treatment

Ex-situ treatment would use aboveground facilities (tanks, equipment, chemicals, etc.) to treat the extracted contaminated groundwater. Ex-situ treatment is potentially effective and applicable but it would require groundwater extraction. Since groundwater extraction has not been retained for further consideration, treatment of the groundwater using ex-situ treatment processes has been eliminated from further consideration.

3.2.6 Disposal

This technology would consist of discharging the treated (or untreated) groundwater to a surface water body or to a POTW where it would undergo either the full or incremental treatment required for discharge. Disposal/discharge is potentially effective and applicable but it would require groundwater extraction and treatment. Because groundwater extraction has not been retained for further consideration, this technology has also been eliminated from further consideration.

3.3 SELECTION OF REPRESENTATIVE GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

The following technologies and process options are retained for development of groundwater remedial alternatives:

- No Action
- Institutional Controls
- Monitoring
- Natural Attenuation
- In-situ Biostimulation Aerobic Biological Treatment
- In-situ Bioaugmentation Aerobic Biological Treatment
- AS

4.0 ASSEMBLY AND DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

4.1 INTRODUCTION

This section presents an evaluation of each remedial alternative with respect to the criteria of the NCP of 40 CFR 300, as revised in 1990. The criteria as required by the NCP and the relative importance of these criteria are described in the following subsections.

4.1.1 Evaluation Criteria

In accordance with the NCP (40 CFR 300.430), the following nine criteria are used for the evaluation of remedial alternatives:

- Overall Protection of Human Health and the Environment,
- Compliance with ARARs,
- Long-term Effectiveness and Permanence,
- Reduction of Toxicity, Mobility, and Volume through Treatment,
- Short-term Effectiveness,
- Implementability,
- Cost,
- State Acceptance, and
- Community Acceptance.

Overall Protection of Human Health and the Environment

Alternatives must be assessed for adequate protection of human health and environment in both the short-and long-terms, from unacceptable risks posed by hazardous substances or contaminants present at the site by eliminating, reducing, or controlling exposure to concentrations exceeding remediation goals. Overall protection draws on the assessments of other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

Compliance with ARARs

Alternatives must be assessed to determine whether they attain ARARs under Federal environmental laws and state environmental or facility siting laws. If one or more regulations that are applicable cannot be complied with, then a waiver must be invoked. Grounds for invoking a waiver would depend on the circumstances described in Section 2.2.2.1 of this FS report.

Long-Term Effectiveness and Permanence

Alternatives must be assessed for the long-term effectiveness and permanence they offer, along with the degree of certainty that the alternative will prove successful. Factors that shall be considered as appropriate include the following:

Magnitude of Residual Risk:

Risk posed by untreated waste or treatment residuals at the conclusion of remedial activities. The characteristics of residuals should be considered to the degree that they remain hazardous, taking into account their volume, toxicity, mobility, and propensity to bioaccumulate.

Adequacy and reliability of controls:

Controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste must be shown reliable. In particular, the uncertainties associated with land disposal for providing long-term protection from residuals, the assessment for the potential need to replace technical components of the alternative (such as a cap, a slurry wall, or a treatment system), and the potential exposure pathways and risks posed should the remedial action need replacement must be considered.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The degree to which the alternative employs recycling or treatment that reduces the toxicity, mobility, or volume shall be assessed, including how treatment is used to address the principal threats posed by the site. Factors that shall be considered, as appropriate, include the following:

- The treatment or recycling processes the alternative employs and the materials that they will treat.
- The amount of hazardous substances, pollutants, or contaminants that will be destroyed, treated, or recycled.
- The degree of expected reduction in toxicity, mobility, or volume of waste due to treatment or recycling and the specification of which reduction(s) are occurring.
- The degree to which the treatment is irreversible.

- The type and quantity of residuals that will remain following treatment considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents.

- The degree to which treatment reduces the inherent hazards posed by principal threats at the site.

Short-Term Effectiveness

The short-term impacts of the alternative shall be assessed considering the following:

- Short-term risks that might be posed to the community during implementation.

- Potential impacts on workers during remedial action, and the effectiveness and reliability of protective measures.

- Potential environmental impacts of the remedial action, and the effectiveness and reliability of mitigative measures during implementation.

- Time until protection is achieved.

Implementability

The ease or difficulty of implementing the alternatives shall be assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy.

- Administrative feasibility, including activities needed to coordinate with other offices and agencies, and the ability and time required to obtain necessary approvals and permits from other agencies.

- Availability of services and materials, including the availability of adequate off-site treatment, storage capacity, and disposal capacity and services, the availability of necessary equipment and specialists, and necessary additional resources, the availability of services and materials, and availability of prospective technologies.

Cost

Capital costs shall include both direct and indirect costs. Annual O&M costs shall be provided. A net present worth (NPW) of the capital and O&M costs shall also be provided. The NPW was calculated using a discount rate of 3.5 percent based on the Office of Management and Budget Circular A-94 Appendix C that was updated in early 2004. Typically, the cost estimate accuracy range is plus 50 percent to minus 30 percent.

State Acceptance

The state's concerns that must be assessed include the following:

- The state's position and key concerns related to the preferred alternative and other alternatives
- State comments on ARARs or the proposed use of waivers

These concerns cannot be evaluated at this time in the FS until the State of Virginia has reviewed and commented on the FS. These concerns will be discussed, to the extent possible, in the Proposed Plan to be issued for public comments.

Community Acceptance

This assessment consists of soliciting community input to the Proposed Plan. This assessment includes determining which components of the alternatives interested persons in the community support, have reservations about, or oppose. This assessment can be done after comments on the Proposed Plan are received from the public.

4.1.2 Relative Importance of Criteria

Among the nine criteria, the threshold criteria are considered to be:

- Overall Protection of Human Health and the Environment
- Compliance with ARARs (excluding those that may be waived)

The threshold criteria must be satisfied in order for an alternative to be eligible for selection.

Among the remaining criteria, the following five criteria are considered to be the primary balancing criteria:

- Long-term Effectiveness and Permanence
- Reduction of Toxicity, Mobility, or Volume Through Treatment
- Short-Term Effectiveness
- Implementability
- Cost

The balancing criteria are used to weigh the relative merits of alternatives.

The remaining two of the nine criteria, namely State Acceptance and Community Acceptance are considered to be modifying criteria that must be considered during remedy selection. These last two criteria can be evaluated after the Proposed Plan has been reviewed by the State of Virginia and has been discussed in a public meeting. Therefore, this document addresses only seven out of the nine criteria.

4.1.3 Selection of Remedy

The selection of a remedy is a two-step process. The first step consists of identification of a preferred alternative and presentation of the alternative in a Proposed Plan to the community for review and comment. The preferred alternative must meet the following criteria:

- Protection of human health and the environment.
- Compliance with ARARs unless a waiver is justified.
- Cost effectiveness in protecting human health and environment and in complying with ARARs.
- Utilization of permanent solutions and alternate treatment technologies or resource recovery technologies to the maximum extent practicable.

The second step consists of the review of the comments and determination of whether or not the preferred alternative continues to be the most appropriate remedial action for the site, in consultation with the State of Virginia.

4.2 ASSEMBLY AND DETAILED ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES

The following alternatives have been developed for groundwater remediation at the WOD site:

1. No Action
2. Natural Attenuation, Institutional Controls, and Monitoring

3. In-Situ Aerobic Biological Treatment (Biostimulation), Institutional Controls, and Monitoring
4. In-Situ Aerobic Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring
5. In-Situ AS Treatment, Institutional Controls, and Monitoring

Alternative 1 was developed and analyzed to serve as a baseline for other alternatives, as required by CERCLA and the NCP.

Alternative 2 was formulated and analyzed to evaluate the adequacy of minimal action. For the WOD site in particular, Alternative 2 was evaluated because the natural attenuation analysis as described in Section 3 indicated strong evidence of an environment favorable to biodegradation in the Columbia Aquifer. The effectiveness of natural attenuation is supported by the fact that benzene concentrations in the plume have decreased since the 1997 and 1998 sampling events.

Alternatives 3, 4, and 5 were formulated to evaluate active remediation of the groundwater contamination at the WOD site. Active remediation at this site is being considered (even though the site is small) because past removal actions may have removed the primary source material and oil disposal practices have been changed according to current regulations. Alternatives 3, 4, and 5 represent in-situ treatment approaches.

A description and detailed analysis of these alternatives are provided in the following sections.

4.2.1 Alternative 1 - No Action

4.2.1.1 Description

This alternative is a "walk-away" alternative that is required under CERCLA to establish a basis for comparison with other alternatives. Under this alternative the property would be released for unrestricted use. This alternative cannot be chosen as the remedy if waste remains on site.

4.2.1.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative 1 would not provide protection of human health and the environment. The current potential for human exposure to contaminated groundwater would remain. Groundwater COCs might migrate that could adversely impact additional human and ecological receptors. Because no monitoring would be performed, potential contaminant migration would not be detected.

Compliance with ARARs and TBCs

Alternative 1 would not comply with chemical-specific ARARs or TBCs because no action would be taken to reduce concentrations of COCs. Compliance with location-specific ARARs or TBCs would be purely incidental. Action-specific ARARs or TBCs are not applicable.

Long-Term Effectiveness and Permanence

Alternative 1 would have no long-term effectiveness and permanence because contaminated groundwater would remain. As there would be no institutional controls to limit groundwater use, the potential would exist for unacceptable risk to develop for human receptors. Because there would be no groundwater monitoring, potential migration of COCs would not be detected. Although concentrations of COCs might eventually decrease to the cleanup goals through attenuation processes, no monitoring would be conducted to verify it.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 1 would not reduce toxicity, mobility, or volume of contaminants through treatment because no treatment would occur. Some reduction of contaminant toxicity or volume might occur through natural dispersion, dilution, or other attenuation process, but no monitoring would be performed to verify it.

Short-term Effectiveness

Since no action would occur, implementation of Alternative 1 would not pose a short-term risk to onsite workers or result in short-term adverse impacts to the local community and the environment. Alternative 1 would not achieve the RAOs and, although the cleanup goals might eventually be achieved through natural attenuation, the time of compliance would not be known.

Implementability

Because no action would occur, Alternative 1 would be readily implementable. The technical feasibility criteria including constructability, operability, and reliability are not applicable. Implementability of administrative measures is not applicable because no such measures would be taken.

Cost

There would be no capital or periodic costs associated with the No-Action alternative.

4.2.2 Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring

4.2.2.1 Description

Alternative 2 was formulated and analyzed to evaluate the adequacy of minimal action. For the WOD site in particular, Alternative 2 was evaluated because the natural attenuation analysis in Section 3 indicated strong evidence of an environment favorable to biodegradation of benzene and other organic contaminants in the Columbia Aquifer. The effectiveness of natural attenuation is supported by the fact that the concentrations of benzene in the plume have decreased since the 1997 and 1998 sampling events.

Alternative 2 is illustrated on Figure 4-1 and would consist of three major components: (1) natural attenuation, (2) institutional controls, and (3) monitoring.

Component 1: Natural Attenuation

Natural attenuation would rely on naturally occurring processes within the Columbia Aquifer to significantly reduce the concentrations of benzene and other organic contaminants. These processes include a combination of biodegradation, dispersion, dilution, and adsorption in various proportions depending on the aquifer conditions. Aquifer conditions would be continually monitored to make sure that they are favorable and to verify that concentrations of COCs are indeed being adequately reduced.

The arsenic contamination is most likely associated with the reduced environment created by the degradation of the WOD organic contaminants. The extent of the arsenic contamination is limited to one well that is on the downgradient edge of the area exhibiting the highly reducing environment. When the natural attenuation processes complete the biodegradation of the benzene and other organic contaminants, the conditions at the site will return to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Component 2: Institutional Controls

Institutional controls would consist of prohibiting the use of the groundwater from the Columbia Aquifer for drinking purposes until the cleanup goals are met. Use of groundwater would be controlled through restrictions documented in the Facility Master Plan. LUC plans would be prepared and would prohibit the installation of drinking water wells that would draw water from the Columbia Aquifer.

Regular site inspections would be performed to verify implementation of the institutional controls until cleanup goals are met. The frequency of these inspections is typically based upon the allowable time of exposure before an unacceptable human health risk associated with residential exposure would develop. At a minimum, the planning and construction phases for a residence is expected to be one year considering the site is located on or near a flightline. Consequently the frequency of site inspections should be annual.

Component 3: Monitoring

Monitoring would consist of regularly collecting and analyzing groundwater samples both from within the contaminant plume to assess performance of the natural attenuation processes and downgradient of the leading edge of the contaminant plumes to verify that COCs are not migrating.

Based on the results of the modeling presented in Appendix B, performance monitoring would take place for a minimum of 5 years at the WOD site. This monitoring would consist of collecting groundwater samples from 9 monitoring wells (7 existing and 2 new monitoring wells) at the WOD site. The two new monitoring wells, an intermediate (15 to 20 feet bgs) and a deep well (25 to 30 feet bgs), would be clustered with the shallow well WFF16-GW5. These new wells would provide improved vertical coverage for monitoring the downgradient edge of the contaminant plume in the Columbia Aquifer.

Groundwater samples would be analyzed for VOCs (e.g., benzene, tetrachloroethene, xylene, and 1,2,4-trimethylbenzene, and any associated degradation compounds identified to be appropriate), SVOCs (e.g., 4-methylphenol and naphthalene), and total and dissolved (field-filtered) metals (arsenic). In addition, during these 5 years, samples would also be analyzed for natural attenuation indicator parameters such as ORP, DO, pH, alkalinity, temperature, conductivity, TOC, ferrous and total iron, sulfur compounds (sulfates, hydrogen sulfide, sulfides), orthophosphates, chloride, metabolic gases (methane, ethane, and ethene), and CO_2.

For cost estimating purposes, the sampling frequency was assumed to be quarterly for the first year, semi-annually for the next 2 years, and annually thereafter. Periodic review and reporting of analytical results could be used to optimize the monitoring program (reduce or increase the number and frequency of samples and vary the analytical parameters). However, for cost estimating purposes this optimization was not predicted. If the results of four consecutive sampling events indicate that the cleanup goals have been met, the site would be considered as remediated. For cost estimating purposes, it was assumed that monitoring to verify that contaminant plumes are not expanding and COCs are not migrating would take place over a period of approximately 5 years at the WOD site. Based on the results of the COC migration modeling provided in Appendix B, 6 of the 9 proposed monitoring wells (monitoring wells

WFF16-GW5S, WFF16-GW5I, WFF16-GW5D, WFF15-GW1, WFF16-GW3, and WFF16-GW4) would be designated as “sentinel” wells. If analysis of the groundwater collected from these “sentinel” wells indicate that the groundwater cleanup goals have been exceeded, the following step-by-step actions would be taken:

1. The sentinel wells where the exceedance was detected would be re-sampled to verify the exceedance.

2. If the exceedance is verified, additional hydrogeological modeling would be performed to determine a revised predicted expansion of the contaminant plume based upon the new monitoring data.

3. If the revised expansion of the contaminant plume predicted by the additional modeling is such that it would be of concern, contingency remedies would be developed.

Reviews would be performed every 5 years to evaluate site status, assess the continued adequacy of remedial activities, and determine whether further action is necessary. These five-year site reviews are required because this alternative allows contaminants to remain in groundwater at concentrations in excess of cleanup goals.

The monitoring component would include the maintenance of the wells that are included in the monitoring program. If there is a change in the ownership of the WOD site from the U.S. government to the private sector, provisions will need to be incorporated into the property transfer documents to make sure that monitoring and LUCs would continue.

4.2.2.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative 2 would be protective of human health and the environment.

Natural attenuation would be protective of human health and the environment as it would eventually reduce COC concentrations to the cleanup goals. Results of the cleanup time projections presented in Appendix B also indicate that this attenuation would be achieved within a reasonable timeframe.

Institutional controls would be protective of human health by prohibiting the use of the groundwater from the Columbia Aquifer for drinking purposes until the cleanup goals are met, thus preventing unacceptable risks from potential future exposure to contaminated groundwater.

Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of COCs so that appropriate contingency measures can be taken, if required.

Some short-term risks could be incurred by workers from exposure to contamination during implementation of this alternative. However, the potential for such exposure would be minimized by the wearing of appropriate personal protection equipment (PPE) and compliance with site-specific health and safety procedures.

No adverse short-term or cross-media effects are anticipated as a result of implementing this alternative.

Compliance with ARARs and TBCs

Alternative 2 would comply with location- and action-specific ARARs and TBCs. In the short-term, Alternative 2 would not comply with chemical-specific ARARs, but compliance would eventually be achieved as natural processes within the aquifer would reduce COC concentrations.

Long-Term Effectiveness and Permanence

Alternative 2 would provide long-term effectiveness and permanence.

Naturally-occurring processes would effectively and permanently reduce the benzene concentrations to the cleanup goal. This is supported by the results of the natural attenuation monitoring and modeling conducted at WOD site and reported upon in Section 3 of this FS Report. These results show evidence of an environment favorable to biodegradation in the Columbia Aquifer where these COCs have been detected. Long-term effectiveness of natural attenuation for the reduction of groundwater benzene concentrations is also supported by USEPA guidance and directives (USEPA, 1999). When the natural attenuation processes to biodegrade the benzene has been completed, the conditions at the site will change to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Until the cleanup goals are met, risk from exposure to contaminated groundwater would be addressed through institutional controls. Groundwater use restrictions would effectively prevent the use of the Columbia Aquifer as a potable water source.

Long-term monitoring would be an effective means to evaluate the progress of natural attenuation and detect the potential migration of COCs.

Reduction of Toxicity, Mobility, or Volume through Treatment

Although no active treatment is included in this alternative, the toxicity and volume of groundwater COCs would be irreversibly reduced over time through natural processes. Alternative 2 would not provide an immediate reduction in contaminant mobility because neither groundwater containment nor extraction is proposed. This alternative would not increase the rate of natural transformation processes that reduce the toxicity, mobility, or volume of contaminants in groundwater, but the contaminant reduction achieved by biodegradation monitored in Alternative 2 would be irreversible. Small quantities of residuals would be produced if Alternative 2 were implemented from the installation and development of the new monitoring wells and purging of the groundwater wells prior to the monitoring.

Short-term Effectiveness

Alternative 2 would have minimal short-term effectiveness concerns. Exposure of workers to contamination during installation of monitoring wells and groundwater sampling would be minimized by wearing of appropriate PPE and complying with site-specific health and safety procedures. Alternative 2 would also not adversely impact the surrounding community or the environment.

The first RAO would be achieved immediately upon implementation of institutional controls and monitoring.

Cleanup time projections, as presented in Appendix B, indicate that Alternative 2 would achieve the second RAO and meet the groundwater cleanup goals through natural attenuation within approximately 5 years at the WOD site (i.e., estimated 4 years plus 1 contingency year).

The reasonableness of this remediation timeframe can be evaluated against the eight criteria provided in the OSWER Directive 9200.4-17P (USEPA, 1999) as discussed below:

Classification of the Groundwater - The Columbia Aquifer is an unconfined water-table aquifer where the direct route of recharge into the aquifer is through infiltration of rainfall, and therefore surficial conditions may affect the quality of the aquifer. Groundwater is the only source for drinking, agricultural, and process water within the WFF area. This is generally true for a large portion of the Eastern Shore. Because of the reliance on groundwater and the coastal proximity of the area, the Commonwealth of Virginia has declared the Eastern Shore of Virginia a Critical Groundwater Area.

Relative Timeframe in Which the Affected Portion Might Be Used As A Future Source - The WFF and the surrounding communities rely on groundwater, primarily from the Yorktown formation, for drinking water supplies. The upper Yorktown Aquifer generally occurs at a depth of about 50 to 100 feet bgs and is isolated from the overlying Columbia aquifer by a clay and silt aquitard that is approximately 20 to 40 feet thick. Aquifer tests at the WFF indicate that there is no significant vertical leakage across the confining unit separating the upper Yorktown aquifer from the overlying Columbia. The development of the shallow aquifer as a water supply is highly unlikely in that the lower Yorktown aquifer is more productive. In addition the WOD is located within an area designated as a Groundwater Management Area under the Virginia Groundwater Management Act. Groundwater use in the area is managed and controlled through a permit application and review process administered by DEQ, the Virginia Department of Health, and the Accomack County Health Department. These agencies operate in consultation with the Accomack-Northampton Planning District Committee and the Eastern Shore of Virginia Groundwater Committee who administer the Groundwater Supply Protection and Management Plan adopted by the county. Under this program, NASA has abandoned the water supply wells that withdraw from the Columbia aquifer.

Subsurface Conditions and Plume Stability-The Columbia Aquifer is composed primarily of fine- to medium-sand with lesser amounts of silt and clay. A silty clay layer was encountered approximately 50 feet below the ground surface which is interpreted as the upper aquitard of the Yorktown Formation. No materials were observed that would create a significant change in the direction or velocity of the groundwater flow. Storm water and run-off controls near the runway are in place and are unlikely to be moved. Thus, the groundwater flow will not be affected by changes in the distribution of run-off and percolation.

Long-Term Impact of Contamination on Water Supplies-There are no water supplies either within or downgradient of the contaminant plume, so there is no long-term impact on water supplies. In addition, the nearest receiving water (unnamed tributary to Little Mosquito Creek and the Little Mosquito Creek) where the contaminants in the groundwater could migrate to is more than 200 feet away from the leading edges of the benzene and arsenic plumes. Based on the results of the modeling presented in Appendix B, the benzene contaminant plume is not predicted to reach this far.

Uncertainties Regarding Mass of Contaminants And Predictive Analyses-Physical properties of the formation were derived from the Supplemental RI field investigation and also relied on information from other sites (Former Fire Training Area and Old Aviation Fuel Tank Farm) at WFF. The Columbia aquifer is generally consistent throughout WFF, so information from one part of WFF can reasonably be applied at other parts of WFF. This information was used for the selection of conservative inputs to the modeling presented in Appendix B. Because of the conservativeness of these inputs, the predicted remediation time is expected to be conservative also.

Reliability of Monitoring And Institutional Controls Over Time-NASA is aware of and sensitive to the environmental issues at the site and; therefore, long-term maintenance of monitoring and institutional controls is expected.

Public Acceptance of Timeframe-Because this FS has not yet been presented to the public, its acceptance of the remediation timeframe for this alternative cannot yet be evaluated.

Provisions by Responsible Party for Adequate Monitoring and Evaluation-NASA will be making the provisions for monitoring and evaluation. This includes performing the required five-year reviews to monitor the progress of each site.

In summary:

- There are no current users or anticipated users of the Columbia Aquifer.
- The subsurface and surface conditions are favorable to stable and consistent groundwater flow conditions.
- No detrimental impacts on other water supplies or environmental resources are predicted.
- NASA is committed to continuing the monitoring of the site if required (as has been done at other sites) and has the resources to maintain institutional controls and monitor environmental conditions.
- Conservative values were used in the model so uncertainties in the time frame are expected to be conservative also.

The above factors support the conclusion that the estimated remediation timeframe of approximately 5 years for the WOD site may be considered as reasonable.

Implementability

The technical implementation of Alternative 2 would be simple as it would only require installation of two new monitoring wells and routine monitoring and maintenance activities.

The administrative implementation of Alternative 2 would be simple. Well permits will be required for the installation of the new wells. No construction permits would be required for this alternative. Appropriate

provisions will be required to make sure of continued implementation of groundwater use restrictions and monitoring.

Cost

The estimated costs for Alternative 2 are:

- Capital Cost: $ 37,000
- 5-Year NPW of O&M Cost: $187,000
- 5-Year NPW: $224,000

A detailed cost estimate for this alternative is provided in Appendix C.

4.2.3 Alternative 3: In-Situ Biological Treatment (Biostimulation), Institutional Controls, and Monitoring

4.2.3.1 Description

Alternative 3 was formulated to evaluate active remediation of the entire contaminant plume at the WOD site. Active remediation at this site is being considered (even though the site is small) because past actions may have removed the primary source material and oil disposal practices have been changed according to current regulations.

Alternative 3 is illustrated on Figure 4-2 and would consist of three major components: (1) in-situ biological treatment (biostimulation) with ORC® injection, (2) institutional controls, and (3) monitoring.

Component 1: In-situ Biostimulation Treatment (ORC®)

In-situ biostimulation treatment would consist of using ORC® to enhance/stimulate the growth of indigenous microorganisms and augment natural biodegradation processes to breakdown the benzene and other organic contaminants into nontoxic forms in the contaminant plume. The enhancement/stimulation of the indigenous microorganisms will increase the rate of biodegradation. A bench-scale treatability study would be required to verify the effectiveness of this alternative and to verify site-specific dosage requirements. The ORC® would be injected into the plume and/or overlying soils using DPT. The groundwater plume would be treated with an ORC® such as magnesium peroxide. Based upon the information obtained from a qualified remediation contractor specializing with this technology, the following ORC® treatment scheme is assumed.

The groundwater plume that consists of benzene would be treated with ORC®. The treatment would consist of injecting ORC® into the plume. The application of ORC® would be performed with an injection system consisting of 12, 30-foot deep DPT injection points at a spacing of 30 feet. The ORC® would be injected at the rate of 450 pounds per injection point in the upper 10-feet of the aquifer (approximately 20 to 30 feet bgs resulting in 5,400 pounds plus a contingency of 300 pounds) for a total of 5,700 pounds of ORC®injected. For the purposes of this FS, it is assumed that no repeat ORC® application would be required.

The arsenic contamination is most likely associated with the reduced environment created by the degradation of the WOD organic contaminants. The extent of the arsenic contamination is not widespread and is found in one well that exhibits the highly reduced environment. In-situ aerobic treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

The exact nature of the treatment scheme would be verified through treatability testing prior to implementation.

Component 2: Institutional Controls

This component would be identical to Component 2 of Alternative 2.

Component 3: Monitoring

Monitoring would consist of regularly collecting and analyzing groundwater samples both from within the contaminant plume to assess performance of the in-situ biodegradation processes and downgradient of the leading edge of the plume to evaluate potential migration of COCs.

Performance monitoring for Alternative 3 would be identical to that for Alternative 2, and monitoring would only last approximately 3 years at the WOD site based on the modeling in Appendix B and 50% source removal (i.e., approximately 2 years plus 1 contingency year). This would include the analysis of the same natural attenuation parameters as in Alternative 2.

Monitoring for potential migration of COCs would be identical to that for Alternative 2 and monitoring would only last approximately 3 years at the WOD site based on the modeling in Appendix B and 50% source removal (i.e., approximately 2 years plus 1 contingency year). The monitoring component would include the maintenance of the existing wells that are sampled.

At the end of five years, a review would be conducted to evaluate site status, assess the continued adequacy of remedial activities, and determine whether further action is necessary.

4.2.3.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative 3 would be protective of human health and the environment.

In-situ biological treatment with ORC® injection would be protective of human health and the environment as it would actively reduce benzene concentrations to concentrations that would no longer constitute an unacceptable human health risk.

Institutional controls would be protective of human health by prohibiting the use of the groundwater from the Columbia Aquifer for drinking purposes until the cleanup goals are met, thus preventing unacceptable risks from potential exposure to contaminated groundwater.

Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of COCs so that appropriate contingency measures could be taken, if required.

Some short-term risks could be incurred by workers from exposure to contamination during implementation of this alternative. However, the potential for this exposure would be minimized by the wearing of appropriate PPE and compliance with site-specific health and safety procedures.

No adverse short-term or cross-media effects are anticipated as a result of implementing this alternative.

Compliance with ARARs and TBCs

Alternative 3 would eventually comply with chemical-specific ARARs and TBCs through active in-situ biological treatment. Alternative 3 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative 3 would provide long-term effectiveness and permanence.

In-situ biological treatment with ORC® injection would effectively and permanently remove groundwater COCs. ORC® injection is a well-established and proven technology for the treatment of organic compounds and treatability testing would be needed to verify its site-specific effectiveness.

Groundwater use restrictions would effectively prevent the use of the Columbia Aquifer as a potable water source until the cleanup goals have been achieved.

Long-term groundwater monitoring would be an effective means to evaluate progress of remediation and verify that no contaminant migration is occurring.

The components proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 3 would reduce the toxicity and volume of groundwater COCs through biological treatment. The ORC® injection systems of this alternative are designed to irreversibly remove a total of approximately 31 pounds of petroleum contaminants (approximately 0.0125 pounds of dissolved benzene from the contaminated groundwater plume and 31 pounds of residual petroleum contamination smeared onto the soil) over their operating life. Because this removal would be achieved through biodegradation, it would be irreversible. During in-situ biological treatment with ORC®,COCs may degrade into daughter products that are potentially more mobile than the parent compound. Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of COCs and degradation compounds so that appropriate contingency measures could be taken, if required. Small quantities of residuals would be produced from the installation of the treatment system, from the installation and development of the new monitoring wells, and from the purging of the groundwater wells for the monitoring.

Short-Term Effectiveness

There would be minimal short-term concerns associated with implementation of Alternative 3. Exposure of onsite workers to contamination during installation of DPT injection points and monitoring wells and groundwater sampling would be minimized by wearing of appropriate PPE and complying with site-specific health and safety procedures. Implementation of this alternative would also not adversely impact the surrounding community or the environment.

The first RAO would be achieved immediately upon implementation of institutional controls and monitoring.

Based on the information received from a qualified contractor and the fate and transport modeling results provided in Appendix B, it is anticipated that ORC® treatment would achieve the second RAO and lower concentrations of groundwater COCs to cleanup goals within approximately 3 years at the WOD site.

Implementability

Alternative 3 would be readily implementable.

Injection of ORC® would be technically implementable but would require the installation of a number of DPT injection points (approximately 12). The location of this activity is near the runway and would need to be completed so that the activity would not interfere with the functions of the active airport facilities. Any interference would be very temporary in nature. Treatability testing would have to be performed to verify the effectiveness and the design parameters for the in-situ biological treatment injection. Groundwater monitoring and performance of five-year reviews could easily be accomplished. Although the number of contractors qualified for the application of ORC® is relatively limited, the resources, equipment, and materials required for these activities are readily available.

The administrative aspects of Alternative 3 would be relatively simple to implement. The substantive requirements of an Underground Injection Control (UIC) permit would have to be met for the injection of ORC®. A construction permit might also be needed for installation of the DPT injection points, but such a permit would be easy to secure. Appropriate provisions will be implemented at WFF to make sure continued implementation of groundwater use restrictions and monitoring.

Cost

The estimated costs for Alternative 3 are:

- Capital Cost: $240,000
- 5-Year NPW of O&M Cost: $157,000
- 5-Year NPW: $397,000

Detailed cost estimates for this alternative are provided in Appendix C.

4.2.4 Alternative 4: In-Situ Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring

4.2.4.1 Description

Alternative 4 was formulated to evaluate active remediation of the entire contaminant plume at the WOD site. Active remediation at this site is being considered (even though the site is small) because past actions may have removed the primary source material and oil disposal practices have been changed according to current regulations.

Alternative 4 is illustrated on Figure 4-3 and would consist of three major components: (1) in-situ biological treatment (bioaugmentation) with SSWM/U.S. Microbics nutrients and microbes injection, (2) institutional controls, and (3) monitoring.

Component 1: In-situ Bioaugmentation Treatment (SSWM/U.S. Microbics nutrients and microbes)

In-situ bioaugmentation treatment would consist of using SSWM/U.S. Microbics nutrients and microbes to augment natural biodegradation processes in the contaminant plumes. SSWM/U.S. Microbics nutrients and microbes would be injected using DPT at 30-foot well spacing. The groundwater plume would be treated with SSWM/U.S. Microbics nutrients and microbes. Based upon the information obtained from a qualified remediation contractor specializing with this technology (SSWM/U.S. Microbics, see Appendix A), the following SSWM/U.S. Microbics nutrients and microbes treatment scheme is assumed.

The groundwater plume that consists of benzene would be treated with SSWM/U.S. Microbics nutrients and microbes. The application of SSWM/U.S. Microbics nutrients and microbes would be performed with an injection system consisting of 12, 30-foot deep DPT injection points in which SSWM/U.S. Microbics nutrients and microbes would be injected in the upper 10-feet of the aquifer (approximately 20 to 30 feet bgs). For the purposes of this FS, it is assumed that no repeat SSWM/U.S. Microbics nutrients and microbes application would be required.

The arsenic contamination is most likely associated with the reduced environment created by the degradation of the WOD organic contaminants. The extent of the arsenic contamination is not widespread and is found in one well that exhibits the highly reduced environment. When the in-situ bioaugmentation processes to biodegrade the VOCs has been completed, the conditions at the site will return to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

The exact nature of the treatment scheme would be verified through treatability testing prior to implementation.

Component 2: Institutional Controls

This component would be identical to Component 2 of Alternative 2.

Component 3: Monitoring

Monitoring would consist of regularly collecting and analyzing groundwater samples both from within the contaminant plume to assess performance of the in-situ biodegradation processes and downgradient of the leading edge of the plume to evaluate potential migration of COCs.

Performance monitoring for Alternative 4 would be identical to that for Alternative 2, and monitoring would last approximately 3 years at the WOD site based on the modeling in Appendix B and 50% source removal (i.e., approximately 2 years plus 1 contingency year). This would include the analysis of the same natural attenuation parameters as in Alternative 2.

Monitoring for potential migration of COCs would be identical to that for Alternative 2, and monitoring would last approximately 3 years at the WOD site based on the modeling in Appendix B and 50% source removal (i.e., approximately 2 years plus 1 contingency year). The monitoring component would include the maintenance of the existing wells that are sampled.

At the end of five years, a review would be conducted to evaluate site status, assess the continued adequacy of remedial activities, and determine whether further action is necessary.

4.2.4.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative 4 would be protective of human health and the environment.

In-situ biological treatment with SSWM/U.S. Microbics nutrients and microbes injection would be protective of human health and the environment as it would actively reduce COCs concentrations to concentrations that would no longer constitute an unacceptable human health risk.

Institutional controls would be protective of human health by prohibiting the use of the groundwater from the Columbia aquifer for drinking purposes until the cleanup goals are met, thus preventing unacceptable risks from potential exposure to contaminated groundwater.

Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of COCs so that appropriate contingency measures could be taken, if required.

Some short-term risks could be incurred by workers from exposure to contamination during implementation of this alternative. However, the potential for this exposure would be minimized by the wearing of appropriate PPE and compliance with site-specific health and safety procedures.

No adverse short-term or cross-media effects are anticipated as a result of implementing this alternative.

Compliance with ARARs and TBCs

Alternative 4 would eventually comply with chemical-specific ARARs and TBCs through active in-situ biological treatment. Alternative 4 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative 4 would provide long-term effectiveness and permanence.

In-situ biological treatment with SSWM/U.S. Microbics nutrients and microbes injection would effectively and permanently remove groundwater COCs. SSWM/U.S. Microbics nutrients and microbes injection is an established and proven technology for the treatment of organic compounds and treatability testing would be needed to verify its site-specific effectiveness.

Groundwater use restrictions would effectively prevent the use of the Columbia aquifer as a potable water source until the cleanup goals have been achieved.

Long-term groundwater monitoring would be an effective means to evaluate progress of remediation and verify that no contaminant migration is occurring.

The components proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 4 would reduce the toxicity and volume of groundwater COCs through biological treatment. The SSWM/U.S. Microbics nutrients and microbes injection system of this alternative is designed to irreversibly remove a total of approximately 31 pounds of petroleum contaminants (approximately 0.0125 pounds of dissolved benzene from the contaminated groundwater plume and 31 pounds of residual petroleum contamination smeared onto the soil) over their operating life. Because this removal would be achieved through biodegradation, it would be irreversible. During in-situ biological treatment via bioaugmentation, COCs may degrade into daughter products that are potentially more mobile than the parent compound. Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of COCs and degradation compounds so that appropriate contingency measures could be taken, if required. Small quantities of residuals would be produced from the installation of the treatment system, from the installation and development of the new monitoring wells, and from the purging of the groundwater wells for the monitoring.

Short-Term Effectiveness

There would be minimal short-term concerns associated with implementation of Alternative 4. Exposure of onsite workers to contamination during installation of DPT injection points and monitoring wells and groundwater sampling would be minimized by wearing of appropriate PPE and complying with site-specific health and safety procedures. Implementation of this alternative would also not adversely impact the surrounding community or the environment.

The first RAO would be achieved immediately upon implementation of institutional controls and monitoring.

Based on the fate and transport modeling in Appendix B and the information received from a qualified contractor, it is anticipated that SSWM/U.S. Microbics nutrients and microbes treatment would achieve the second RAO and lower concentrations of groundwater COCs to cleanup goals within approximately 3 years at the WOD site.

Implementability

Alternative 4 would be readily implementable.

Injection of SSWM/U.S. Microbics nutrients and microbes would be technically implementable but would require the installation of a significant number of DPT injection points (approximately 12). The location of

this activity is near the runway and would need to be completed so that the activity would not interfere with the functions of the active airport facilities. Any interference would be very temporary in nature. Treatability testing would have to be performed to verify the effectiveness and the design parameters for the in-situ biological treatment injection. Groundwater monitoring and performance of five-year reviews could easily be accomplished. Although the number of contractors qualified for the application of SSWM/U.S. Microbics nutrients and microbes is relatively limited, the resources, equipment, and materials required for these activities are readily available.

The administrative aspects of Alternative 4 would be relatively simple to implement. The substantive requirements of an UIC permit would have to be met for the injection of SSWM/U.S. Microbics nutrients and microbes. A construction permit might also be needed for installation of the DPT injection points, but such a permit would be easy to secure. Appropriate provisions will be implemented at WFF to make sure continued implementation of groundwater use restrictions and monitoring.

Cost

The estimated costs for Alternative 4 are:

- Capital Cost: $175,000
- 5-Year NPW of O&M Cost: $355,000
- 5-Year NPW: $530,000

Detailed cost estimates for this alternative are provided in Appendix C.

4.2.5 Alternative 5: In-Situ AS Treatment, Institutional Controls, and Monitoring

Alternative 5 was formulated to evaluate active remediation of the entire contaminant plume at the WOD site. Remediation of the entire contaminant plume at the WOD includes the benzene plume of approximately 0.2 acres (8,400 square feet).

Alternative 5 is illustrated on Figure 4-4 and would consist of three major components: (1) AS treatment, (2) institutional controls, and (3) monitoring.

4.2.5.1 Detailed Description

Component 1: AS Treatment

This component would consist of installing an AS system and operating the system for a period of approximately 2 years at the WOD site. Figure 4-5 shows the process flow diagram for a typical AS System. The AS system would consist of one or more AS blower systems, each connected to an array of AS wells screened to a specific depth. Each AS blower system would feature a blower and the necessary instrumentation and controls. The AS blower system would be placed in a pre-engineered, pre-constructed structure in a fenced-in area.

Design AS flows would be 6 to 12 cubic feet per minute (cfm) per well. Based upon the operating results of similar AS system at the Old Aviation Fuel Tank Farm and factoring in a conservative overlap, it is assumed that the effective treatment area and radius of influence (ROI) of each AS well would be 700 ft^2 and 15 feet, respectively.

The AS system would feature air blower systems connected to an array of AS wells. For the WOD contaminant plume, the AS blower system would consist of one 150 cfm blower. The AS well array would consist of 12 wells screened from 15 to 20 feet below the water table (35 to 40 feet bgs). Conceptual design calculations for the AS systems are provided in Appendix A.

The arsenic contamination is most likely associated with the reduced environment created by the degradation of the WOD VOC contaminants. The extent of the arsenic contamination is not widespread and is found at one well that exhibits the highly reduced environment. AS treatment would change the site to an oxic environment that should cause the arsenic to transform to insoluble oxidized compounds.

Component 2: Institutional Controls

This component would be identical to Component 2 of Alternative 2.

Component 3: Monitoring

This component would be identical to Component 3 of Alternative 2, except that performance monitoring samples would not be analyzed for natural attenuation parameters and the monitoring would occur for approximately 3 years based on the modeling in Appendix B and 50% source removal (i.e., approximately 2 years plus 1 contingency year).

4.2.5.2 Detailed Analysis

Overall Protection of Human Health and the Environment

Alternative 5 would be protective of human health and the environment.

AS treatment of the WOD contaminant plume would be protective of human health and the environment as it would actively reduce COC concentrations to concentrations that would no longer constitute a human health risk. The cleanup time projections presented in Appendix B indicate that this attenuation would be achieved within a reasonable timeframe.

Institutional controls would be protective of human health by prohibiting the use of the groundwater from the Columbia Aquifer for drinking purposes until the cleanup goals are met, thus preventing unacceptable risks from potential future exposure to contaminated groundwater.

Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of contaminated groundwater so that appropriate contingency measures could be taken, if required.

Some short-term risks could be incurred by workers from exposure to contamination during implementation of this alternative. However, the potential for this exposure would be minimized by the wearing of appropriate PPE and compliance with site-specific health and safety procedures. Fugitive emissions would also result from AS treatment and it is conservatively estimated that the maximum initial level of fugitive emission would not exceed the VDEQ de minimis level based on the concentrations in the soil.

No adverse short-term or cross-media effects are anticipated as a result of implementing this alternative.

Compliance with ARARs and TBCs

Alternative 5 would eventually comply with chemical-specific ARARs and TBCs through in-situ AS treatment. Alternative 5 would also comply with location- and action-specific ARARs and TBCs.

Long-Term Effectiveness and Permanence

Alternative 5 would provide long-term effectiveness and permanence.

AS treatment would effectively and permanently remove groundwater COCs. AS treatment is a well-established technology and its effectiveness has been proven at similar sites.

Groundwater use restrictions would effectively prevent the use of the Columbia aquifer as a potable water source until the cleanup goals have been achieved.

Long-term monitoring would be an effective means to evaluate the progress of remediation and verify that no contaminant migration is occurring.

The components proposed in this alternative are considered reliable.

Reduction of Toxicity, Mobility, or Volume through Treatment

Alternative 5 would reduce the toxicity and volume of groundwater COCs through AS treatment. The AS systems of Alternative 5 are designed to irreversibly remove a total of approximately 31 pounds of petroleum contaminants (approximately 0.0125 pounds of dissolved benzene from the contaminated groundwater plume and 31 pounds of residual petroleum contamination smeared onto the soil) over its operating life. Alternative 5 would be irreversible. AS treatment, especially during the early stages, may change the local groundwater flow regime and contaminant migration pathways at the WOD site. Monitoring would be protective of the environment by evaluating the progress of remediation and detecting potential migration of contaminated groundwater so that appropriate contingency measures could be taken, if required. Small quantities of residuals would be produced from the installation of the treatment system, from the installation and development of the new monitoring wells, and from the purging of the groundwater wells for the monitoring.

Short-Term Effectiveness

There would be minimal short-term concerns associated with implementation of Alternative 5. Exposure of workers to contamination during installation of AS and monitoring wells and groundwater sampling would be minimized by wearing of appropriate PPE and complying with site-specific health and safety procedures. Implementation of this alternative would also not adversely impact the surrounding community or the environment.

The first RAO would be achieved immediately upon implementation of institutional controls and monitoring.

Based on the performance of similar AS systems currently operating and the results of the fate and transport modeling presented in Appendix B, it is anticipated that the second RAO and the groundwater cleanup goals would be achieved within approximately 3 years at the WOD site.

Implementability

Alternative 5 would be implementable.

Although it could be implemented for the WOD contaminant plume, installation of the AS system featuring 12 AS wells and several thousand feet of air distribution piping over an area approximately 0.2 acres would have somewhat of an impact. However, the site interference would be relatively temporary in nature. The placement of the building for housing the system would need to be coordinated with NASA to avoid any impact on the fight line. Qualified personnel would be required to operate and maintain this system; and such personnel are available. Installation of new monitoring wells, maintenance of new and existing monitoring wells, sampling and analysis of groundwater, and if necessary of surface water and sediment, and performance of five-year reviews could easily be accomplished. The resources, equipment, and materials required for these activities are readily available.

The administrative aspects of Alternative 5 would be relatively simple to implement. This alternative would require construction permits and possibly erosion and sediment control plans for installation of the AS systems but such permits would be simple to obtain. Appropriate provisions will be implemented at WFF to make sure continued implementation of groundwater use restrictions and monitoring.

Cost

The estimated costs for Alternative 5 for the WOD contaminant plume are:

- Capital Cost: $307,000
- 5-Year NPW of O&M Cost: $186,000
- 5-Year NPW: $493,000

A detailed cost estimate for this alternative is provided in Appendix C.

5.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

This section compares the analyses for each of the remedial alternatives presented in Section 4.0 of this FS. The criteria for comparison are identical to those used for the detailed analysis of individual alternatives.

5.1 COMPARISON OF GROUNDWATER REMEDIAL ALTERNATIVES BY CRITERIA

The following remedial alternatives for the WOD groundwater are being compared in this section:

- Alternative 1: No Action
- Alternative 2: Natural Attenuation, Institutional Controls, and Monitoring
- Alternative 3: In-Situ Biological Treatment (Biostimulation), Institutional Controls, and Monitoring
- Alternative 4: In-Situ Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring
- Alternative 5: In-Situ AS Treatment, Institutional Controls, and Monitoring

5.1.1 Overall Protection of Health and Environment

Alternative 1 would not provide protection of human health and the environment because contaminants would remain in groundwater, and potential use of groundwater for drinking purpose could result in unacceptable risk to human receptors. Also under this alternative, no warning would be provided of the potential for migration of COCs because no monitoring would occur.

Alternatives 2, 3, 4, and 5 would be protective of human health and the environment.

The natural attenuation component of Alternative 2 would be protective of human health and the environment because it would eventually reduce the concentrations of COCs to the PRGs over a reasonable timeframe. The institutional controls component of Alternative 2 would be protective of human health and the environment as it would reduce exposure to contaminated groundwater by prohibiting use of the Columbia Aquifer for drinking purposes until the PRGs are met. The monitoring component of Alternative 2 would be protective of human health and the environment by evaluating the

progress of remediation and detecting potential migration of COCs so that appropriate contingency measures can be taken.

Alternatives 3, 4, and 5 would be more protective than Alternative 2 because, in addition to the same institutional controls and monitoring components, these three alternatives would also include an active treatment component that would remove the groundwater COC benzene and the petroleum contamination in the subsurface soil at the water table. Although Alternative 5 could result in fugitive emissions, the operation of the AS system would be controlled so that the rate of these emissions would remain well under the VADEQ's allowable de minimis of 15 pounds of VOCs per day. Alternatives 3, 4, and 5 would be more protective than Alternative 2 because they would achieve complete protection in a shorter time.

5.1.2 Compliance with ARARs and TBCs

Alternative 1 would not comply with chemical- and location-specific ARARs. Action-specific ARARs or TBCs would not apply.

Alternatives 2, 3, 4, and 5 would comply with location- and action-specific ARARs and TBCs.

Alternatives 2, 3, 4, and 5 would not immediately comply with chemical-specific ARARs and TBCs, but these four alternatives would eventually achieve compliance as they attain PRGs either through natural attenuation alone (Alternative 2) or through active treatment (Alternatives 3, 4, and 5). First to achieve compliance would be Alternatives 3, 4, and 5, followed by Alternative 2.

5.1.3 Long-Term Effectiveness and Permanence

Alternative 1 would have very limited long-term effectiveness and permanence because no contaminant removal or reduction would occur through treatment although, over time, some contaminant reduction would occur through natural attenuation. As there would be no institutional controls to restrict residential development or use of the Columbia Aquifer groundwater for drinking water purposes, the potential would also exist for unacceptable risk to develop due to direct exposure of human or ecological receptors to contamination. Because there would be no monitoring, potential migration of COCs would remain undetected.

Alternatives 2, 3, 4, and 5 would provide long-term effectiveness and permanence.

Given that source control activities have been implemented, the natural attenuation component of Alternative 2 would effectively and permanently reduce concentrations of groundwater COCs to PRGs. The institutional controls component of Alternative 2 would effectively prevent the use of the Columbia Aquifer as a drinking water source until the PRGs have been achieved. The long-term monitoring component of Alternative 2 would provide an effective means of evaluating the progress of remediation and verifying that no COC migration is occurring.

Alternatives 3, 4, and 5 would be more effective than Alternative 2 because in addition to the same institutional controls and monitoring components, these three alternatives would also include an active treatment component that accelerates the removal of the VOC COC benzene and the petroleum contamination in the subsurface soil at the water table. Alternatives 3, 4, and 5 would all meet the PRGs at roughly the same time. Alternatives 3 and 4 would be slightly less effective than Alternative 5 because the in-situ biological application for these alternatives would use technologies that would require treatability testing compared to AS which is a well-proven technology.

5.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternatives 1 and 2 would not achieve any reduction of toxicity, mobility, or volume of COCs through treatment. Both alternatives would achieve reduction of contaminant toxicity and volume through natural attenuation; however, under Alternative 1, this reduction would neither be verified nor quantified. The contaminant reduction achieved through biodegradation and verified by monitoring in Alternative 2 would be irreversible.

Alternatives 3, 4, and 5 would achieve a reduction in VOC COC toxicity and volume through treatment.

Alternatives 3, 4, and 5 would irreversibly remove an estimated 31 pounds (less than 1 pound of soluble COCs from groundwater and 31 pounds of residual/smeared petroleum on the soil) contamination through either in-situ biological or AS treatment. Alternatives 3, 4, and 5 would generate some residues during the installation of the treatment systems and the groundwater monitoring. However, Alternatives 3, 4, and 5 would not generate treatment residues.

5.1.5 Short-Term Effectiveness

Implementation of Alternative 1 would not result in risks to site workers or adversely impact the surrounding community or environment because no remedial activities would be performed. Alternative 1 would not achieve the groundwater RAOs and although the groundwater cleanup goals might eventually be attained through natural processes, this would not be verified.

Implementation of Alternative 2 would result in a slight possibility of exposing site workers to contaminated groundwater during the installation, maintenance, and sampling of new and existing monitoring wells. However, these risks of exposure would be effectively controlled by wearing appropriate PPE and compliance with proper site-specific health and safety procedures. Implementation of Alternative 2 would not adversely impact the surrounding community or environment. Alternative 2 would achieve the first RAO immediately upon implementation of institutional controls and monitoring. Based on the results of the modeling presented in Appendix B, the second RAO and the groundwater PRGs would be attained within an estimated 5 years at the WOD site.

Implementation of Alternatives 3, 4, or 5 would result in a significant possibility of exposing construction workers to contaminated groundwater during the construction and operation of the groundwater treatment systems and the sampling of existing wells. However, these risks of exposure would be effectively controlled by wearing appropriate PPE and compliance with proper site-specific health and safety procedures. Implementation of Alternatives 3, 4, and 5 would not adversely impact the surrounding community or environment. Alternatives 3, 4, and 5 would achieve the first RAO immediately upon implementation of institutional controls. It is estimated that the timeframes to achieve the second RAO and the groundwater PRGs at the WOD site would be 3 years for Alternatives 3, 4, and 5.

5.1.6 Implementability

Alternative 1 would be easiest to implement because there would be no activities to implement.

Technical implementation of the various components of Alternatives 2, 3, 4, and 5 would be relatively simple.

The technical implementation of the natural attenuation, institutional controls, and monitoring components of Alternative 2 would be very simple. The resources, equipment, and material required for the activities associated with these components are readily available.

The technical implementation of Alternatives 3, 4, and 5 would be somewhat more difficult than that of Alternative 2 because each of these alternatives would require the installation and O&M of a groundwater treatment system. Of these three alternatives, Alternatives 3 and 4 would be easiest to implement because it would only require the installation of small diameter injection points and the feeding of chemicals without installation of permanent equipment. However, treatability testing would have to be performed to verify the effectiveness and design parameters for the treatment injection. Alternative 5 would be technically harder to implement than Alternatives 3 and 4 because it would require construction of an AS system with numerous sparging wells, interconnecting piping, and one or more blower systems.

However, the resources, equipment, and material necessary to implement these three alternatives are readily available.

Administrative implementation of the various components of Alternatives 2, 3, 4, and 5 would be relatively simple.

Administrative implementation of the institutional controls component of Alternative 2 would be simple because LUCs or a Facility Master Plan, including land and groundwater use restrictions, would be formulated and implemented to prevent the use of the groundwater from the shallow Columbia aquifer at the WOD site. Administrative implementation of the monitoring component of Alternative 2 would also be simple and it would not require permits.

The administrative implementation of Alternatives 3, 4, and 5 would be slightly more difficult than that of Alternative 2. In addition to the same requirements as Alternative 2, Alternatives 3, 4, and 5 might require a construction permit for installation of DPT injection points, and Alternatives 3 and 4 would need underground injection permits for the delivery of the chemicals. However, these permits should be relatively easy to obtain. Alternative 5 may also require the preparation of an erosion and sedimentation control plan. In addition, coordination of construction schedules and the placement of the building to house the systems associated with Alternative 5, would require coordination and approval of NASA personnel responsible for maintaining the active runway.

5.1.7 Cost

The capital and O&M costs and NPW of the groundwater alternatives are as follows.

Groundwater Alternatives	Capital	NPW of O&M (year)	NPW (year)
1	$0	$0	$0
2	$37,000	$187,000 (5 Years)	$224,000 (5 Years)
3	$240,000	$157,000 (5 Years)	$397,000 (5 Years)
4	$175,000	$355,000 (5 Years)	$530,000 (5 Years)
5	$307,000	$186,000 (5 Years)	$493,000 (5 Years)

Detailed cost estimates are provided in Appendix C.

5.2 SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES

Table 5-1 summarizes the comparative analysis of the groundwater remedial alternatives.

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TABLES

TABLE 1-1

OCCURRENCE AND DISTRIBUTION OF ORGANICS AND INORGANICS IN WASTE OIL DUMP GROUNDWATER

WOD FS

NASA WFF - WALLOPS ISLAND, VIRGINIA

	Background Data								Site-Related Data								
	Freq.	Range of Positive							Freq.	Range of Positive							
	of	Detection					Mean of	Sampling Round and	of	Detection					Mean of	Sampling Round and	Representative
Substance	Detection	Min.			Max.		All Data	Location of Maximum	Detection	Min.			Max.		All Data	Location of Maximum	Concentration
Aluminum	2/2	297		-	376	J	337	MW3R-20030312	5/5	831	J	-	8220		2780	WOD-MW4	8220
Arsenic	0/2			-					1/8	21.4		-	21.4		3.99	WOD-WFF16-GW2D	10.4
Barium	1/1	21.6		-	21.6		21.6	MW3R-20030220	11/11	32.4		-	117		55.4	WOD-WFF16-GW2S	71.6
Cadmium	0/2			-					1/12	0.92	K	-	0.92	K	0.398	WOD-WFF16-GW2D	0.463
Calcium	2/2	6740		-	11600		9170	MW3R-20030312	12/12	1230		-	40500		14200	WOD-WFF16-GW6	40500
Chromium	0/1			-					3/3	6.1		-	147		92.4	WOD-WFF16-GW1	147
Iron	1/1	203		-	203		203	MW3R-20030312	12/12	50.6		-	49900		8930	WOD-WFF16-GW7	49900
Lead	0/2			-					2/12	5.1		-	68.6		7.81	WOD-WFF15-GW7	7.81
Magnesium	2/2	4350		-	4970		4660	MW3R-20030220	12/12	1520		-	19900		6710	WOD-WFF16-GW5	13100
Manganese	1/1	13.4		-	13.4		13.4	MW3R-20030220	12/12	15		-	641		121	WOD-WFF15-GW7	483
Nickel	0/1			-					2/3	40.2		-	49.1		29.9	WOD-WFF16-GW3	49.1
Potassium	2/2	1460		-	1880		1670	MW3R-20030220	12/12	1160		-	10900		2910	WOD-WFF16-GW5	4480
Silver	1/2	2.3		-	2.3		1.65	MW3R-20030312	4/9	2		-	3.1	K	1.76	WOD-WFF16-GW2D	2.75
Sodium	2/2	3250		-	4190		3720	MW3R-20030220	12/12	2810		-	30200		8310	WOD-WFF16-GW7-DUP	13400
Vanadium	1/1	1.5		-	1.5		1.5	MW3R-20030220	1/3	9.9		-	9.9		3.53	WOD-MW4	9.9
2-Methylnaphthalene	0/2			-					1/12	130		-	130		13.1	WOD-WFF15-GW7	19.9
4-Methylphenol	0/2			-					1/11	42		-	42		6.09	WOD-WFF15-GW2	9.65
Acenaphthene	0/2			-					2/12	1	J	-	9		2.92	WOD-WFF15-GW7	3.9
Bis(2-ethylhexyl) Phthalate	0/2			-					3/12	2	J	-	18		3.23	WOD-WFF16-GW7-DUP	4.11
Dibenzofuran	0/2			-					1/12	4	J	-	4	J	2.63	WOD-WFF15-GW7	2.82
Fluorene	0/2			-					2/12	2	J	-	12		3.25	WOD-WFF15-GW7	4.17
Naphthalene	0/2			-					1/12	130		-	130		13.1	WOD-WFF15-GW7	19.9
Phenanthrene	0/2			-					2/12	2	J	-	15		3.5	WOD-WFF15-GW7	4.62
1,2,4-Trimethylbenzene	0/2			-					1/12	170		-	170		14.6	WOD-WFF15-GW7	29.3
1,2-Dichloroethene (cis)	0/2			-					4/12	1		-	3		0.917	WOD-WFF15-GW1	1.38
1,3,5-Trimethylbenzene	0/2			-					1/12	74		-	74		6.63	WOD-WFF15-GW7	11.1
2-Butanone	0/2			-					1/12	6		-	6		2.79	WOD-WFF15-GW2	3.21
Benzene	0/2			-					2/12	8		-	11		2	WOD-WFF15-GW7	4.69
Ethylbenzene	0/2			-					2/12	8		-	68		6.75	WOD-WFF15-GW7	21.5
Isopropylbenzene	0/2			-					2/12	1		-	6		1	WOD-WFF15-GW7	1.45
M,p-xylene	0/2			-					1/12	370		-	370		31.3	WOD-WFF15-GW7	82.5
Methylcyclohexane	0/2			-					1/12	18		-	18		1.96	WOD-WFF15-GW7	2.91
O-xylene	0/2			-					1/12	170		-	170		14.6	WOD-WFF15-GW7	29.3
Styrene	0/2			-					2/12	1		-	5		0.917	WOD-WFF15-GW7	1.31
Tetrachloroethene	0/2			-					1/12	5		-	5		0.875	WOD-WFF15-GW7	1.21
Toluene	0/2			-					2/12	2		-	120		10.6	WOD-WFF15-GW7	22.8
Xylene (Total)	0/2			-					1/12	540		-	540		45.5	WOD-WFF15-GW7	143

Notes:

Units are ug/L.
Number of sample results excludes rejected data or blank-qualified data. Duplicates are consolidated into one result.
Mean of all data includes positive detections and non-detected results. Detection limits are divided by two.
The determination of representative concentrations is based on comparison of maximum to the 95 % UCL, which is presented in a separate table.
Frequency of detection refers to number of times compound was detected among all samples versus total number of samples.
Number of samples may vary based on the number of usable results.

TABLE 1-2

SUMMARY OF RISK ASSESSMENT RESULTS
WOD FS
NASA WFF – WALLOPS ISLAND, VIRGINA

MEDIUM	ECOLOGICAL RISK	HUMAN HEALTH RISKS		
		RECEPTOR	RME CANCER	NONCANCER (1)
Surface Soil	No	Current Industrial	2.69 E-07	<1
		Future Industrial	1.73 E-06	<1
		Residential Child	6.32 E-06	<1
		Residential Adult	2.92 E-06	<1
		Lifetime Resident	9.24 E-06	NA
Total Soil	NA	Current Industrial	2.13 E-07	<1
		Future Industrial	1.36 E-06	<1
		Construction	1.62 E-07	<1
		Residential Child	4.99 E-06	<1
		Residential Adult	2.31 E-06	<1
		Lifetime Resident	7.30 E-06	NA
Groundwater	NA	Construction	4.61 E-08	<1
		Residential Child	**1.87 E-04**	**30.2**
		Residential Adult	**2.38 E-04**	**14.8**
		Lifetime Resident	**4.25 E-04**	NA

(1) Total HI for media and risk scenario. If >1, target organ specific risks evaluated.
RME = Reasonable Maximum Exposure.
NA = Not applicable.
Bolded and shaded values exceed the acceptable risk range.

TABLE 1-3
SUMMARY OF SUPPLEMENTAL CHROMIUM INVESTIGATION RESULTS
WOD FS
NASA WFF - WALLOPS ISLAND, VIRGINIA

Sample ID:	WFF16-GW1		WFF16-GW3		WFF16-GW3D		WFF16-MW3R		Federal	EPA
Laboratory ID:	WU3433-003		WU3433-001		WU3433-002		WU3433-004		MCL[1]	Region
Sample Date:	10/05/04		10/05/04		10/05/04		10/05/04			III
Notes:					Duplicate of					RBC[2]
					WFF16-GW3					
	RESULT	QUAL	RESULT	QUAL	RESULT	QUAL	RESULT	QUAL	ug/L	ug/L
MISCELLANEOUS PARAMETERS (ug/L)										
Hexavalent Chromium	12	J	25	U	25	U	25	U		**110**
INORGANICS (ug/L)										
Chromium	13.3		0.8	U	0.8	U	2.3		**100**	

Data Qualifiers:
J -- Value is considered estimated due to exceedance of technical quality control criteria or because result is less than the Contract Required Quantitation Limit (CRQL).
U -- Value is a non-detected result as reported by the laboratory.

(1) Maximum Concentration Limit for Public Water Supplies
(2) USEPA Region III Risk Based Concentration for Tap Water, 2004b.

TABLE 1-4

OCCURRENCE AND DISTRIBUTION OF RISK CONTRIBUTORS
FUTURE RESIDENTIAL GROUNDWATER USE
WOD FS
NASA WFF – WALLOPS ISLAND, VIRGINIA

CONTAMINANT	WOD-RELATED		WOD-RELATED BACKGROUND		BASE-WIDE BACKGROUND[3]	
	Freq. of Detection[1]	Range of Detections[2]	Freq. of Detection	Range of Detections	Freq. of Detection	Range of Detections
Arsenic	1/8	21.4	0/2	-	6/19	3.6 - 17.7
bis(2-Ethylhexyl) phthalate	3/12	2J - 18	0/2	-	0/11	-
Benzene	2/12	8 - 11	0/2	-	0/18	-
Tetrachloroethene	1/12	5	0/2	-	0/16	-
Iron	12/12	50.6 - 49,900	1/1	203	11/12	452 - 50,000
Aluminum	5/5	831J - 8,220	2/2	297 - 376	16/17	56.3 - 59,200
Manganese	12/12	15 - 641	1/1	13.4	15/15	4.5 - 3,110
4-Methylphenol	1/11	42	0/2	-	0/16	-
Xylene (total)	1/12	540	0/2	-	0/21	-
1,2,4-trimethybenzene	1/12	170	0/2	-	0/18	-
Naphthalene	1/12	130	0/2	-	0/19	-

(1) Frequency of detection indicates the number of detections and the number of total analyses for that contaminant, excluding rejected data and blank-qualified data.
(2) Units are µg/L. "J" denotes estimated value.
(3) Base-wide background results as reported in *Background Soil and Groundwater Investigation Report for the Main Base, TtNUS, May 2003.*

TABLE 2-1

FEDERAL CHEMICAL-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Safe Drinking Water Act (SWDA) Regulations, MCLs	40 CFR Part 141	Relevant and Appropriate	Establishes enforceable standards for potable water for specific contaminants that have been determined to adversely affect human health.	Would be used as protective levels for groundwater or surface waters that are current or potential drinking water sources.
SDWA Regulations, National Secondary Drinking Water Standards (SMCLs)	40 CFR Part 143	To Be Considered (TBC)	Establishes welfare-based standards for public water systems for specific contaminants or water characteristics that may affect the aesthetic qualities of drinking water.	Would be used as protective levels for groundwater or surface waters that are current or potential drinking water sources.
U.S. EPA Office of Drinking Water, Health Advisories		Potential TBC	Health advisories are estimates of non-carcinogenic risk due to consumption of contaminated drinking water.	These advisories would be considered for contaminants in surface water and groundwater that is or could be used as a potable water source.
Cancer Slope Factors (CSFs)		TBC	CSFs are guidance value used to evaluate the potential carcinogenic hazard caused by exposure to contaminants.	CSFs would be considered for development of human health protection PRGs for groundwater at this site.
Reference Doses (RfDs)		TBC	RfDs are guidance values used to evaluate the potential noncarcinogenic hazard caused by exposure to contaminants.	RfDs would be considered for development of human health protection PRGs for groundwater at this site.
CWA, Federal AWQC	40 CFR Part 131	Potentially Applicable	These guidelines set concentrations of pollutants that are considered adequate to protect human health and aquatic life	The AWQC may be used as a basis for determining cleanup concentrations in the absence of State water quality standards.

TABLE 2-2

STATE CHEMICAL-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA
PAGE 1 OF 2

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Virginia Surface Water Antidegradation Policy	9 VAC 25-260-30	Potentially Relevant and Appropriate	Establishes minimum standards for protecting existing water quality and uses.	Because this policy applies to all activities that potentially impact Virginia surface waters, it should be considered for remedial actions that involve a discharge to surface waters.
Virginia Numerical Criteria for Dissolved Oxygen, pH, and Maximum Temperature	9 VAC 25-260-50	Potentially Applicable	Establishes numeric criteria for specific surface water quality parameters that must be maintained to protect surface water uses.	Because these standards are specifically tailored to Virginia surface waters, they should be used in establishing discharge limits. These criteria are potentially applicable for a remedy that includes a discharge of groundwater to surface water.
Virginia Water Quality Standards	9 VAC 25-260-140	Potentially Applicable	This administrative code establishes criteria for listed pollutants to maintain surface water quality based on designated uses.	Because these standards are specifically tailored to Virginia waters, they should be used to establish cleanup concentrations rather than the Federal AWQCs. The Federal AWQCs for recreational uses, freshwater aquatic life, and non-public water supplies will be attained where a state standard does not exist.
Water Control Law -Groundwater Standards	9 VAC 25-280, Part IV	Applicable	Establishes minimum standards for groundwater quality.	Because these standards are specifically tailored to Virginia groundwater, they should be considered for developing groundwater remediation goals.
Water Control Law - Water Quality Criteria for Groundwater	9 VAC 25-280, Part V	TBC	Establishes guidance for groundwater quality.	Because these standards are specifically tailored to Virginia groundwater, they would be used for developing groundwater remediation goals.

TABLE 2-2

STATE CHEMICAL-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA
PAGE 2 OF 2

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Virginia Voluntary Remediation Program	9 VAC 20-160	TBC	This administrative code establishes guidance for groundwater cleanup concentrations that can be developed on a site-by-site basis. The guidance for this administrative code also provides tables that indicated groundwater with concentrations less than the listed values are considered "free from" contamination.	These guidelines would be used in determining cleanup goals. The values provided in the tables would be considered when determining cleanup concentrations for groundwater. By definition of ARARs in the NCP, state requirements must be a state law or regulation; an environmental or facility siting law; promulgated; more stringent than the Federal requirement; identified in a timely manner; and consistently applied. These parameters must be met according to the NCP. The Virginia Voluntary Remediation Program is promulgated as law or regulation and should be considered ARARs.
Department of Health Waterworks Regulations	12 VAC 5-590-10	Potentially Applicable	Establishes enforceable standards for potable water for contaminants that have been determined to adversely affect human health (MCLs/ SMCLs).	Would be used as protective concentrations for groundwater that are current or potential drinking water sources. In the absences of MCLs/SMCLs, other health-based standards or professional judgments based on risk may be employed.

TABLE 2-3

FEDERAL LOCATION-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA
PAGE 1 OF 2

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Endangered Species Act Regulations	50 CFR Parts 81, 225, 402	Potentially Applicable	This act requires Federal agencies to act to avoid jeopardizing the continued existence of federally listed endangered or threatened species.	If a site investigation or remediation could potentially affect an endangered species, these regulations would apply.
Archaeological and Historic Preservation Act	36 CFR Part 62 and 65	Potentially Applicable	Establishes requirements relating to potential loss or destruction of significant scientific, historical, or archaeological data. Also requires Federal agencies to consider to existence and location of landmarks on the National Registry of Natural Landmarks to avoid undesirable impacts on such landmarks.	The existence of significant scientific, historical, archaeological data, or Natural Landmarks would be identified prior to remedial activities onsite including remedial investigations
Fish and Wildlife Coordination Act Regulations	33 CFR Subsection 320.3	Potentially Applicable	Requires that the United States Fish and Wildlife Service (USFWS), National Marine Fisheries Service, and related state agencies be consulted prior to structural modification of any body of water, including wetlands. If modifications must be conducted, the regulation requires that adequate protection be provided for fish and wildlife	If a remedial alternative involves the alteration of a stream or wetland, these agencies would be consulted.

TABLE 2-3

FEDERAL LOCATION-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA
PAGE 2 OF 2

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
National Environmental Policy Act (NEPA) Regulations, Wetlands, Floodplains, etc., Executive Order 11990	40 CFR Subsection 6.302 [a]	Potentially Applicable	These regulations contain the procedures for complying with Executive Order 11990 on wetlands protection. Appendix A states that no remedial alternative adversely affect a wetland if another practicable alternative is available. If no alternative is available, impacts from implementing the chosen alternative must be mitigated.	If remedial action affects a wetland, these regulations would apply.
NEPA Regulations, Floodplain Management, Executive Order 11988	40 CFR Part 6, Appendix A	Potentially Applicable	Appendix A describes the policy for carrying out the Executive Order regarding floodplains. If no practicable alternative exists to performing cleanup in a floodplain, potential harm must be mitigated and actions taken to preserve the beneficial value of the floodplain.	If removal actions take place in a floodplain, alternatives would be considered that would reduce the risk of flood loss and restore and preserve the floodplain.
Fish and Wildlife Conservation Act	40 CFR Section 6.302	Potentially Applicable	Requires action to be taken to protect fish and wildlife from projects affecting streams or rivers.	United States Fish and Wildlife Service (USFWS) officials would be consulted on how to minimize impacts of any remedial activities on any wildlife.

TABLE 2-4

STATE LOCATION-SPECIFIC ARARs AND TBCs
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Wetlands Mitigation Compensation Policy	4 VAC 20-390-10	Applicable	These regulations contain the procedures on wetlands protection and standards for construction activities in the 100-year floodplain. These regulations also determine the extent of mitigation where wetlands are impacted.	If remedial action affects a wetland, these regulations would apply.
Chesapeake Bay Preservation Area Designation and Management Regulations	9 VAC 10-20-10	Potentially Applicable	Sites within an area designated by local government as Resource Protection Areas or Resource Management Areas must comply with these regulations to avoid undesirable impacts.	The existence of Resource Protection Areas or Resource Management Areas would be identified prior to remedial activities onsite including remedial investigations
Virginia Natural Areas Preserve Act	Va. Code Ann. §§ 10.1-209	TBC	The provisions of this Act are applicable for projects where the Department of Conservation and Recreation has accepted dedication of a natural area preserve.	If a site investigation or remediation could potentially affect a preserve area, this Act may restrict certain uses of the area and would apply.
Endangered Species Act Regulations	4 VAC 15-20-130	Potentially Applicable	These regulations from the Department of Game and Inland Fisheries prohibit the taking of endangered species. The cited regulations provide listings of endangered species and definitions of actions which constitute taking.	If a site investigation or remediation could potentially affect an endangered species, these regulations would apply.
Endangered Plant and Insect Species Act Regulations	2 VAC 5-320-10	Potentially Applicable	These regulations from the Department of Game and Inland Fisheries prohibit the taking of endangered plant and insect species.	If a site investigation or remediation could potentially affect an endangered species, these regulations would apply.
Virginia Private Well Regulations	12 VAC 5-630	Applicable	Private wells are prohibited if a source of contamination could adversely affect the well and preventative measures are not available to protect groundwater.	Wells would not be permitted at the WOD site until groundwater has been remediated and is no longer a source of groundwater contamination.

TABLE 2-5

FEDERAL AND VIRGINIA GROUNDWATER ARARs AND TBCs FOR CONTAMINANTS OF POTENTIAL CONCERN WOD FS REPORT NASA WFF – WALLOPS ISLAND, VIRGINIA PAGE 1 OF 2

Chemical	Safe Drinking Water Act (µg/L)		Health Advisory (mg/L) [4]		Reference Dose[1] (mg/kg/day)		Cancer Slope Factor[1] $(mg/kg/day)^{-1}$		Exposure Point Concentration	Maximum Site Concentration[1]	WOD Risk[1]
	MCL	MCLG			Oral	Inhalation	Oral	Inhalation	(µg/L)	(µg/L)	Cancer(c) Noncancer (n)
Arsenic	10	0	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	- --	3.00×10^{-4}	-	1.50×10^{0}	1.51×10^{1}	15.1	21.4	3.81×10^{-4} (c)
Bis(2ethylhexyl)phthalate	6[3]	0	10-kg Child - 1 day[3] 10-kg Child - 10 day[3] Lifetime[3]	- - -	2.00×10^{-2}	-	1.40×10^{-2}	1.40×10^{-2}	4.4	18	2.14×10^{-6} (c)
Benzene	5	0	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	0.2 0.2 -	4.00×10^{-3}	8.60×10^{-3}	5.50×10^{-2}	2.70×10^{-2}	8.5	11	1.11×10^{-5} (c)
Tetrachloroethene	5	0	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	2 2 0.01	1.00×10^{-2}	1.40×10^{-1}	5.40×10^{-1}	2.00×10^{-2}	2.55	5	3.08×10^{-5} (c)
Iron	300[2]	NA	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	NA NA NA	3.00×10^{-1}	-	-	-	49,900	49,900	14.4 (n)
Aluminum	50 to 200[2]	NA	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	NA NA NA	2.70×10^{-1}	1.00×10^{-3}	1.20×10^{-1}	-	8,220	8,220	0.7 (n)
Manganese	50[2]	NA	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	1 1 0.3	2.4×10^{-2}	1.43×10^{-5}	-	-	466	641	1.8 (n)

TABLE 2-5

FEDERAL AND VIRGINIA GROUNDWATER ARARs AND TBCs FOR CONTAMINANTS OF POTENTIAL CONCERN WOD FS REPORT NASA WFF – WALLOPS ISLAND, VIRGINIA PAGE 2 OF 2

Chemical	Safe Drinking Water Act (µg/L)		Health Advisory (mg/L) (4)		Reference Dose(1) (mg/kg/day)		Cancer Slope Factor(1) (mg/kg/day)$^{-1}$		Exposure Point Concentration	Maximum Site Concentration(1	WOD Risk(1)
	MCL	MCLG			Oral	Inhalation	Oral	Inhalation	(µg/L)	(µg/L)	Cancer(c) Noncancer (n)
4-Methylphenol	NA	NA	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	NA NA NA	$5.00x10^{-3}$	-	-	-	22.1	42	0.4 (n)
Xylene (total)	10,000	10,000	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	40 40 -	$2.00x10^{-1}$	$2.80x10^{-2}$	-	$1.50x10^{-2}$	495	540	0.5 (n)
1,2,4-trimethylbenzene	70	70	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	0.1 0.1 0.07	$5.00x10^{-2}$	$1.70x10^{-3}$	-	-	104	170	1.75(n)
Naphthalene	NA	NA	10-kg Child - 1 day 10-kg Child - 10 day Lifetime	0.5 0.5 0.1	$2.00x10^{-2}$	$8.60x10^{-4}$	-	-	80.3	130	2.5 (n)

NA Not Available.
1 OD Supplemental RI (TtNUS, 2004a)
2 n-enforceable Secondary Standard established to control taste, odor, and/or staining.
3 (2-ethylhexyl) phthalate synonym listed for bis(2-ethylhexyl)phthalate.
4 04 Edition of the Drinking Water Standards and Health Advisories (USEPA, 2004a).

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FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Air/Superfund National Technical Guidance	EPA/450/1-89/001-EPA/450/1-89/004	Potential TBC	This guidance describes methodologies for predicting risks due to air release at a Superfund site.	These guidance documents would be considered when risks due to air releases from fugitive dust, air stripping, and thermal desorption are being evaluated.
Clean Air Act (CAA) Regulations, National Ambient Air Quality Standards (NAAQSs)	40 CFR Part 50	Potentially Relevant and appropriate for on-site treatment, storage, and disposal facility (TSDF) and Applicable for off-site TSDF	Establishes primary (health-based) and secondary (welfare-based) air quality standards for carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulfur oxides emitted from a major source of air emissions. The NAAQSs form the basis for the regulations promulgated under the CAA. However, the NAAQSs themselves are non-enforceable and are not ARARs themselves.	Site remediation activities must comply with NAAQS. The principal application of these standards is during remedial activities resulting in exposures through dust and vapors. In general, emissions from CERCLA activities are not expected to qualify as a major source, and are therefore, not expected to be applicable requirements. However, the requirements may be determined to be relevant and appropriate for non-major sources with significantly similar emissions.
CAA Regulations, New Source Performance Standards (NSPS)	40 CFR Part 60	Potentially Relevant and Appropriate	This rule establishes NSPS for specified sources that are similar to a source that has established NSPSs (such as air stripping technologies). The NSPSs limit the emissions of a number of different pollutants, including the six criteria pollutants list (for which NAAQSs are established) as well fluorides, sulfuric acid mist, and total reduced sulfur (including hydrogen sulfide [H_2S]).	This rule may be a relevant and appropriate requirement for a new source that is similar to a source that has established NSPSs (such as air stripping technologies). If it is determined that the remedy would create potential air impacts, the response action or the equipment for the response action may qualify as a new source; therefore, these requirements would be met.
CAA National Emission Standards for Hazardous Air Pollutants	40 CFR Part 61	Potentially Applicable	NESHAPs are a set of emissions standards for specific chemicals from specific production activities.	Emissions of hazardous air pollutants would be minimized by fugitive dust control and off gas treatment from a thermal desorption facility.

TABLE 2-6

FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
(NESHAPs)				
CWA, National Pollution Discharge Elimination System (NPDES)	40 CFR Parts 122 through 125, and 131	Potentially Relevant and Appropriate	NPDES permits are required for any discharges to navigable waters. If remedial activities include such a discharge, the NPDES standards would be ARARs.	Any alternative which would discharge into any navigable water would require compliance with these regulations including treatment, if necessary.
CWA Regulations, National Pretreatment Standards	40 CFR Part 403	Potentially Relevant and Appropriate	Sets pretreatment standards through the National Categorical Standards of the General Pretreatment Regulations for the introduction of pollutants from non-domestic sources into publicly owned treatment works (POTWs) in order to control pollutants that pass through, cause interference, or are otherwise incompatible with treatment processes at a POTW.	If groundwater is discharged to a POTW or federally owned treatment work (FOTW), the discharge must meet local limits imposed by the POTW. A discharge from a CERCLA site must meet the POTW's pretreatment standards in the effluent of the POTW. Discharge to a POTW is considered an offsite activity and is, therefore subject to both the substantive requirements of this rule.
Federal Facilities Compliance Act of 1992	HR 2194	Potentially Relevant and Appropriate	This act amends the Solid Waste Disposal Act (SWDA) to clarify provisions concerning the application of certain requirements to federal facilities, such as providing a conditional exception to the Resource Conservation and Recovery Act's (RCRA) domestic sewage exclusion for FOTWs. In general, it allows state agencies and the U.S. EPA to enforce hazardous waste laws at government sites.	This act expands the domestic sewage exclusion policy to FOTWs. In addition, when wastewater is considered a hazardous waste under RCRA, but is mixed with domestic waste as it flows through the sewer system to the FOTW, the FOTW would not be required to meet the additional regulatory requirements for a RCRA facility.
Occupational Safety and Health Act	29 CFR Part 1910	Applicable	Requires establishment of programs to assure worker health and safety at	These regulations would apply to the response activities.

TABLE 2-6

FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
(OSHA) Regulations, General Industry Standards			hazardous waste sites, including employee training requirements.	
OSHA Regulations, Occupational Health and Safety Regulations	29 CFR Part 1910, Subpart Z	Potentially Applicable	Establishes permissible exposure limits for workplace exposure to a specific listing of chemicals.	Standards are applicable for worker exposure to OSHA hazardous chemicals during remedial activities.
OSHA Regulations, Record Keeping, Reporting, and Related Regulations	29 CFR Part 1904	Potentially Applicable	Provides record keeping and reporting requirements applicable to remedial activities.	These requirements apply to the site contractors and subcontractors and must be followed during the site work.
OSHA Regulations, Health and Safety Standards	29 CFR Part 1926	Potentially Applicable	Specifies the type of safety training, equipment, and procedures to be used during the site investigation and remediation.	The phases of the remedial response project would be executed in compliance with this regulation.
RCRA Regulations, Identification and Listing of Hazardous Wastes	40 CFR Part 261	Potentially Relevant and appropriate for on-site TSDF and Applicable for off-site TSDF	Defines the listed and characteristic hazardous wastes subject to RCRA. Appendix II contains the Toxicity Characteristic Leaching Procedure.	These regulations would apply when determining whether waste onsite is hazardous, either by being listed or by exhibiting a hazardous characteristic, as described in the regulations.
RCRA Regulations, Contingency Plan and Emergency Procedures	40 CFR 264, Subpart D	Potentially Relevant and Appropriate	Outlines requirements for emergency procedures to be followed in case of an emergency.	The administrative requirements established in this rule would be met for remedial actions involving the management of hazardous waste.

TABLE 2-6

FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
RCRA Regulations, General Facility Standards	40 CFR Subpart B, 264.10-264.18	Potentially Relevant and Appropriate	Sets the general facility requirements including general waste analysis, security measures, inspections, and training requirements. Section 264.18 establishes that a facility located in a 100-year floodplain must be designed, constructed, and maintained to prevent washout of any hazardous wastes by a 100-year flood.	If the remedial action involves construction of an onsite treatment facility, such as a groundwater treatment facility, the substantive requirements of this rule would be applicable requirements. A permitted treatment facility must be selected for offsite treatment. These regulations do not apply to the aboveground treatment or storage of hazardous waster before it is injected into underground. However, this rule may be an applicable requirement for alternatives that do not involve groundwater reinjection.
RCRA Regulations, Miscellaneous Units	40 CFR Part 264, Subpart X	Potentially Relevant and Appropriate	These standards are applicable to miscellaneous units not previously defined under existing RCRA regulations. Subpart X outlines performance requirements that miscellaneous units be designed, constructed, operated, and maintained to prevent releases to the subsurface, groundwater, and wetland that may have adverse effects on human health and the environment.	The design of proposed treatment alternatives, not specifically regulated under other subparts of RCRA, must prevent the release of hazardous constituents and future impacts on the environment. This subpart would apply to onsite construction of any treatment facility that is not previously defined under the RCRA regulation.
RCRA Regulations, Preparedness and Prevention	40 CFR Part 264, Subpart C	Potentially Relevant and Appropriate	Outlines requirements for safety equipment and spill control for hazardous waste facilities. Facilities must be designed, maintained, constructed, and operated to minimize the possibility of an unplanned release that could threaten human health or the environment.	Safety and communication equipment would be incorporated into all aspects of the remedial process and local authorities would be familiarized with site operations.

TABLE 2-6

FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
RCRA Regulations, Releases from Solid Waste Management Units (SWMUs)	40 CFR Part 264, Subpart F	Potentially Relevant and Appropriate	Establishes the requirements for SWMUs at RCRA regulated TSDFs. The scope of the regulation encompasses groundwater protection standards, point of compliance, compliance period, and requirements for groundwater monitoring.	These regulations would be followed for the treatment of hazardous waste.
RCRA Regulations, Standards for Owners and Operators of Hazardous Waste TSDF	40 CFR Part 264	Potentially Relevant and Appropriate	Establishes minimum national standards defining the acceptable management of hazardous wastes for owners and operators of facilities that treat, store, or dispose of hazardous wastes.	If remedial actions involving management of RCRA wastes at an off-site TSDF or if RCRA wastes are managed onsite, the requirements of this rule would be followed.
RCRA Regulations, Use and Management of Containers	40 CFR Part 264, Subpart I	Potentially Relevant and Appropriate	Sets standards for the storage of containers of hazardous waste.	This requirement would apply if a remedial alternative involves the storage of a hazardous waste (i.e. contaminated groundwater) in containers, prior to treatment.
RCRA Regulations, Land Disposal Restrictions (LDRs)	40 CFR Part 268	Potentially Relevant and appropriate for on-site TSDF. Applicable for off-site TSDF	This regulation prohibits the land disposal of untreated hazardous wastes and provides criteria for the treatment of hazardous waste prior to land disposal.	Remedial actions that involve treating and redepositing hazardous groundwater would comply with LDRs.
RCRA, Treatment Standards for Hazardous Debris – Thermal Desorption	40 CFR 268.45	Potentially Applicable	Sets treatment standards for utilizing thermal desorption.	Thermal desorption units would be operated in compliance with treatment standards.
SWDA Subtitle D	40 CFR 258	Potentially relevant and appropriate	Establishes design and operating criteria for solid waste (nonhazardous) landfills.	These requirements would be relevant and appropriate for landfill closure and post-closure care.

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FEDERAL ACTION-SPECIFIC ARARs AND TBCs
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
SWDA Regulations, Underground Injection Control Regulations	40 CFR Parts 144, 146, 147, and 1000	Potentially Relevant and Appropriate	Establishes minimum program and performance standards for underground injection programs. Technical criteria are included in Part 146. Also requires protection of underground sources of drinking water.	Discharge of treated groundwater, by well injection, would be in accordance with these regulations, as well as meet State Underground Injection Control Program requirements. Treated groundwater would meet SWDA standards for reinjection prior to well injection.
Department of Defense	NA	TBC	Identify Natural Resource Injury and, when practicable, redress it as part of the site assessment, investigation, and remedy selection process.	Alternatives that address natural resource injury will be developed and evaluated in the FS.
Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites	OSWER Directive 9200.4-17P	TBC	Guidelines for use of monitored natural attenuation for the remediation of contaminated soil and groundwater sites.	TBC if monitored natural attenuation is one of the selected remedial options.

TABLE 2-7

STATE ACTION-SPECIFIC ARARs AND TBCs
WOD FS REPORT
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Virginia Waste Management Act and Solid Waste Management Regulation	9 VAC 20-80	Potentially Applicable	These regulations govern the handling, storage, treatment, or disposal of solid wastes. Further, the Act provides requirements for the transportation of solid wastes.	These regulations would apply if waste onsite needed to be stored, transported, or disposed of properly.
Virginia Hazardous Waste Regulation	9 VAC 20-60	Potentially Applicable	These regulations govern the handling, storage, treatment, or disposal of hazardous waste.	These regulations would apply if waste onsite were deemed hazardous and needed to be stored, transported, or disposed of properly.
Virginia Pollutant Discharge Elimination System Permit Regulation	9 VAC 25-31-10	Potentially Applicable	This regulation governs the discharge to surface waters that must meet site-specific effluent limits.	These regulations would apply to remedial activities that involve discharges to surface water including potential sources of drinking water.
Virginia Pollutant Abatement Permit Regulation	9 VAC 25-32-10	Potentially Applicable	This regulation governs the discharge of pollutants adjacent to State waters (including groundwater) that must meet site-specific effluent discharge limits.	These regulations would apply to remedial activities that involve discharges.
Virginia Stormwater Management Act Regulation	4 VAC 3-20-10	Potentially Relevant and Appropriate	Establishes requirements for discharges of stormwater to protect the surface water of the state.	Remedial actions would consider the impact of the discharge of stormwater.
Virginia Erosion and Sediment Control Act Regulations	4 VAC 50-30-10	Potentially Relevant and Appropriate	Establishes requirements for erosion control to protect the surface water of the state.	Remedial actions would consider the impact soil erosion and sediment control.

TABLE 2-7

STATE ACTION-SPECIFIC ARARs AND TBCs
WOD FS REPORT
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Requirement	Citation	Status	Synopsis	Evaluation/Action to be Taken
Virginia Water Protection Permit Regulation	9 VAC 25-210-10	Potentially Applicable	This regulation delineates the requirements applicable to activities such as dredging, filling or discharging pollutants into, or adjacent to, surface waters (the Commonwealth's definition of surface waters includes wetlands). The requirements of the regulation are in addition to those which may be found in a Corps of Engineers § 404 permit.	These regulations would apply to remedial activities that involve discharges.
Virginia Ambient Air Quality Standards	9 VAC 5-30-10	Potentially Relevant and Appropriate	This rule also establishes ambient air quality standards and air emission standards from disturbance of soil at a site, or from treatment of soil or water or from other pollutant management activities.	Although this rule is directly applicable to industrial polluters, these requirements are relevant and appropriate for a remedial action that could result in release of regulated contaminants to the atmosphere, such as may occur during air stripping or excavation.
Virginia Standards of Performance for Visible Emission and Fugitive Dust/Emissions, Standards of Performance for Toxic Pollutants, and Environmental Protection Agency National Emission Standards for Hazardous Pollutants	9 VAC 5-50-60, 9 VAC 5-50-160, and 9 VAC 5-60-60	Potentially Relevant and Appropriate	These rules establish air emission standards from disturbance of soil at a site, or from treatment of soil or water or from other pollutant management activities.	Although this rule is directly applicable to industrial polluters, these requirements are relevant and appropriate for a remedial action that could result in release of regulated contaminants to the atmosphere, such as may occur during air stripping or excavation.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

General Response Action	Technology	Process Options	Description	Screening Comment
No Action	None	Not Applicable	No activities conducted at site to address contamination.	Required by law. Retain for baseline comparison to other technologies.
Limited Action	Monitoring	Sampling and Analysis	Periodic sampling and analysis of groundwater and other media to track the spread of contamination.	Retain to assess natural attenuation and/or migration of contaminants from site and evaluate effectiveness of remedial actions. Use in combination with other technologies if contaminated groundwater remains in place.
	Institutional Controls	Active Controls: Physical Barriers/ Security Guards	Fencing, markers, and warning signs to restrict site access.	Eliminate because the site is located within a limited access area and contaminated groundwater is not available for direct contact.
		Alternative Water Supply	Replacement of contaminated groundwater source with alternative water supply for end user.	Would be considered in the event that potable water use is required in this area. A water supply system is not currently present in this area.
		Passive Controls: Deed and Land Use Restrictions, Facility Master Plan	Administrative action using property deeds to restrict future site activities and use of groundwater as source of drinking water.	Retain to limit human exposure to contaminated groundwater through the installation of wells and/or structures. Use in combination with other technologies if contaminated groundwater remains in place.
	Natural Attenuation	Naturally-Occurring Biodegradation and Dilution	Monitoring the groundwater to assess the natural processes (dilution, degradation, etc.) that affect the rate of migration and the concentrations of contaminants.	Retain. Use in combination with other technologies if contaminated groundwater remains in place.
Containment	Vertical Barriers	Slurry Wall	Low-permeability wall formed in a perimeter trench to restrict horizontal	Eliminate because the area lacks a viable confining unit to tie barrier into, this process is not appropriate for sites with low

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

General Response Action	Technology	Process Options	Description	Screening Comment
Containment (Continued)	Vertical Barriers (Continued)	Slurry Wall (Continued)	migration of groundwater.	contaminant concentrations (low waste mass) because it is capital cost intensive, and the process does not treat groundwater contamination or reduce the clean up time.
		Grout Curtain	Pressure injection of grout to form a low-permeability perimeter wall to restrict horizontal migration of groundwater.	Eliminate because the area lacks a viable confining unit to tie barrier into, this process is not appropriate for sites with low contaminant concentrations (low waste mass) because it is capital cost intensive, and the process does not treat groundwater contamination or reduce the clean up time.
		Sheet Piling	Metal sheet piling driven into the ground to restrict horizontal migration of groundwater.	Eliminate because the area lacks a viable confining unit to tie barrier into, this process is not appropriate for sites with low contaminant concentrations (low waste mass) because it is capital cost intensive, and the process does not treat groundwater contamination or reduce the clean up time.
		Biochemical Barrier	Interception and removal of organic contaminants through injection of nutrients, oxygen release compounds (ORC®s), or hydrogen release compounds (HRC®s).	Eliminate because this technology is better suited to in-situ treatment and is retained for that purpose.
	Horizontal Barriers	Capping	Use of impermeable or semi-permeable materials (e.g., soil, clay, synthetic membrane) to prevent exposure to contamination and/or to reduce the vertical migration of contaminants to groundwater.	Eliminate. Capping will not address groundwater contamination. Contaminants are already present in the groundwater and the soil at the water table.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
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General Response Action	Technology	Process Options	Description	Screening Comment
Containment (Continued)	Horizontal Barriers (Continued)	Liner Physical Barrier	Injection of bottom sealing slurry beneath source to minimize vertical migration of groundwater.	Eliminate. Source materials are present at or below the water table and this will not address groundwater contamination.
Removal	Groundwater Extraction	Extraction Wells	Series of conventional pumping wells used to remove contaminated groundwater.	Retain to remove contaminated groundwater. Use in combination with other technologies.
		Collection Trench	A permeable trench used to intercept and collect groundwater from the plume.	Retain to remove contaminated groundwater. Groundwater is shallow enough to implement an effective collection trench.
In-situ Treatment	Biological – Biostimulation	Aerobic/ Anaerobic	Enhancement of biodegradation of organics in an aerobic (oxygen-rich) and/or anaerobic (oxygen-deficient) environment by injection of nutrients and ORC®/HRC®) or by injection of Bimetallic Nanoscale Particles (BNP).	Retain aerobic enhancement of the primary site organic contaminants. Anaerobic enhancement would not be effective for treatment of the primary site organic contaminants. Metals may precipitate under aerobic and more alkaline conditions.
	Biological – Bioaugmentation	Aerobic/ Anaerobic	Enhancement of biodegradation of organics in an aerobic (oxygen-rich) and/or anaerobic (oxygen-deficient) environment by injection of microbes, inoculum, and/or bacterium.	Retain aerobic bioaugmentation of the primary site organic contaminants. Anaerobic bioaugmentation would not be effective for treatment of the primary site organic contaminants. Metals may precipitate under aerobic and more alkaline conditions.
	Physical	Air Sparging (AS) or Air Sparging/ Vapor Extraction (AS/VE)	Volatilization and enhancement of biodegradation of organic compounds by supply of air with or without capture and treatment of volatilized compounds.	Retain for treatment of VOCs. Will also treat VOC and SVOC contaminated soil. Metals may precipitate under aerobic conditions.
		Permeable Reactive Barriers or Biological Barriers	Use of a permeable barrier which allows the passage of groundwater and reacts with the contaminants.	Eliminate because it does not address the source area and it is not appropriate for low concentrations of organic contaminants.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

General Response Action	Technology	Process Options	Description	Screening Comment
In-situ Treatment (Continued)	Thermal	Dynamic Underground Stripping/Electrical Resistive Heating/ Thermal Conductive Heating	Steam injection/ electrical current/ conductive heating elements are used to create a high-temperature zone resulting in the vaporization of volatile compounds bound to soil and the movement of contaminants to a extraction wells.	Eliminate because it is inappropriate for the removal of relatively low concentrations of organic COCs.
	Chemical	Enhanced Oxidation	Chemical destruction of organic COCs through oxidation with hydrogen peroxide and ferrous iron (Fenton's Reagent) or potassium permanganate.	Eliminate because it is inappropriate for the removal of relatively low concentrations of organic COCs.
		Precipitation	Adjustment of soil/groundwater chemistry to decrease the solubility of metals. Actions may include the addition of calcium hydroxide to increase the groundwater pH and/or oxygen to convert the metals to less soluble ions.	Eliminate. The process does not address the primary contaminant (benzene). It may be useful to address the arsenic in the groundwater; however, it is an innovative and emerging technology that would not be warranted for the single detection of arsenic above the PRG at this site. The process is implemented using permeable barriers or direct push technology and injection.
Ex-situ Treatment	Biological	Aerobic/ Anaerobic	Natural degradation of organic COCs via microorganisms in an aerobic (oxygen-rich) or anaerobic (oxygen-deficient) environment.	Retain aerobic for treatment of the primary site organic contaminants. Anaerobic would not be effective for treatment of the primary site organic contaminants.
	Physical	Filtration	Separation of suspended solids from water via entrapment in a bed of granular media or membrane.	Retain as a potential pretreatment step prior to certain ex-situ organic removal processes.
		Reverse Osmosis	Use of high pressure and membranes to separate dissolved materials from water.	Eliminate because primarily applicable to the removal of dissolved inorganic compounds.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

General Response Action	Technology	Process Options	Description	Screening Comment
Ex-situ Treatment (Continued)	Physical (Continued)	Air Stripping	Contact of water with air to remove VOCs.	Retain for removal of VOCs.
		Granular Activated Carbon (GAC) Adsorption	Separation of dissolved contaminants from water via adsorption onto activated carbon.	Retain for removal of VOCs.
		Solvent Extraction	Separation of contaminants from a solution by contact with an immiscible liquid with a higher affinity for the contaminants of concern.	Eliminate because not applicable to the removal of relatively low concentrations of organic contaminants. Solvent extraction is rarely used for groundwater remediation.
		Dewatering	Mechanical removal of free water from wastes using equipment such as a filter press or a vacuum filter.	Retain to be used in combination with other technologies. Dewatering of sludges resulting from precipitation processes for metals removal may be required.
		Distillation	Vaporization of a liquid followed by condensation of the vapors to concentrate various constituents.	Eliminate because not applicable to the removal of relatively low concentrations of contaminants.
		Equalization	Dampening of flow and/or contaminant concentration variation in a large vessel to promote constant discharge rate and water quality.	Retain to be used in combination with other technologies. Equalization is feasible at the front end of a groundwater treatment system.
		Sedimentation	Separation of solids from water via gravity settling.	Retain as a potential pretreatment step prior to certain organics ex-situ removal processes.
	Chemical	Coagulation/ Flocculation	Use of chemicals to neutralize surface charges and promote attraction of colloidal particles to facilitate settling.	Retain as a potential pretreatment step prior to certain ex-situ organic removal processes.
		Neutralization/pH Adjustment	Use of acids or bases to counteract excess pHs.	Retain as a potential pretreatment step or final step prior to discharge.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
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General Response Action	Technology	Process Options	Description	Screening Comment
Ex-situ Treatment (Continued)	Chemical (Continued)	Precipitation	Use of reagents to convert soluble compounds into insoluble compounds.	Retain. Precipitation may be warranted for dissolved metals removal.
		Ion Exchange	Removal of dissolved ions from a liquid through exchange with similarly-charged ions held by electrostatic forces to the active sites on a synthetic resin that is contacted with the liquid to be treated.	Eliminate because primarily applicable to removal of dissolved inorganic compounds.
		Enhanced Oxidation	Use of oxidizers such as ozone, hydrogen peroxide, or potassium permanganate to breakdown certain organic compounds through cleavage of the C-C bond.	Eliminate because not applicable to the removal of relatively low concentrations of contaminants.
		Reduction	Use of reducers such as sulfur dioxide, sulfite compounds, or ferrous iron compounds to decrease the oxidation state of organic and inorganic compounds.	Eliminate because not applicable to organic COCs.
Discharge/ Disposal	Surface Discharge	Direct or Indirect Discharge	Discharge of collected/treated water.	Retain for discharge of treated groundwater. A flowing surface water body is in the area for direct discharge with a NPDES permit or a POTW is near by for indirect discharge.
		Off-Site Treatment Facility	Treatment and disposal of water at a permitted off-site treatment works.	Eliminate because impractical due to large volume of treated groundwater.

TABLE 3-1

PRELIMINARY SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

General Response Action	Technology	Process Options	Description	Screening Comment
Discharge/ Disposal (Continued)	Subsurface Discharge	Reinjection	Use of injection wells, spray irrigation, or infiltration to discharge collected/treated groundwater underground.	Eliminate because groundwater is too shallow for effective discharge to the surficial aquifer and because no suitable area is located close to the WOD site for deep well injection. Spray irrigation requires relatively large areas that are not available at this facility.

TABLE 3-2
SUMMARY OF FIELD AND LABORATORY WATER QUALITY RESULTS
WOD FS
NASA WFF - WALLOPS ISLAND, VIRGINIA

Sample ID:	WFF15-GW7		WOD-MW4		WOD-WFF15-GW1		WOD-WFF15-GW2		WOD-WFF16-GW1		WOD-WFF16-GW2D		WOD-WFF16-GW2S	
Sample Date:	**03/14/03**		**03/17/03**		**03/12/03**		**03/12/03**		**03/18/03**		**03/12/03**		**03/12/03**	
Field														
Alkalinity (mg/L as $CaCO_3$)	50		20		250		50		75		90		160	
Conductivity (mS/cm)	0.116		0.105		0.133		0.141		0.281		0.16		0.258	
Dissolved Oxygen (mg/L)	0.79		3.98		0.71		2.33		6.89		0.49		2.79	
Ferrous Iron (mg/L)	6			ND	2		2.5			ND	9		3.8	
Hydrogen Sulfide (mg/L)	3			ND	0.1		0.5			ND	0.1			ND
Oxidation Reduction Potential (mv)	3		174		38		0		147		-51		-51	
pH (SU)	5.42		6.49		6.89		6.29		6.69		6.32		6.77	
Salinity (%)		ND		ND		ND		ND		ND		ND		ND
Temperature (°C)	13.1		12.3		12.4		8.8		15		14.3		12.1	
Turbidity (NTU)	15		130		2.31		18.09		0.6		7.5		9	
Laboratory														
Carbon Dioxide (mg/L)	222.8		51		93.6		35.4		75.9		74.1		43.3	
Chloride (mg/L)	8.1		5.6		4.4		25		7.3		4		5.7	
Ethane (ug/L)	1.15		0.01	U	0.08		0.01	U	0.01	U	0.5		0.05	
Ethene (ug/L)	0.06		0.01		0.01	U	0.04		0.01	U	0.04		0.01	
Hydrogen (nm/L as gas)	2.7		2.4		2.5		2.2		4.8		14		10.2	
Methane (ug/L)	529.7		0.2	U	444.2		168.4		2.9		876.3		495.5	
Nitrate (mg/L)	0.033	J	0.74		0.072	J	0.1	UJ	2.5		0.1	UJ	0.03	J
Nitrogen (mg/L)	10.2		14.3		9.2		10.7		9.1		8.1		7.6	
Oxygen (mg/L)	0.18		2.89		0.15	U	0.15	U	3.86		0.15	U	0.82	
Sulfate (mg/L)	6.4		9.1		6.3		13		21		7.2		6.2	
Total Organic Carbon (mg/L)	13		6	U	6	U	8.2		6	U	6	U	10	

Sample ID:	WOD-WFF16-GW3		WOD-WFF16-GW4		WOD-WFF16-GW5		WOD-WFF16-GW6		WOD-WFF16-GW7		WOD-WFF16-GW7-DUP		WOD-WFF16-MW3R	
Sample Date:	**03/18/03**		**03/14/03**		**03/13/03**		**03/17/03**		**03/18/03**		**03/18/03**		**03/12/03**	
Field														
Alkalinity (mg/L as $CaCO_3$)	75		35		675		50		25		NA		40	
Conductivity (mS/cm)	0.07		0.04		0.324		0.351		0.573		NA		0.113	
Dissolved Oxygen (mg/L)	7.98		9.76		3.06		1.3		0.68		NA		8.56	
Ferrous Iron (mg/L)		ND		ND	0.1			ND		ND	NA			ND
Hydrogen Sulfide (mg/L)		ND		ND		ND		ND		ND	NA			ND
Oxidation Reduction Potential (mv)	283		231		3		148		-51		NA		107	
pH (SU)	5.01		5.95		7.72		5.88		7.14		NA		6.41	
Salinity (%)		ND		ND		ND		ND		ND	NA			ND
Temperature (°C)	12.5		8.9		10.2		9.3		10.9		NA		14.8	
Turbidity (NTU)	2.31		90.7		27.4		2.9		9		NA		5.8	
Laboratory														
Carbon Dioxide (mg/L)	10.6		5.4		60.5		139.3		211.7		223.2		NA	
Chloride (mg/L)	8.6		4.2		3.4		12		24		24		NA	
Ethane (ug/L)	0.01	U	0.01	U	0.01	U	0.01		0.01	U	0.01	U	NA	
Ethene (ug/L)	0.01	U	0.01	U	0.01	U	0.01	U	0.01	U	0.01	U	NA	
Hydrogen (nm/L as gas)	1.9		39.2		NA		3.1		2.6		2		NA	
Methane (ug/L)	10.6		1		8.1		0.2	U	9521.8		10263.8		NA	
Nitrate (mg/L)	1.5		0.23	J	0.22		12		0.41		0.38		NA	
Nitrogen (mg/L)	7		13.7		13		12.8		2.2		2.7		NA	
Oxygen (mg/L)	3.21		7.16		0.45		0.86		0.15	U	0.15	U	NA	
Sulfate (mg/L)	4.4		4.7		26		38		28		27		NA	
Total Organic Carbon (mg/L)	6	U	6	U	6	U	7.5		17		17		NA	

TABLE 5-1

SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

Evaluation Criteria	Alternative 1: No Action	Alternative 2: Natural Attenuation, Institutional Controls and Monitoring	Alternative 3: In-Situ Biological Treatment (Biostimulation), Institutional Controls, and Monitoring	Alternative 4: In-Situ Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring	Alternative 5: In-Situ AS Treatment, Institutional Controls, and Monitoring
Overall Protection of Human Health and Environment	Would not be protective of human health and the environment because no action would occur. Migration of COCs would continue and remain undetected.	Would be protective of human health and the environment because natural attenuation would reduce COC concentrations down to PRGs over a reasonable timeframe. Institutional controls and monitoring would provide immediate protection until the PRGs are met by restricting the use of the aquifer for drinking purposes and checking for potential migration of COCs.	Would be more protective of human health and the environment than Alternative 2 because, in addition of institutional controls and monitoring, it would feature active treatment that would accelerate the removal of COCs.	Would be more protective of human health and the environment than Alternative 2 because, in addition of institutional controls and monitoring, it would feature active treatment that would accelerate the removal of COCs. Would be as protective of human health and the environment as Alternative 3	Would be as protective of human health and the environment as Alternatives 3 and 4 because it would provide most of the same protective components (i.e., institutional controls, and monitoring) and also accelerate the removal of COCs, but through in-situ AS treatment rather than in-situ bioremediation.
Compliance with ARARs and TBCs:					
Chemical-Specific	Would not comply	Would eventually comply	Would eventually comply	Would eventually comply	Would eventually comply
Location-Specific	Would not comply	Would comply	Would comply	Would comply	Would comply
Action-Specific	Not applicable	Would comply	Would comply	Would comply	Would comply
Long-Term Effectiveness and Permanence	Would have very limited long-term effectiveness and permanence because no action would occur. Contaminant reduction or migration would remain undetected because no monitoring would occur.	Would be long-term effective and permanent. Natural attenuation would eventually reduce COC concentrations down to PRGs. Institutional controls would effectively prevent unacceptable human health risk from exposure to contaminated groundwater. Monitoring would effectively evaluate the progress of remediation and detect potential migration of COCs.	Would be more long-term effective and permanent than Alternative 2 by accelerating the removal of COCs through active in-situ bioremediation. However, the effectiveness of ORC® injection would have to be verified through treatability testing. The long-term effectiveness and permanence of the institutional controls, and monitoring would be the same as for Alternative 2.	Would be more long-term effective and permanent than Alternative 2 by accelerating the removal of COCs through active in-situ bioremediation. However, the effectiveness of SSWM/U.S. Microbics nutrients and microbes injection would have to be verified through treatability testing. The long-term effectiveness and permanence of the institutional controls, and monitoring would be the same as for Alternative 2.	Would be more long-term effective and permanent than Alternative 2 because it would provide the same accelerated removal of COCs, but through in-situ AS treatment that does not need to be tested. The long-term effectiveness and permanence of the institutional controls and monitoring would be the same as for Alternative 2.
Reduction of Contaminant Toxicity, Mobility, or Volume through Treatment	Would not reduce contaminant toxicity, mobility, or volume through treatment because no treatment would occur.	Would not reduce contaminant toxicity, mobility, or volume through treatment because no treatment occurs. However, the reduction of the estimated 31 pounds of dissolved and sorbed phase contamination through biodegradation (in-situ natural attenuation processes) would be irreversible.	Would irreversibly and permanently reduce contaminant toxicity, mobility, and volume by removing an estimated 31 pounds of dissolved and sorbed phase contamination through in-situ bioremediation.	Would irreversibly and permanently reduce contaminant toxicity, mobility, and volume by removing an estimated 31 pounds of dissolved and sorbed phase contamination through in-situ bioremediation.	Would irreversibly and permanently reduce contaminant toxicity, mobility, and volume by removing an estimated 31 pounds of dissolved and sorbed phase contamination through in-situ AS treatment.
Short-Term Effectiveness	Would not result in any short-term risk to site workers or adversely impact the surrounding community or environment because no action would occur. The RAOs would never be achieved with the implementation of this alternative.	Would result in a slight possibility of exposing site workers to contaminated groundwater as a result of monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The first RAO would be achieved immediately upon implementation of the institutional controls and monitoring. The second RAO and the PRGs would be met within	Would result in a possibility of exposing site workers to contaminated groundwater as a result of bioremediation and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The first RAO would be achieved immediately upon implementation of the institutional controls and monitoring. The second RAO and the PRGs would be met within	Would result in a possibility of exposing site workers to contaminated groundwater as a result of bioremediation and monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The first RAO would be achieved immediately upon implementation of the institutional controls and monitoring. The second RAO and the PRGs would be met within 3 years.	Would result in a possibility of exposing site workers to contaminated groundwater as a result of the installation and O&M of the in-situ AS treatment system and of monitoring activities. This risk would be reduced through compliance with appropriate site-specific health and safety procedures. There would be no risk to the surrounding community and environment. The first RAOs would be achieved immediately upon implementation of the institutional controls and monitoring. The second RAO and the PRGs would be met within 3 years.

TABLE 5-1

SUMMARY OF COMPARATIVE ANALYSIS OF GROUNDWATER REMEDIAL ALTERNATIVES
WOD FS REPORT
NASA WFF – WALLOPS ISLAND, VIRGINIA

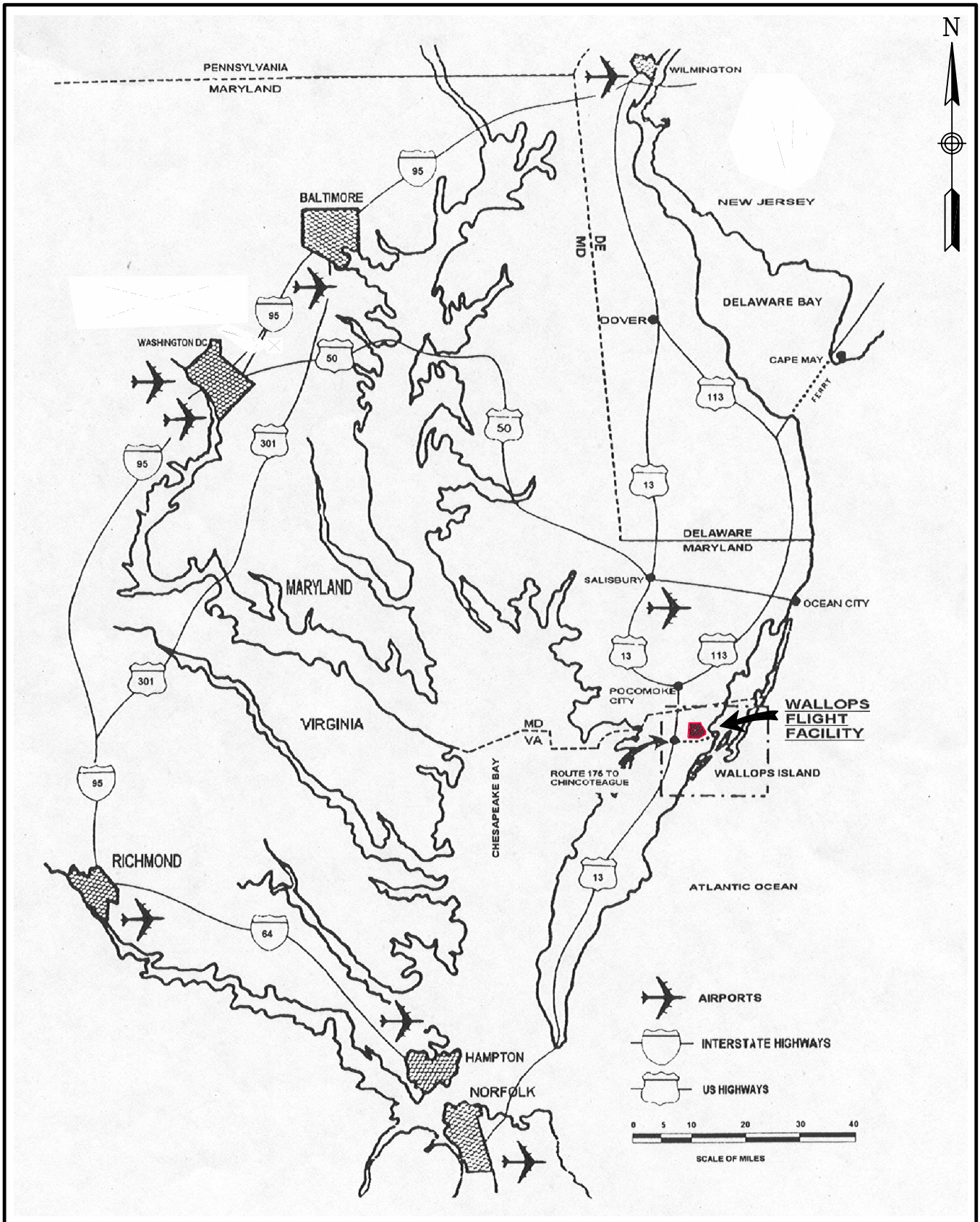
Evaluation Criteria	Alternative 1: No Action	Alternative 2: Natural Attenuation, Institutional Controls and Monitoring	Alternative 3: In-Situ Biological Treatment (Biostimulation), Institutional Controls, and Monitoring	Alternative 4: In-Situ Biological Treatment (Bioaugmentation), Institutional Controls, and Monitoring	Alternative 5: In-Situ AS Treatment, Institutional Controls, and Monitoring
		5 years.	3 years.		
Implementability	Technical and administrative implementation would be extremely simple because there would be no action to implement.	Technical implementation of the monitoring would be simple. Administrative implementation of the institutional controls would be simple.	Technical implementation of the in-situ bioremediation would be simple although it would create temporary site disruptions, and the number of qualified contractors would be limited. Technical implementation of the monitoring would be simple. Administrative implementation of the institutional controls would be simple. A construction permit might be required for installation of the ORC® injection points. A UIC permit will be required.	Technical implementation of the in-situ bioremediation would be simple although it would create temporary site disruptions, and the number of qualified contractors would be limited. Technical implementation of the monitoring would be simple. Administrative implementation of the institutional controls would be simple. A construction permit might be required for installation of the SSWM/U.S. Microbics injection points. A UIC permit will be required.	Technical implementation of the in-situ AS treatment would be significantly more complex than that of in-situ bioremediation and create much greater site disruptions. However, implementation would still be technically possible and site disruptions would be acceptable. Technical implementation of the monitoring would be simple. Administrative implementation of the institutional controls would be simple. Construction permits would be required for the installation of the in-situ AS treatment systems.
Costs: Capital NPW of O&M NPW	 $0 $0 $0	 $37,000 $187,000 (5 Years) $224,000 (5 Years)	 $240,000 $157,000 (5 Years) $397,000 (5 Years)	 $175,000 $355,000 (5 Years) $530,000 (5 Years)	 $307,000 $186,000 (5 Years) $493,000 (5 Years)

NOTES:

ARARs	Applicable or Relevant and Appropriate Requirements
AS	Air sparging
COCs	Chemicals of concern
NPDES	National Pollutant Discharge Elimination System
NPW	Net present worth
O&M	Operation and maintenance
ORC®	Oxygen release compound
PRG	Preliminary Remediation Goal
RAO	Remedial Action Objective
TBC	To-be-considered (criterion)
UIC	Underground Injection Control

FIGURES

2541/0230/2541CP01.DWG 05/17/05 MKB

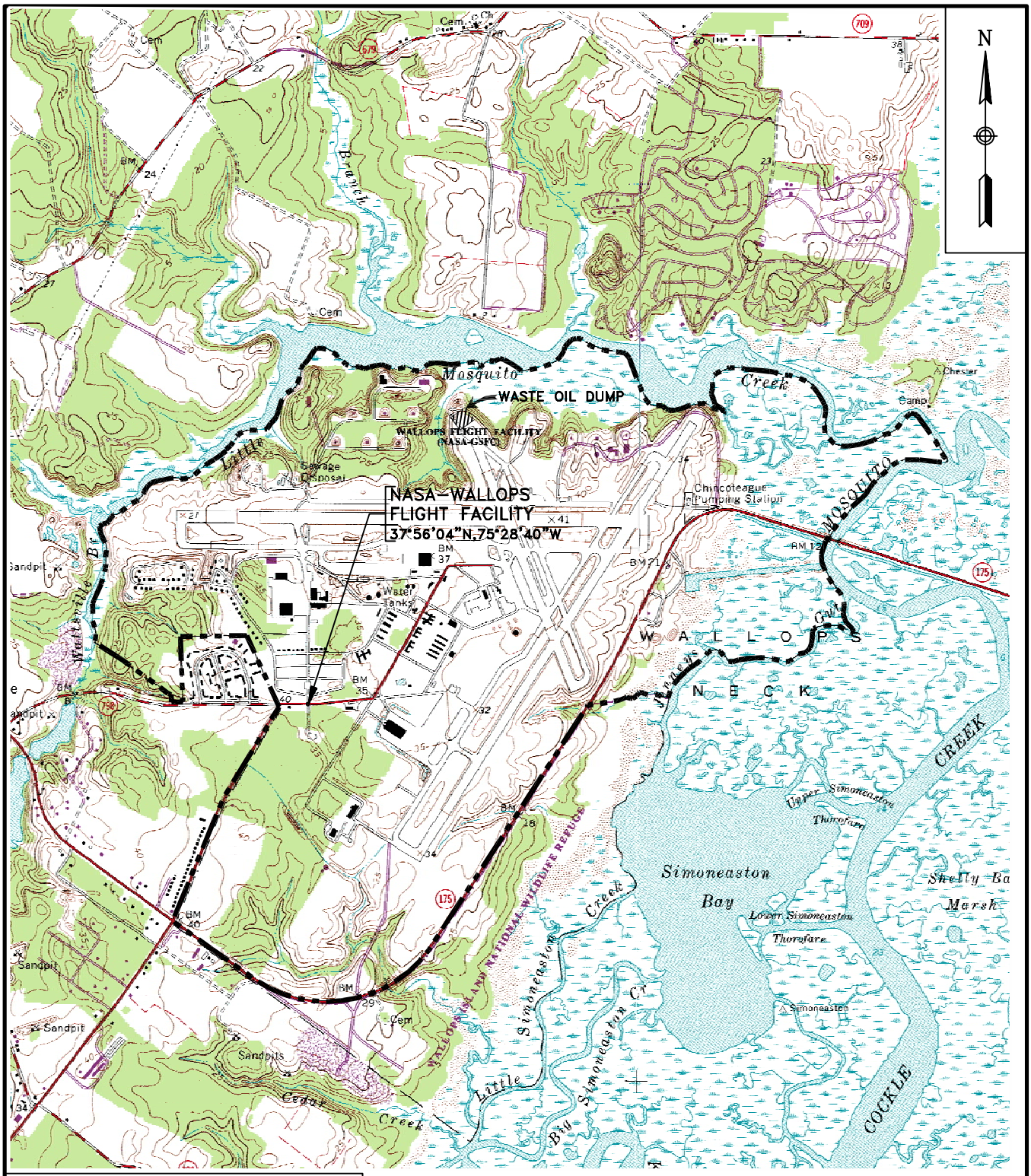


TETRA TECH NUS, INC.

SITE LOCATION MAP OF NASA WALLOPS FLIGHT FACILITY WALLOPS ISLAND, VIRGINIA

SCALE	AS NOTED
FILE	2541CP01.DWG
REV	0
DATE	05/17/05
FIGURE NUMBER	FIGURE 1–1

1612/1111/1612BM01.DWG 10/07/05 MKB



0 2000 4000

SCALE IN FEET

SOURCE: U.S.G.S. 7.5' QUADRANGLE MAPS, WALLOPS ISLAND, VA. (37075–G4), AND BLOXOM, VA. (37075–G5).

TETRA TECHNUS, INC.

STUDY AREA LOCATION MAP OF NASA WALLOPS FLIGHT FACILITY WALLOPS ISLAND, VIRGINIA

SCALE
AS NOTED

FILE:
1612BM01.DWG

REV | DATE
10/07/05

FIGURE NUMBER
FIGURE 1–2

ACAD:1612GM07.dwg 2/7/05 DM PIT

LEGEND

1.00 ELEVATION CONTOUR (METERS)

EXCAVATED AREAS

STAINED SOIL

STRESSED VEGETATION

N

LITTLE MOSQUITO CREEK

MARSH OUTLINE

TREELINE

DEBRIS PILE (SITE 15)

HEDGE

HEDGE

END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

WASTE OIL DUMP
SITE MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE: 1612GM07 DM PIT	SCALE AS NOTED
FIGURE NUMBER FIGURE 1–3	REV DATE 2/7/05

ACAD:1612GP02.dwg 08/07/03 HJB PIT

LEGEND

1.00 — ELEVATION CONTOUR (METERS)

= MONITORING WELL

= GROUNDWATER CONTOUR (DASHED WHERE INFERRED)

(1.65) = GROUNDWATER ELEVATION (METERS)

STAINED SOIL

STRESSED VEGETATION

N

LITTLE MOSQUITO CREEK

FTA-MW104S

WFF-MW4 (1.24)

WFF16-GW4 (1.42)

WFF16-GW3 (1.50)

WFF16-GW5 (1.29)

WFF16-GW6 (1.22)

WFF15-GW1 (1.04)

WFF16-GW2S (1.65)

WFF16-GW2D

WFF16-GW7 (1.16)

WFF15-GW2 (1.45)

WFF15-GW7 (1.90)

WFF16-GW1 (1.71)

WFF15-GW3 (1.47)

WFF15-MW3R (1.90)

MARSH

OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

WASTE OIL DUMP
GROUNDWATER ELEVATIONS (3/19/03)
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE: 1612GP02	SCALE AS NOTED
FIGURE NUMBER FIGURE 1-4	REV DATE 2/7/05

ACAD:1612GT03.dwg 02/08/05 DM PIT

LEGEND

1.00 — ELEVATION CONTOUR (METERS)

MONITORING WELL (SAMPLED 2003)

J ESTIMATED

ug/L MICROGRAMS PER LITER

N

LITTLE MOSQUITO CREEK

WFF–MW4 3/17/03

INORGANICS	ug/L
CHROMIUM	6.1
LEAD	5.1

WOD–WFF16–GW2D 3/12/03

INORGANICS	ug/L
ARSENIC	21.4
VOLATILES	ug/L
1,2–DICHLOROETHENE (CIS)	2
BENZENE	8
ETHYLBENZENE	8
ISOPROPYLBENZENE	1

WOD–WFF16–GW2S 3/12/03

SEMIVOLATILES	ug/L
ACENAPHTHENE	1 J
BIS(2–ETHYLHEXYL)PHTHALATE	2 J
VOLATILES	ug/L
1,2–DICHLOROETHENE (CIS)	1

WOD–WFF16–GW3 3/18/03

INORGANICS	ug/L
CHROMIUM	124

WOD–WFF16–GW5 3/13/03

SEMIVOLATILE	ug/L
STYRENE	1

WOD–WFF15–GW1 3/12/03

SEMIVOLATILES	ug/L
FLUORENE	2 J
PHENANTHRENE	2 J
VOLATILES	ug/L
1,2–DICHLORETHENE (CIS)	3

WOD–WFF16–GW7 3/18/03

SEMIVOLATILE	ug/L
BIS(2–ETHYLHEXYL)PHTHALATE	18

WOD–WFF16–GW1 3/18/03

INORGANICS	ug/L
CHROMIUM	147

WOD–WFF15–GW7 3/14/03

INORGANICS	ug/L
LEAD	68.6
SEMIVOLATILE	ug/L
2–METHYLNAPHTHALENE	130
ACENAPHTHENE	9
BIS(2–ETHYLHEXYL)PHTHALATE	4 J
DIBENZOFURAN	4 J
FLUORENE	12
NAPTHALENE	130
PHENANTHRENE	15
VOLATILES	ug/L
1,2,4–TRIMETHYLBENZENE	170
1,2–DICHLOROETHENE (CIS)	1
1,3,5–TRIMETHYLBENZENE	74
BENZENE	11
ETHYLBENZENE	68
ISOPROPYLBENZENE	6
M,P,–XYLENE	370
METHYLCYCLOHEXANE	18
O–XYLENE	170
STYRENE	5
TETRACHLOROETHENE	5
TOLUENE	120
XYLENE (TOTAL)	540

WOD–WFF15–GW2 3/12/03

SEMIVOLATILES	ug/L
4–METHYLPHENOL	42
VOLATILES	ug/L
2–BUTANONE	6
TOLUENE	2

(NOT SAMPLED)

OUTLINE TREELINE HEDGE HEDGE END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

WASTE OIL DUMP
SELECT GROUNDWATER SAMPLE RESULTS
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE: 1612GT03	SCALE AS NOTED
FIGURE NUMBER FIGURE 1–5	REV DATE 2/7/05

ACAD:1612GP03.dwg 03/01/05 DM PIT

LEGEND

- 1.00 = ELEVATION CONTOUR (METERS)
- = MONITORING WELL
- = GROUNDWATER EXCEEDING BENZENE PRG (5 ug/L)
- = GROUNDWATER EXCEEDING ARSENIC PRG (10 ug/L)
- = GENERALIZED GROUNDWATER FLOW DIRECTION

N

LITTLE MOSQUITO CREEK

MARSH

OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

FTA–MW104S

WFF–MW4

WFF16–GW4

WFF16–GW5

WFF16–GW3

WFF16–GW6

WFF16–GW2S

WFF16–GW2D

WFF15–GW1

WFF16–GW7

WFF16–GW1

WFF15–GW2

WFF15–GW7

WFF15–GW3

WFF15–MW3R

WOD–WFF16–GW2D 3/12/03	
INORGANICS	ug/L
ARSENIC	21.4
VOLATILES	ug/L
BENZENE	8

WOD–WFF15–GW7 3/14/03	
VOLATILES	ug/L
BENZENE	11

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

WASTE OIL DUMP GROUNDWATER COCs IN EXCESS OF PRGs

NASA WALLOPS FLIGHT FACILITY

WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GP03 DM PIT	AS NOTED
FIGURE NUMBER	REV / DATE
FIGURE 2–1	2/7/05

ACAD:1612GT04.dwg 03/01/05 DM PIT

LEGEND

- —1.00— = ELEVATION CONTOUR (METERS)
- = MONITORING WELL
- = 2003 SUPPLEMENTAL SUBSURFACE SAMPLE RI
- = 2001 RI SUBSURFACE SAMPLE
- J = ESTIMATED
- K = BIASED HIGH
- L = BIASED LOW
- mg/kg = MILLIGRAMS PER KILOGRAM
- ug/kg = MICROGRAMS PER KILOGRAM
- STAINED SOIL
- STRESSED VEGETATION
- ESTIMATED LIMIT OF CONTAMINATED SUBSURFACE SOIL AREA

N

MOSQUITO CREEK

TTLE

MARSH

HEDGE

HEDGE

WOD-SU-111-0507 2/11/03	
INORGANICS	mg/kg
ANTIMONY	18.3 L
CADMIUM	23.4 L
SILVER	389
THALLIUM	3.5 K
SEMIVOLATILES	ug/kg
BENZ(a)ANTHRACENE	45 J
BENZALDEHYDE	45 J
BENZO(a)PYRENE	55 J
BENZO(b)FLUORANTHENE	88 J
BIS(2-ETHYLHEXYL)PHTHALATE	78 J
CHRYSENE	73 J
FLUORANTHENE	45 J
PYRENE	93 J
VOLATILES	ug/kg
1,2,4-TRIMETHYLBENZENE	4 J
2-BUTANONE	25 J
BENZENE	42 J
CARBON DISULFIDE	4 J
ETHYLBENZENE	2 J
M,P-XYLENE	4 J
O-XYLENE	1 J
TOLUENE	10 J
XYLENE (TOTAL)	5 J

WOD-SU-112-0204 2/11/03	
INORGANICS	mg/kg
SILVER	0.11

WOD-SU-108-0608 2/10/03	
INORGANICS	mg/kg
THALLIUM	0.18 L

WOD-SU-114-0406 2/11/03	
INORGANICS	mg/kg
THALLIUM	0.18

WOD-SU-116-0204 2/12/03	
INORGANICS	mg/kg
FLUORANTHENE	40 J

WOD-SU-110-0204 2/11/03	
INORGANICS	mg/kg
SILVER	0.2

WOD-SU-117-0102 2/12/03	
INORGANICS	mg/kg
SILVER	0.11

WOD-SU-115-0305 2/12/03	
INORGANICS	mg/kg
CADMIUM	0.54

WOD-SU-120-0406 2/12/03	
INORGANICS	mg/kg
CADMIUM	0.034
SEMIVOLATILE	ug/kg
BIS(2-ETHYLHEXYL)PHTHALATE	66 J

2WFF16-SB4S2 5/7/98	
SEMIVOLATILE	ug/kg
2-METHYLNAPHTHALENE	310 J
ACENAPHTHENE	54 J
FLUORENE	100 J
PHENANTHRENE	290 J
VOLATILES	ug/kg
XYLENE (TOTAL)	64 J

WOD-SU-124-0203 2/13/03	
VOLATILES	ug/kg
METHYL ACETATE	5 J

WOD-SU-126-0203 2/26/03	
INORGANICS	mg/kg
SILVER	0.46
BIS(2-ETHYLHEXYL)PHTHALATE	63 J
VOLATILES	ug/kg
XYLENE (TOTAL)	9 U

WOD-SU-127-0203 2/25/03	
INORGANICS	mg/kg
SILVER	0.24
SEMIVOLATILE	ug/kg
BIS(2-ETHYLHEXYL)PHTHALATE	190 J

2WFF16-SB3S2 5/7/98	
SEMIVOLATILE	ug/kg
PHENANTHRENE	43 J

WOD-SU-125-0203 2/13/03	
SEMIVOLATILE	ug/kg
BENZO(b)FLUORANTHENE	56 J
CHRYSENE	39 J
FLUORANTHENE	43 J
PYRENE	47 J
VOLATILES	ug/kg
1,2,4-TRIMETHYLBENZENE	1 J
1,3,5-TRIMETHYLBENZENE	1 J
M,P-XYLENE	1 J
XYLENE (TOTAL)	1 J

WOD-SU-119-0507 2/12/03	
INORGANICS	mg/kg
CADMIUM	0.062 K
SILVER	0.21 L

2WFF16-SB2S2 5/7/98	
SEMIVOLATILE	ug/kg
2-METHYLNAPHTHALENE	29000 J
ACENAPHTHENE	1800 J
DIBENZOFURAN	1100 J
FLUORENE	2800 J
NAPHTHALENE	7700 J
PHENANTHRENE	7800 J
PYRENE	580 J
VOLATILES	ug/kg
CHLOROETHANE	110 J
ETHYLBENZENE	2200 J
TOLUENE	1700 J
XYLENE (TOTAL)	13000 J

WOD-SU-102-1517 2/6/03	
VOLATILES	ug/kg
1,2,4-TRIMETHYLBENZENE	42
1,3,5-TRIMETHYLBENZENE	93
CHLOROETHANE	13
M,P-XYLENE	10 J
O-XYLENE	9 J
TETRACHLOROETHENE	3 J
XYLENE (TOTAL)	20

2WFF16-SB1S2 5/7/98	
SEMIVOLATILE	ug/kg
2-METHYLNAPHTHALENE	22000 J
FLUORENE	2100 J
PHENANTHRENE	5700 J
PYRENE	290 J
VOLATILES	ug/kg
ETHYLBENZENE	1000
TETRACHLOROETHENE	81 J
TOLUENE	320
XYLENE (TOTAL)	6600 J

2WFF16-SB1S2 DUP	
SEMIVOLATILE	ug/kg
2-METHYLNAPHTHALENE	16000 J
FLUORENE	2900 J
PHENANTHRENE	4100 J
PYRENE	230 J
VOLATILES	ug/kg
CHLOROETHANE	56 K
ETHYLBENZENE	1200 J
TETRACHLOROETHENE	320
TOLUENE	1400
XYLENE (TOTAL)	9200 J

WOD-SU-105-0507 2/11/03	
INORGANICS	mg/kg
SILVER	0.35 K

WOD-SU-104-1012 2/6/03	
SEMIVOLATILE	ug/kg
BIS(2-ETHYLHEXYL)PHTHALATE	37 J

SB-101 SB-103 SB-106 SB-107 SB-109 SB-113 SB-118 SB-119 SB-121 SB-122 SB-123

0.25 0.50 0.75 1.25 2.50 3.75 5.00 6.25 7.50 8.75

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

WASTE OIL DUMP
LOCATION OF CONTAMINATED SUBSURFACE SOIL AREA
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE: 1612GT04	SCALE AS NOTED
FIGURE NUMBER FIGURE 2-2	REV DATE 2/7/05

ACAD:1612GM01.dwg 02/08/05 DM PIT

LEGEND

- = MONITORING WELL
- mv = MILLIVOLT
- 1.00 — ELEVATION CONTOUR (METERS)
- 200 — ORP CONTOUR (INFERRED WHERE DASHED) (MARCH 2003)

N

LITTLE MOSQUITO CREEK

MARSH OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

FTA–MW104S

WFF–MW4 (174 mv)

WFF16–GW4 (231 mv)

WFF16–GW3 (283 mv)

WFF16–GW5 (3 mv)

WFF16–GW6 (148 mv)

WFF16–GW7 (–51 mv)

WFF15–GW1 (38 mv)

WFF16–GW2D
WFF16–GW2S (–51 mv)

WFF16–GW1 (147 mv)

WFF15–GW2 (0 mv)

WFF15–GW7 (3 mv)

WFF15–GW3

WFF15–MW3R (107 mv)

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC (METERS).

TETRA TECH NUS, INC.

WASTE OIL DUMP
ORP ISOCONCENTRATION MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GM01	AS NOTED
FIGURE NUMBER	REV / DATE
FIGURE 3–3	2/8/05

FIGURE 3-1

TREND OF BTEX IN WELL WFF15-GW7
FORMER WASTE OIL DUMP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

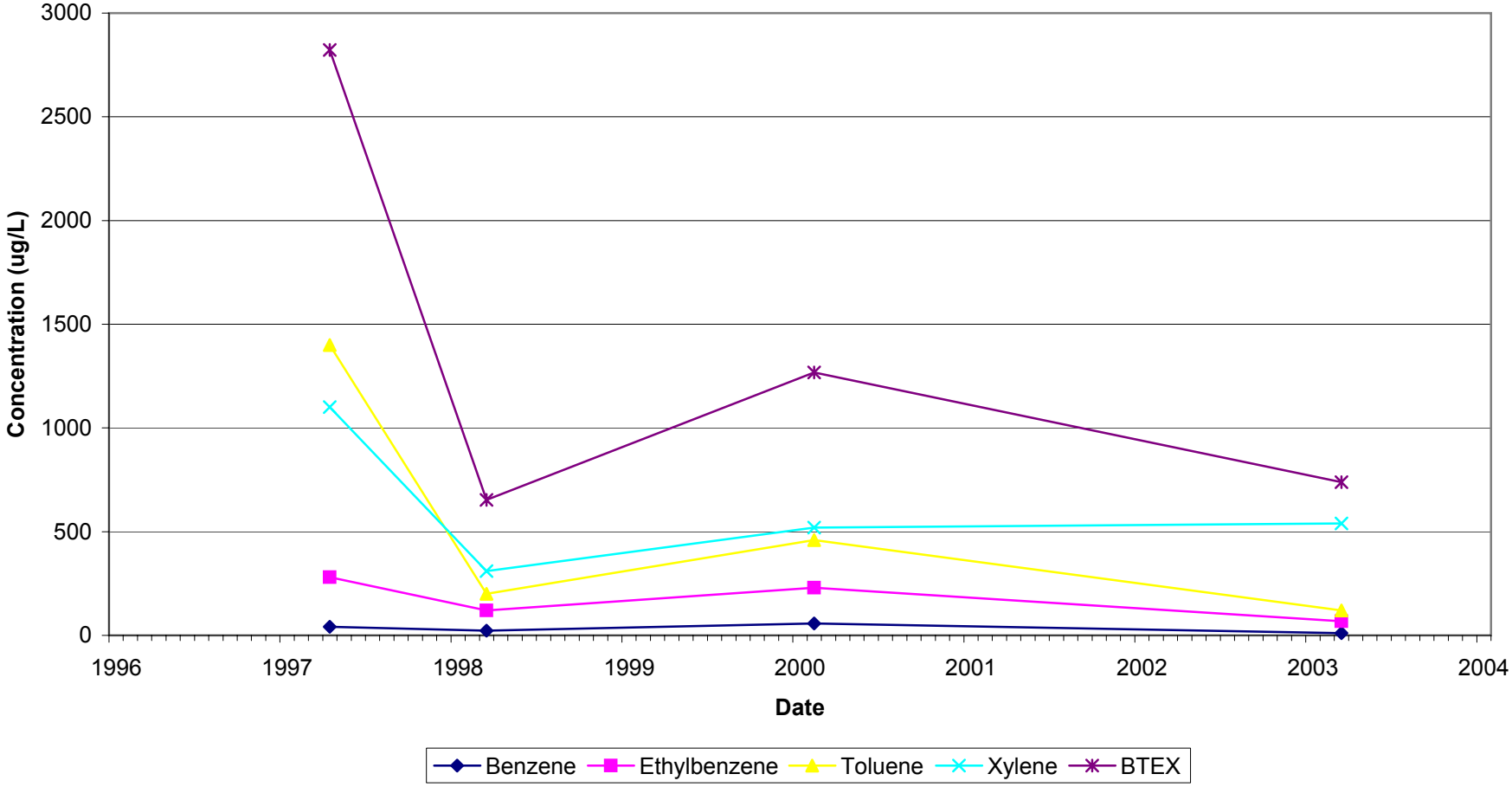
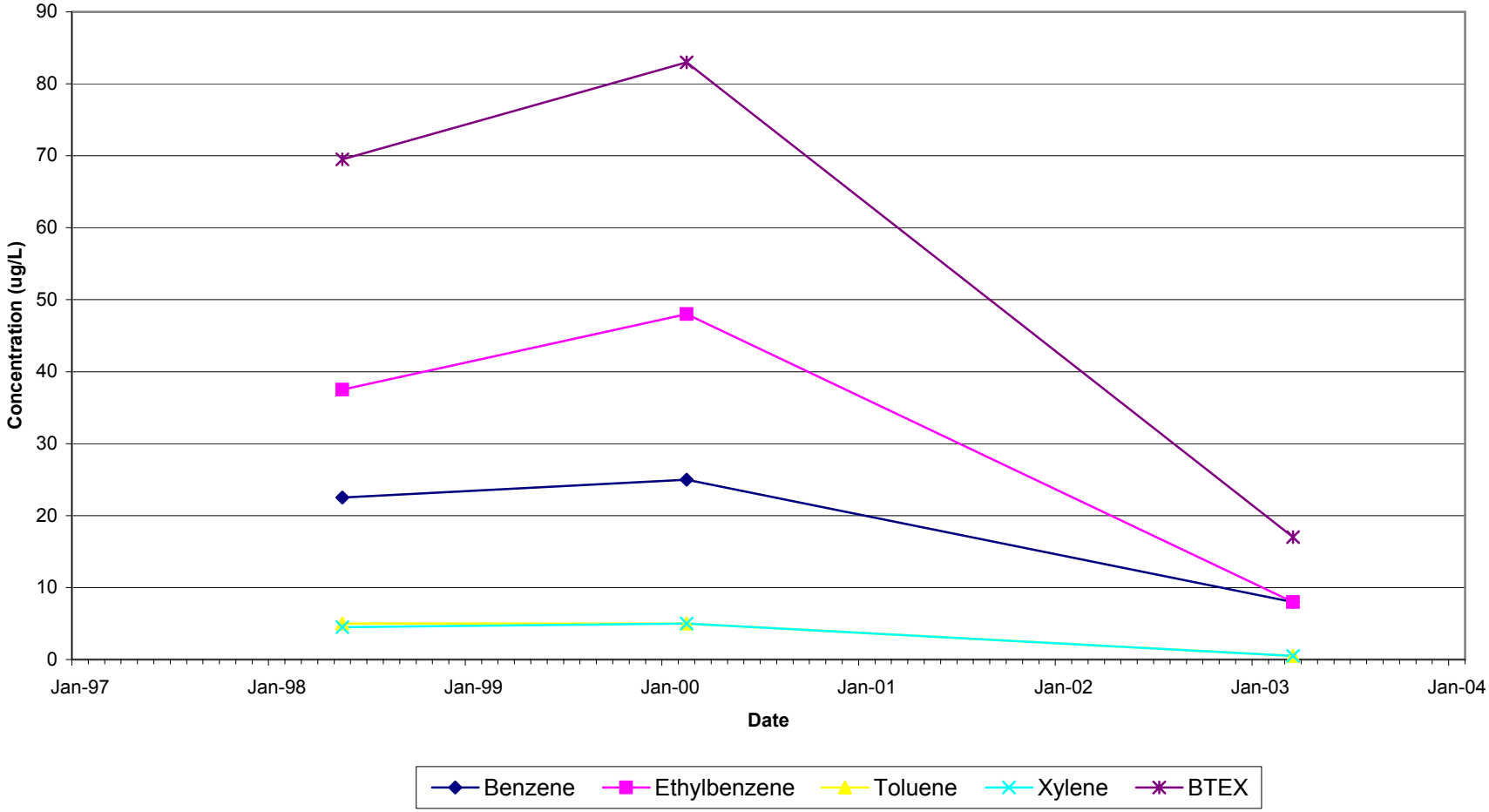


FIGURE 3-2

TREND OF BTEX IN WELL WFF16-GW2D
FORMER WASTE OIL DUMP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA



ACAD:1612GM01.dwg 02/08/05 DM PIT

LEGEND

- = MONITORING WELL
- mv = MILLIVOLT
- 1.00 — ELEVATION CONTOUR (METERS)
- 200 — ORP CONTOUR (INFERRED WHERE DASHED) (MARCH 2003)

N

LITTLE MOSQUITO CREEK

MARSH OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

FTA–MW104S

WFF–MW4 (174 mv)

WFF16–GW4 (231 mv)

WFF16–GW3 (283 mv)

WFF16–GW5 (3 mv)

WFF16–GW6 (148 mv)

WFF16–GW7 (–51 mv)

WFF15–GW1 (38 mv)

WFF16–GW2D
WFF16–GW2S (–51 mv)

WFF16–GW1 (147 mv)

WFF15–GW2 (0 mv)

WFF15–GW7 (3 mv)

WFF15–GW3

WFF15–MW3R (107 mv)

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC (METERS).

TETRA TECH NUS, INC.

WASTE OIL DUMP
ORP ISOCONCENTRATION MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GM01	AS NOTED
FIGURE NUMBER	REV / DATE
FIGURE 3–3	2/8/05

ACAD:1612GM03.dwg 02/08/05 DM PIT

LEGEND

= MONITORING WELL

mg/L = MILLIGRAMS PER LITER

1.00 ELEVATION CONTOUR (METERS)

5 DO CONTOUR (INFERRED WHERE DASHED) (MARCH 2003)

DO = DISSOLVED OXYGEN

N

MOSQUITO CREEK

FTA–MW104S

WFF–MW4 (3.98 mg/L)

WFF16–GW4 (9.76 mg/L)

WFF16–GW5 (3.06 mg/L)

WFF16–GW3 (7.98 mg/L)

WFF16–GW6 (1.3 mg/L)

WFF16–GW2D
WFF16–GW2S
(2.79 mg/L)

WFF15–GW1 (0.71 mg/L)

WFF16–GW7 (0.68 mg/L)

WFF15–GW2 (2.33 mg/L)

WFF15–GW7 (0.79 mg/L)

WFF16–GW1 (6.89 mg/L)

WFF15–GW3

WFF15–MW3R (8.56 mg/L)

MARSH

OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC (METERS).

TETRA TECH NUS, INC.

WASTE OIL DUMP
DO ISOCONCENTRATION MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GM03	AS NOTED
FIGURE NUMBER	REV / DATE
FIGURE 3–4	2/8/05

ACAD:1612GM04.dwg 01/13/05 DM PIT

LEGEND

= MONITORING WELL

ug/L = MICROGRAMS PER LITER

1.00 ELEVATION CONTOUR (METERS)

10 METHANE CONTOUR (INFERRED WHERE DASHED) (MARCH 2003)

N

LITTLE MOSQUITO CREEK

FTA-MW104S

WFF-MW4 (ND)

WFF16-GW4 (1 ug/L)

WFF16-GW5 (8.1 ug/L)

WFF16-GW3 (10.6 ug/L)

WFF16-GW6 (ND)

WFF16-GW7 (9521.8 ug/L)

WFF15-GW1 (444.2 ug/L)

WFF16-GW2D
WFF16-GW2S (495.5 ug/L)

WFF15-GW2 (168.4 ug/L)

WFF15-GW7 (529.7 ug/L)

WFF16-GW1 (2.9 ug/L)

WFF15-GW3

WFF15-MW3R (26.2 ug/L)

MARSH OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 - 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC (METERS).

TETRA TECH NUS, INC.

WASTE OIL DUMP
METHANE ISOCONCENTRATION MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GM04	AS NOTED
FIGURE NUMBER: FIGURE 3-5	REV / DATE: 2/8/05

ACAD:1612GM02.dwg 01/12/05 DM PIT

LEGEND

= MONITORING WELL

1.00 ELEVATION CONTOUR (METERS)

6.0 pH CONTOUR (INFERRED WHERE DASHED) (MARCH 2003)

SU = STANDARD UNIT

N

LITTLE MOSQUITO CREEK

FTA–MW104S

WFF–MW4 (6.49 SU)

WFF16–GW4 (5.95 SU)

WFF16–GW3 (5.01 SU)

WFF16–GW6 (5.88 SU)

WFF16–GW5 (7.72 SU)

WFF15–GW1 (6.89 SU)

WFF16–GW2D
WFF16–GW2S (6.77 SU)

WFF15–GW7 (5.42 SU)

WFF16–GW7 (7.14 SU)

WFF16–GW1 (6.69 SU)

WFF15–GW2 (6.29 SU)

WFF15–GW3

WFF15–MW3R (6.41 SU)

MARSH OUTLINE

TREELINE

HEDGE

HEDGE

END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

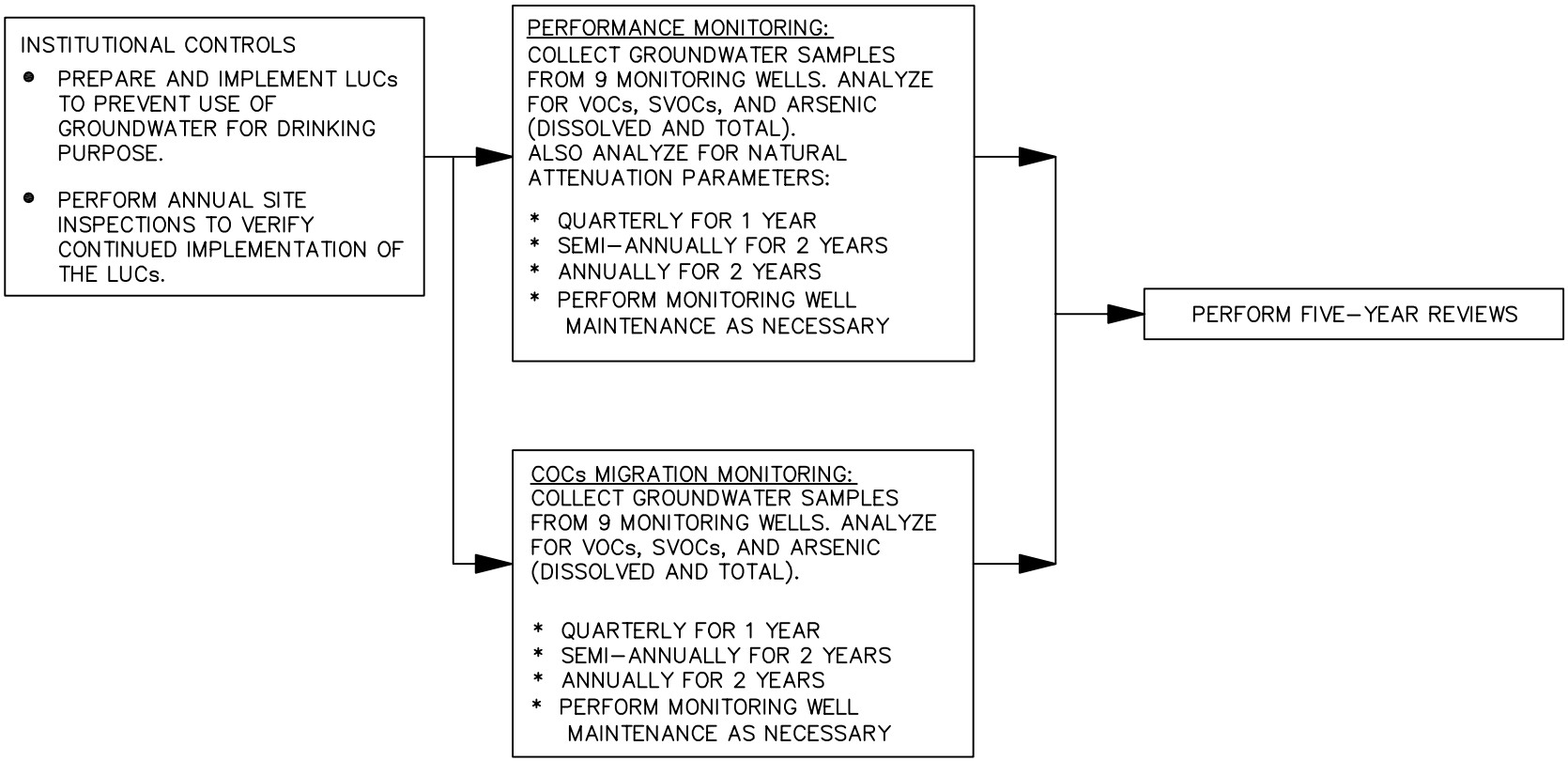
ELEVATION CONTOURS ARE METRIC (METERS).

TETRA TECH NUS, INC.

WASTE OIL DUMP
pH ISOCONCENTRATION MAP
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE:	SCALE
1612GM02	AS NOTED
FIGURE NUMBER	REV / DATE
FIGURE 3–6	2/8/05

NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING



NOTES:

COCs	CHEMICALS OF CONCERN
LUCS	LAND USE CONTROLS
VOC	VOLATILE ORGANIC COMPOUND
SVOC	SEMIVOLATILE ORGANIC COMPOUND

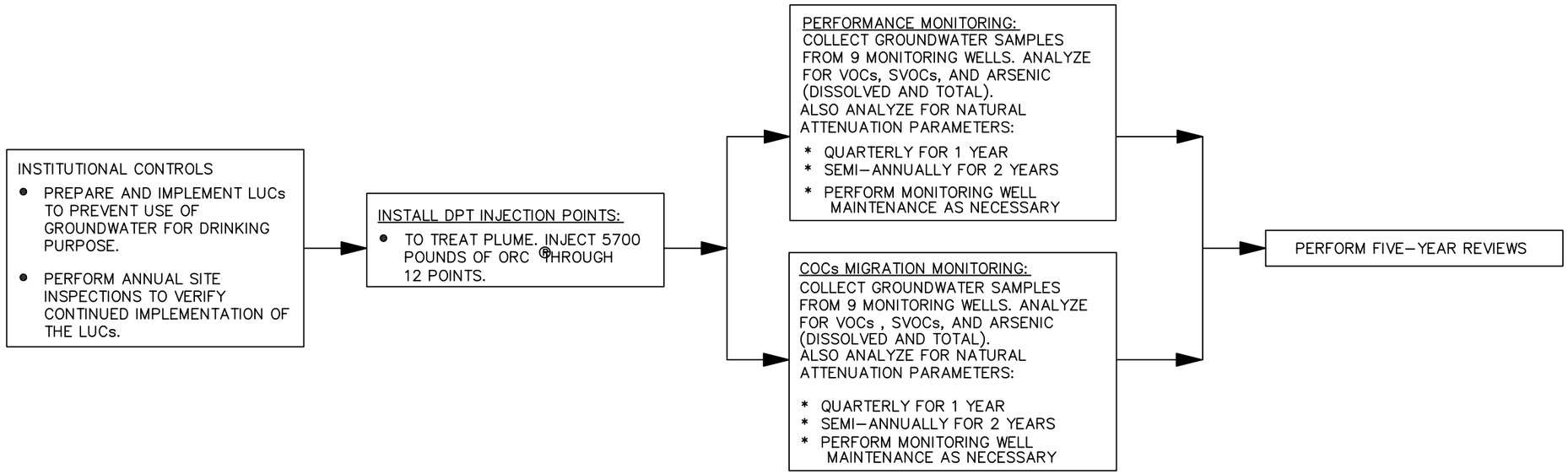
TETRA TECH NUS, INC.

BLOCK FLOW DIAGRAM
GROUNDWATER ALTERNATIVE 2
WOD FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

SCALE	NOT TO SCALE
FILE	4740CF01
REV	0
DATE	2/9/05
FIGURE NUMBER	FIGURE 4-1

ACAD: 4740CF02.dwg 03/01/05 DM PIT

IN–SITU BIOLOGICAL TREATMENT (BIOSTIMULATION) INSTITUTIONAL CONTROLS, AND MONITORING



NOTES:

COCs	CHEMICALS OF CONCERN
LUCS	LAND USE CONTROLS
VOC	VOLATILE ORGANIC COMPOUND
SVOC	SEMIVOLATILE ORGANIC COMPOUND

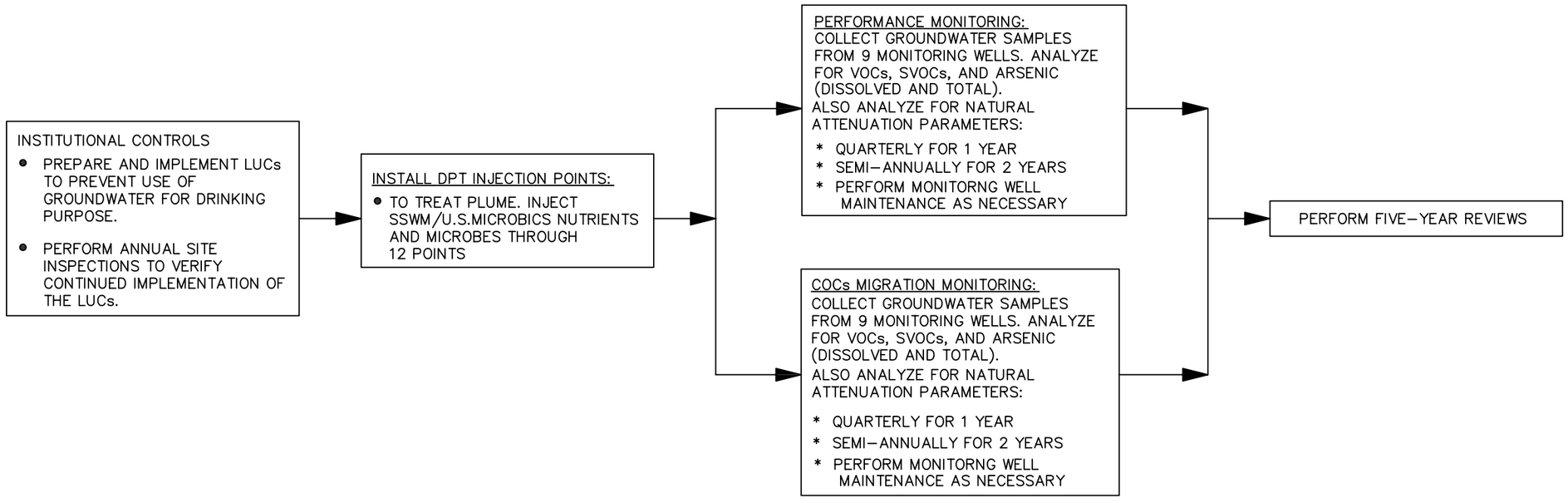
TETRA TECH NUS, INC.

BLOCK FLOW DIAGRAM
GROUNDWATER ALTERNATIVE 3
WOD FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE	SCALE
4740CF02	NOT TO SCALE
FIGURE NUMBER	REV / DATE
FIGURE 4–2	0 / 2/9/05

ACAD: 4740CF03.dwg 03/01/05 DM PIT

IN–SITU BIOLOGICAL TREATMENT (BIOAUGMENTATION) INSTITUTIONAL CONTROLS, AND MONITORING



NOTES:

COCs	CHEMICALS OF CONCERN
LUCS	LAND USE CONTROLS
VOC	VOLATILE ORGANIC COMPOUND
SVOC	SEMIVOLATILE ORGANIC COMPOUND

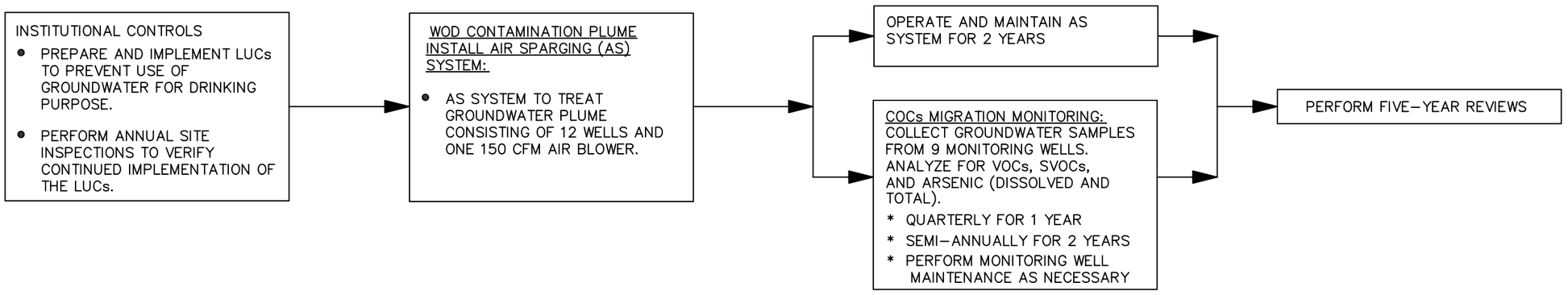
TETRA TECH NUS, INC.

BLOCK FLOW DIAGRAM
GROUNDWATER ALTERNATIVE 4
WOD FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE	SCALE
4740CF03	NOT TO SCALE
FIGURE NUMBER	REV / DATE
FIGURE 4–3	0 / 2/9/05

ACAD: 4740CF04.dwg 03/01/05 DM PIT

IN–SITU AIR SPARGING INSTITUTIONAL CONTROLS, AND MONITORING



NOTES:

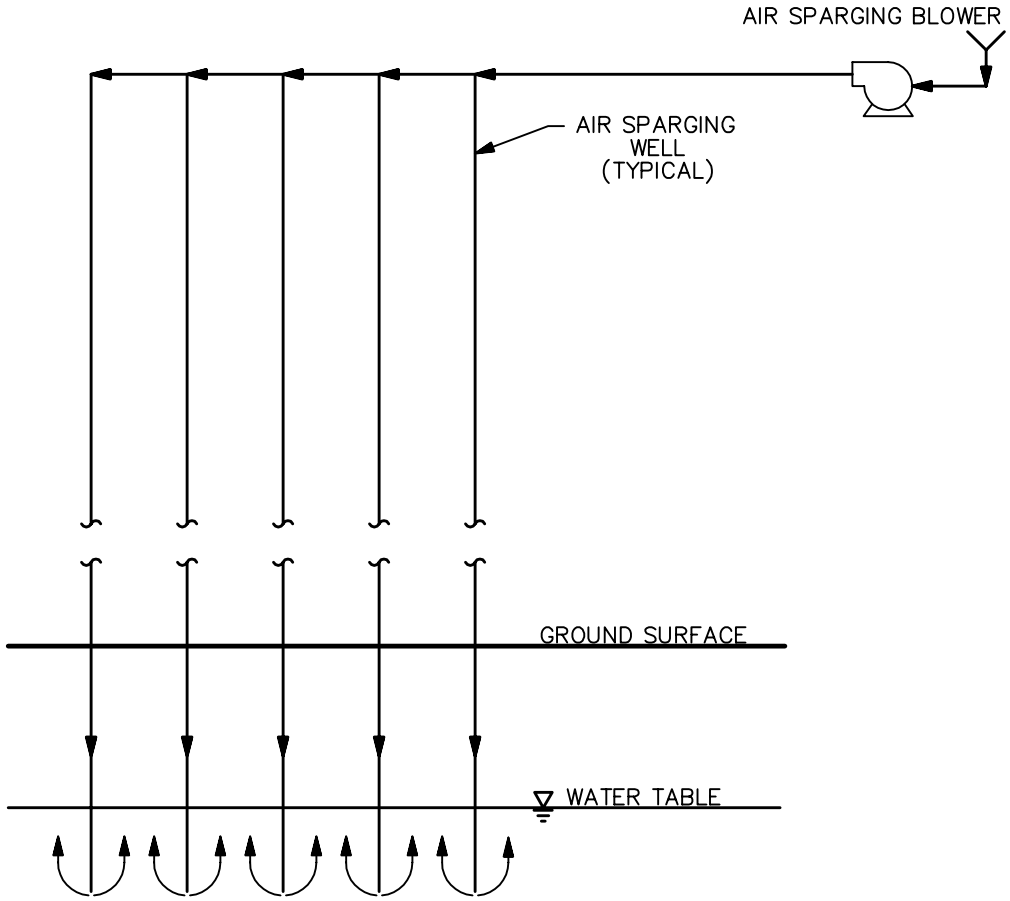
COCs	CHEMICALS OF CONCERN
LUCS	LAND USE CONTROLS
VOC	VOLATILE ORGANIC COMPOUND
SVOC	SEMIVOLATILE ORGANIC COMPOUND
WOD	WASTE OIL DUMP

TETRA TECH NUS, INC.

BLOCK FLOW DIAGRAM
GROUNDWATER ALTERNATIVE 5
WOD FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE	SCALE
4740CF04	NOT TO SCALE
FIGURE NUMBER	REV / DATE
FIGURE 4–4	0 / 2/9/05

ACAD: 4740CF05.dwg 02/09/05 HJB PIT



TETRA TECHNUS, INC.

PROCESS FLOW DIAGRAM
TYPICAL IN-SITU AS SYSTEM
WOD FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

SCALE	NOT TO SCALE
FILE	4740CF05
REV	0
DATE	2/9/05
FIGURE NUMBER	FIGURE 4-5

APPENDIX A

CALCULATIONS

- **A.1 - VOLUME AND MASS CALCULATIONS**
- **A.2 - ALTERNATIVE 3 IN-SITU BIOREMEDIATION (BIOSTIMULATION)**
- **A.3 - ALTERNATIVE 4 IN-SITU BIOREMEDIATION (BIOAUGMENTATION)**
- **A.4 - ALTERNATIVE 5 AIR SPARGING**

A.1 - VOLUME AND MASS CALCULATIONS

CLIENT: NASA Wallops Flight Facility, Virginia		JOB NUMBER: 1612-1110
SUBJECT: Volume and Mass Calculations (Waste Oil Dump)		
BASED ON: Attached figures		DRAWING NUMBER:
BY: TWS Date: 02-09-05	CHECKED BY: CAR Date: 2/9/05	APPROVED BY: DATE:

Converting to gallons using a conversion factor of 7.48052 gallons per cubic foot;

Volume of plume =	157,100 gallons	52,400 gallons

Average Concentration and Dissolved Mass of COCs

As indicated above, the COCs within the groundwater plume are benzene and arsenic. The average concentration of benzene and arsenic were calculated using the analytical data presented in the Supplemental RI. Using that average concentrations, the dissolved mass of benzene and arsenic were calculated using the volume of contaminated groundwater.

Benzene Average concentration of positive detections:

From sample WOD-WFF15-GW7	11 ug/L
From sample WOD-WFF16-GW2D	8 ug/L
Average Concentration	9.5 ug/L

Arsenic Average concentration of positive detections (filtered groundwater):

From sample WOD-WFF16-GW2DF	19.5 ug/L
Average Concentration	19.5 ug/L

Dissolved mass of each constituent is calculated by multiplying the average concentration by the volume of contaminated groundwater.

Benzene

	Volume of groundwater containing COCs =	157,100 gallons
	Average concentration of benzene =	9.5 ug/L
	1 gallon =	3.785412 Liters
	Mass of benzene =	5,649,538 ug
Using the following conversions	1 microgram =	1E-09 kilogram
	1 kilogram =	2.205 pound
	Mass of benzene =	**0.0125 pounds**

Arsenic

	Volume of groundwater containing COCs =	52,400 gallons
	Average concentration of arsenic =	19.5 ug/L
	1 gallon =	3.785412 Liters
	Mass of arsenic =	3,867,934 ug
Using the following conversions	1 microgram =	1E-09 kilogram
	1 kilogram =	2.205 pound
	Mass of arsenic =	**0.0085 pounds**

CLIENT: NASA Wallops Flight Facility, Virginia		JOB NUMBER: 1612-1110
SUBJECT: Volume and Mass Calculations (Waste Oil Dump)		
BASED ON: Attached figures		DRAWING NUMBER:
BY: TWS Date: 02-09-05	CHECKED BY: CAR Date: 2/9/05	APPROVED BY: DATE:

The reduction in concentration required to meet the PRG is calculated by subtracting the PRG from the average concentration and then dividing by the average concentration.

PRG for benzene = 5 ug/L
PRG for arsenic = 10 ug/L

Percent reduction for benzene = (9.5 ug/L - 5 ug/L) / 9.5 ug/L
= 47%

Percent reduction for arsenic = (19.5 ug/L - 10 ug/L) / 19.5 ug/L
= 49%

Estimated Soluble Contaminant Mass Remaining in Water Table Fluctuation Zone

The purpose of this calculation is to determine the amount of soluble petroleum contaminant mass that continues to act as a source of contamination to the groundwater plume.

Based on Figure 3 provided on page 8 of 8 and the distribution of soil contamination provided in the Supplemental Remedial Investigation the area expected to be continuing as a source for the groundwater contamination is the area designated around soil borings 2WFF16-SB1S2 and 2WFF16-SB2S2.

Conservative measurements indicate an aerial extent that is 50 feet wide by 50 feet long.

Area of continuing source = 2,500 sf

The contamination likely resulted from the historic presence of floating free petroleum product on the water table that has smeared onto the soil as a result of fluctuating groundwater table elevations and sinking into the groundwater zone. Assuming that this free petroleum product is located in a smear zone approximately 5 feet thick and that the residual petroleum has adsorbed onto these soils, the volume of soil acting as a continual source can be determined. In addition, using an assumed soil density based on soil types, and an estimated petroleum concentration within the soil, the mass of petroleum contamination within the soil can be calculated.

Volume of contaminated soil acting as source = 12,500 cf (2,500 sf x 5 ft thick)
Assumed soil density = 110 lb/cf

Mass of source zone soil = 1,375,000 lbs (12,500 cf x 110 lb/cf)

To determine the mass of petroleum contamination within this zone, the analytical results for BTEX and SVOCs were used to calculate a percentage of petroleum contamination within the soil. To generate a conservative estimate of the concentration, positive detections from boring 2WFF16-SB2S2 (boring with highest concentrations) were used in the calculation.

CLIENT: NASA Wallops Flight Facility, Virginia		JOB NUMBER: 1612-1110	
SUBJECT: Volume and Mass Calculations (Waste Oil Dump)			
BASED ON: Attached figures		DRAWING NUMBER:	
BY: TWS Date: 02-09-05	CHECKED BY: CAR Date: 2/9/05	APPROVED BY:	DATE:

The following concentrations were used to calculate the percentage (May 1998 data):

2-Methylnaphthalene	29,000 ug/kg		
Acenaphthene	1,800 ug/kg		
Dibenzofuran	1,100 ug/kg		
Fluorene	2,800 ug/kg		
Naphthalene	7,700 ug/kg		
Phenanthrene	7,800 ug/kg		
Pyrene	580 ug/kg		
Chloroethane	110 ug/kg		
Ethylbenzene	2,200 ug/kg		2,200 ug/kg
Toluene	1,700 ug/kg		1,700 ug/kg
Xylene (total)	13,000 ug/kg		13,000 ug/kg
Total	67,790 ug/kg	Total BTEX	16,900 ug/kg

Concentration percentage = 0.0068% Total BTEX = 0.0017%

Total mass of petroleum contamination in smear zone =
(Source zone mass) x (concentration percentage) = (1,375,000 lbs) x (0.0068%)

Total mass of petroleum contamination in smear zone (1998) = 93 lbs
= 42 kgs

Using the same equations: (1,375,000 lbs) x (0.0017%)

Total mass of BTEX contamination in smear zone (1998) = 23 lbs
= 11 kgs

CORRELATION WITH CONTAMINANT FATE & TRANSPORT MODEL

Two Bioscreen models were run using two different horizontal hydraulic conductivities (1.42 ft/day and 140 ft/day). The model results are presented in Appendix B. The models were calibrated through trial and error over the period from 1997 to 2003. The mass of benzene within the source area was entered into the model on a trial and error basis to determine what mass of benzene was needed in the source area to result in the concentrations that were being seen in the groundwater plume. The results of the calibration are as follows.

K_H =	1.42 ft/day	equates to	0.0061 kg of benzene in source area (1997)
K_H =	140 ft/day	equates to	0.61 kg of benzene in source area (1997)

A similar calibration was done with the model to determine the mass of BTEX that must be present within the source area to see the BTEX concentrations present in the groundwater plume.

K_H =	1.42 ft/day	equates to	0.41 kg of BTEX in source area (1997)
K_H =	140 ft/day	equates to	41 kg of BTEX in source area (1997)

The models were also used to determine the expected benzene source mass in 2003. The results of these model runs are presented below.

CLIENT: NASA Wallops Flight Facility, Virginia		JOB NUMBER: 1612-1110
SUBJECT: Volume and Mass Calculations (Waste Oil Dump)		
BASED ON: Attached figures		DRAWING NUMBER:
BY: TWS Date: 02-09-05	CHECKED BY: CAR Date: 2/9/05	APPROVED BY: DATE:

	K_H 1.42 ft/day	K_H 140 ft/day
Mass of Benzene in source 2003 =	0.0015 kg	0.175 kg

Assuming the BTEX degrades at a similar rate as the benzene from 1997 to 2003 and using the calibrated mass of BTEX in 1997, the expected mass of BTEX within the source area in 2003 can be calculated.

	K_H 1.42 ft/day	K_H 140 ft/day
Mass of BTEX in source 2003 =	0.10 kgs	11.76 kgs

When comparing the two calibrated model BTEX mass estimates to the calculated mass of BTEX in the calculation above (11 kgs in 1998), although there is not a direct correlation, the two calibrated masses (0.41 kg and 41 kg in 1997) bracket the calculated source mass. When evaluating which calibration provides better results, the calibration using a K_H of 140 ft/day puts the modeled source mass (41 kgs in 1997) within the same order of magnitude as the calculated source mass (11 kgs in 1998). Therefore, the predictions in cleanup times for no action, 50% source removal, and 90% source removal generated by the calibrated with a K_H of 140 ft/day is expected to be more accurate.

Waste Oil Dump Estimated Current Source Masses*		
Benzene	=	< 0.05 kg
BTEX	=	< 4 kg
Petroleum	=	< 14 kg

* Used modeled and calculated results to estimate these numbers.

ACAD:1612GP03.dwg 02/07/05 DM PIT

LEGEND

- —1.00— = ELEVATION CONTOUR (METERS)
- = MONITORING WELL
- = GROUNDWATER EXCEEDING BENZENE PRG (5 ug/L)
- = GROUNDWATER EXCEEDING ARSENIC PRG (10 ug/L)
- = GENERALIZED GROUNDWATER FLOW DIRECTION

N

LITTLE MOSQUITO CREEK

FTA-MW104S

WFF-MW4

WOD-WFF16-GW2D 3/12/03

INORGANICS	ug/L
ARSENIC	21.4
VOLATILES	ug/L
BENZENE	8

WFF16-GW4

WFF16-GW3

WFF16-GW5

WFF16-GW2S

WFF16-GW2D

WFF16-GW6

MARSH OUTLINE

WFF16-GW7

TREELINE

WFF15-GW1

WFF16-GW1

WFF15-GW2

WOD-WFF15-GW7 3/14/03

VOLATILES	ug/L
BENZENE	11

WFF15-GW7

WFF15-GW3

WFF15-MW3R

HEDGE

HEDGE

END OF RUNWAY 17 – 35

0 100± 200±

SCALE IN FEET

NOTE:

ELEVATION CONTOURS ARE METRIC.

TETRA TECH NUS, INC.

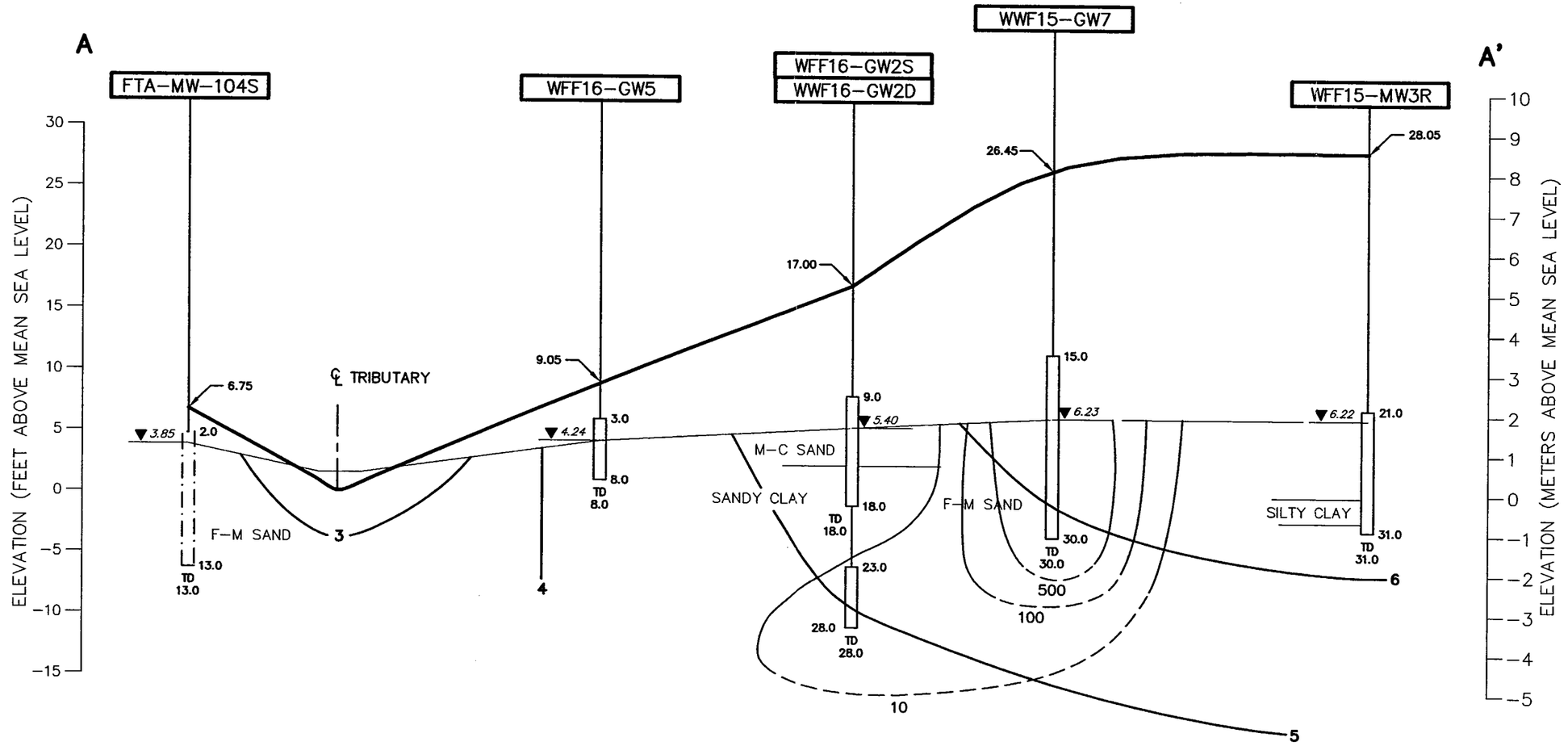
FORMER WASTE OIL DUMP GROUNDWATER COCs IN EXCESS OF PRGs

NASA WALLOPS FLIGHT FACILITY

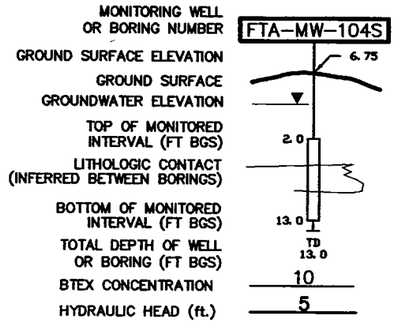
WALLOPS ISLAND, VIRGINIA

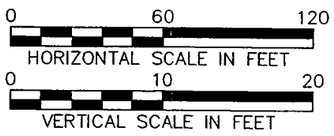
FILE: 1612GP03 DM PIT	SCALE AS NOTED
FIGURE NUMBER FIGURE 1	REV DATE 2/7/05

ACAD:1612GX02.dwg 02/07/05 DM PIT



LEGEND:





TETRA TECH NUS, INC.

FORMER WASTE OIL DUMP
GEOLOGICAL CROSS SECTION
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA

FILE	SCALE
1612GX02	AS NOTED
FIGURE NUMBER	**REV** / **DATE**
FIGURE 2	0 / 2/7/05

A.2 - ALTERNATIVE 3 IN-SITU BIOREMEDIATION (BIOSTIMULATION)

ORC Design Software for Grid Applications Using Slurry Injection

US Version 3.1

Regenesis Technical Support: USA (949) 366-8000, www.regenesis.com

Site Name: Former Fire Training Area
Location: NASA Wallops Flight Facility
Consultant: J.P. Kumar/TtNUS

Site Conceptual Model/Extent of Plume Requiring Remediation

Width of plume (intersecting gw flow direction)	52	ft			
Length of plume (parallel to gw flow direction)	162	ft	=	8,424	sq. ft.
Depth to contaminated zone	20	ft			
Thickness of contaminated saturated zone	10	ft			
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	sand				
Total porosity	0.25		Eff. porosity	0.05	
Hydraulic conductivity	25	ft/day	=	8.8E-03	cm/sec
Hydraulic gradient	0.005	ft/ft			
Seepage velocity	912.5	ft/yr	=	2.500	ft/day
Treatment Zone Pore Volume	21,060	ft^3	=	157,550	gallons

Dissolved Phase Oxygen Demand:

Individual species that represent oxygen demand:	Contaminant Conc (mg/L)	Contaminant Mass (lb)	Stoich. (wt/wt) O_2/contam.	ORC (lb) (10% O_2)
benzene	0.01	0.0	3.1	0
toluene	0.12	0.2	3.1	5
ethylbenzene	0.07	0.1	3.2	3
xylenes	0.54	0.7	3.2	23
MTBE	0.00	0.0	2.7	0
dichloroethene	0.00	0.0	0.7	0
vinyl chloride	0.00	0.0	1.3	0
4-methyphenol	0.04	0.1	4.0	2
naphthalene	0.13	0.2	6.0	10
reduced metals: Fe (+2) and Mn(+2)	20.00	26.3	0.10	26
Measures of total oxygen demand				
Total Petroleum Hydrocarbons	0.00	0.0	3.1	0
Biological Oxygen Demand (BOD)	0.00	0.0	1	0
Chemical Oxygen Demand (COD)	0.00	0.0	1	0

Estimates for Sorbed Phase Oxygen Demand:

Soil bulk density	1.76	g/cm^3	=	110 lb/cf
Fraction of organic carbon: foc	0.001	range: 0 to 0.01		

(Estimated using Soil Conc=foc*Koc*Cgw)
(Adjust Koc as nec. to provide realistic est.)

Individual species that represent oxygen demand:	Koc (L/kg)	Contaminant Conc (mg/kg)	Contaminant Mass (lb)	Stoich. O_2/contam.	ORC (lb) (10% O_2)
benzene	800	0.01	0.1	3.1	2
toluene	2800	0.34	3.1	3.1	96
ethylbenzene	6500	0.44	4.1	3.2	131
xylenes	4900	2.65	24.5	3.2	784
MTBE	0	0.00	0.0	2.7	0
dichloroethene	0	0.00	0.0	0.7	0
vinyl chloride	0.0	0.00	0.0	1.3	0
4-methyphenol	0.0	0.00	0.0	4.0	0
naphthalene	0.0	0.00	0.0	6.0	0
Measures of total oxygen demand					
Total Petroleum Hydrocarbons	0	0.00	0.0	3.1	0
Biological Oxygen Demand (BOD):	Use a multiple of dissolved phase -> 1.00		0.0	1	0
Chemical Oxygen Demand (COD):	Use a multiple of dissolved phase -> 1.00		0.0	1	0

Summary of Estimated ORC Requirements

	ORC for Dissolved Phase (lbs)	ORC for Sorbed Phase (lbs)	Add Dem Factor (1 to 10x)	ORC Total w/ Add Dem Factor	ORC Cost at $ 10.00	
Individual Species: Total BTEX, MTBE	70	1,013	5	5,414	$ 54,139	<-
Total Petroleum Hydrocarbons	-	-	2	-	$ -	
Biological Oxygen Demand (BOD)	-	-	2	-	$ -	
Chemical Oxygen Demand (COD)	-	-	1	-	$ -	

Select above measure (button) to specify required ORC quantity (in 30 lb increments) ——> 5,430 **pounds ORC**

Delivery Design for ORC Slurry

Spacing within rows (ft)	30.0	feet
# points per row	2	points/row
Spacing between rows (ft)	30.0	ft
# of rows	6	rows
Advective travel time bet. rows (days)	12	days
Number of points in grid	12	points
Required ORC per foot	45.3	lbs/foot
Total ORC	5,430	lbs of ORC

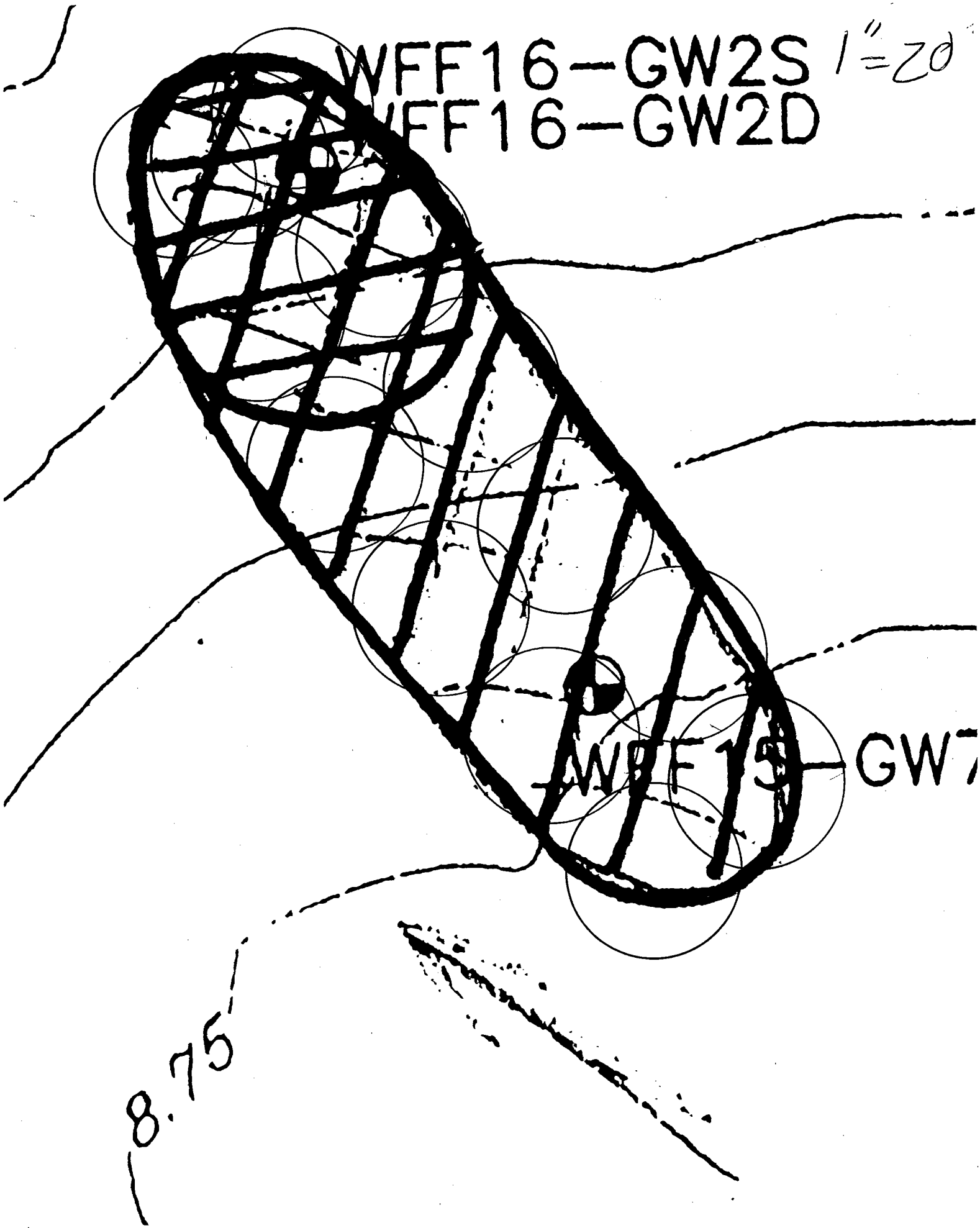
Slurry Mixing Volume for Injections

Pounds per location	453
Buckets per location	15.1
Design solids content (20-40% by wt. for injections)	30%
Volume of water required per hole (gal)	127
Total water for mixing all holes (gal)	1519
Simple ORC Backfilling: min hole dia. for 67% slurry	11.1
Feasibility for slurry injection in sand: ok up to 15 lb/ft	(call Regenesis)
Feasibility for slurry injection in silt: ok up to 10 lb/ft	(call Regenesis)
Feasibility for slurry injection in clay: ok up to 5 lb/ft	(call Regenesis)

Project Summary		
ORC bulk material for slurry injection (lbs)		5,430
Number of 30 lb ORC buckets		181.0
ORC bulk material cost	$	9.00
Cost for bulk ORC material	$	48,870
Shipping and Tax Estimates in US Dollars		
Sales Tax rate: 0%	$	-
Total Matl. Cost	$	48,870
Shipping (call for amount)	$	-
Total Regenesis Material Cost	$	48,870

ORC Slurry Injection Cost Est. (responsibility of customer to contract work)		
Footage for each inj. point = uncontaminated + HRC inj. interval (ft)		30
Total length for direct push for project (ft)		360
Estimated daily installation rate (ft per day: 400 for push, 150 for drilling)		400
Estimated points per day (15 to 30 is possible for direct push)		13.3
Required number of days		1
Mob/demob cost for injection subcontractor	$	1,000
Daily rate for inj. Sub. ($1-2K for push $3-4K for drill rig)	$	1,500
Total injection subcontrator cost for application	$	2,500
Total Install Cost (not including consultant, lab, etc.)	$	51,370

Other Project Cost Estimates		
Design	$	-
Permitting and reporting	$	-
Construction management	$	-
Groundwater monitoring and rpts	$	-
Other	$	-
Other	$	-
Other	$	-
Other	$	-
Total Project Cost	$	51,370


WFF16-GW2S 1"=20'
WFF16-GW2D
WFF15-GW
8.75

A.3 - ALTERNATIVE 4 IN-SITU BIOREMEDIATION (BIOAUGMENTATION)

SSWM
Sub-Surface Waste Management of Delaware, Inc.

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Littleton. CO 80122
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Fax (303) 347-6389

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Charleston. SC 29414
Ph (843) 225-5646
Fax: (843) 225-4455

San Diego, CA
6451 El Camino Real
Carlsbad. CA 92009
Ph (760) 918-1860
Fax (760) 918-1855

U.S. MICROBICS INC.
Website: www.bugsatwork.com
E-mail: bbeattie@bugsatwork.com
Public Trading Symbols:
SSWM and BUGS

February 7, 2005
SSWM Proposal Number P-05-001
via e-mail: DavisB@ttnus.com

Mr. Bob Davis
Tetra Tech NUS, Inc.
661 Anderson Drive
Foster Plaza 7
Pittsburg, PA 15220

RE: Virginia Bioaugmentation Proposal

Dear Mr. Davis,

Sub-Surface Waste Management (SSWM) is pleased to submit this conceptual proposal to provide assistance in implementing a bioaugmentation component to your remedial design for the project located in Virginia. This conceptual proposal presents our understanding of the project based on your e-mail dated February 1, 2005, and our proposed conceptual design and budget.

PROJECT SUMMARY

Based on the e-mail and phone conversations, the project site is summarized as follows:

- Plume is oval shaped; 160 ft by 60 ft and generally 10 feet thick
- Geology is fine-to-medium-grained quartz sand with some silt
- Hydraulic conductivity is 4.9E-2 cm/sec and hydraulic gradient is 0.009 ft/ft
- Benzene is the primary contaminant of concern with concentrations ranging from 8 to 11 ppb compared to a clean-up goal of 5 ppb
- Low levels of twenty to thirty VOCs and SVOCs including some chlorinated compounds have been detected in some of the soil and groundwater samples collected at the site

Tetra Tech is considering bioaugmentation to remediate the benzene at this site. This proposal presents SSWM's microbial technology, conceptual design and delivery, and budgetary costs and remedial timeline based on the information provided.

TECHNOLOGY DESCRIPTION

The scientific community has long recognized that many microbes and microbial consortia are capable of transforming or degrading a wide range of environmental pollutants including petroleum hydrocarbons, crude oil compounds, solvents, and even some metals. However, in the past some people have shied away from this technology because these processes can take a long time and are difficult to predict. The rate of degradation for each contaminant is a function of a variety of physical, chemical, and biological limitations of the waste stream. Much of the work in recent years has directed toward addressing these limitations and accelerating biodegradation and biotransformation rates to speeds that are viable to provide successful remediation of large impacted sites.

Bioaugmentation is a process whereby naturally occurring, performance-selected bacteria cultures are introduced to the impacted area after having been individually grown in high concentrations in a laboratory. Impacted soil/groundwater contains hundreds of bacteria strains. Some strains are tolerant of contamination but will not degrade or consume the contaminants. Other strains may be capable of degrading the contaminants, but are not present in high enough populations to affect a degradation process. It is also possible that bacterial strains capable of degrading contaminants are present in small quantities but are competing for nutrients with bacterial strains that are simply tolerant of the site conditions and not degrading contaminants. Bioaugmentation is the process by which the beneficial strains of bacteria are cultured off site and then applied to the soil or waste stream to treat the contaminants. In this manner, the contaminant-specific bacteria are applied and available to degrade contaminants with the essential nutrients present.

SSWM and US Microbics have 40 years of experience in scientific and engineering research, development and field application associated with accelerating bioremediation rates. Building on our knowledge of microbial community dynamics, biotransformation and biodegradation processes, bio-molecular engineering, and phyto-remediation, we have developed a proprietary approach that utilizes a combination of biostimulation, bioaugmentation, and biosurfactant enhancement. By implementing this approach, we have been able to successfully accelerate bioremediation rates and achieve biodegradation of both light and heavy hydrocarbons. USM has developed various microbial blends for treatment of petroleum hydrocarbons, MTBE, TBA, and chlorinated solvents. USM's natural, non-genetically engineered specialty microorganisms received approval from the U.S. Department of Agriculture in 1979 and have received its highest safety designation as "relatively safe".

CONCEPTUAL DESIGN

SSWM has investigated and experimented with various bioaugmentation treatment approaches including enhanced bio-sparge/SVE, groundwater extraction with re-injection of bio-augmented water, bio-walls and bio-gates, and other alternatives. This site appears to be very similar to one of our projects in South Carolina and the system installed by SSWM is described below.

The site contained two 1,000-gallon and one 550-gallon underground storage tanks (USTs) for the storage and dispensing of fuel for retail sale. The USTs were removed in December of 1991. Soil and groundwater contamination were detected in October 1993 during a site assessment. A dissolved phase plume spread with the flow of groundwater. Dissolved phase BTEX (benzene, toluene, ethylbenzene, and xylenes), MTBE, and naphthalene are present in the wells downgradient of the former UST basin. Groundwater is present in the superficial Pleistocene sediments under water table conditions. Depths to groundwater at the site generally range from 3 to 10 feet below the ground surface. The hydraulic conductivity is approximately 20 ft/day (7.1E-3 cm/sec) and the hydraulic gradient is approximately 0.015 ft/ft.

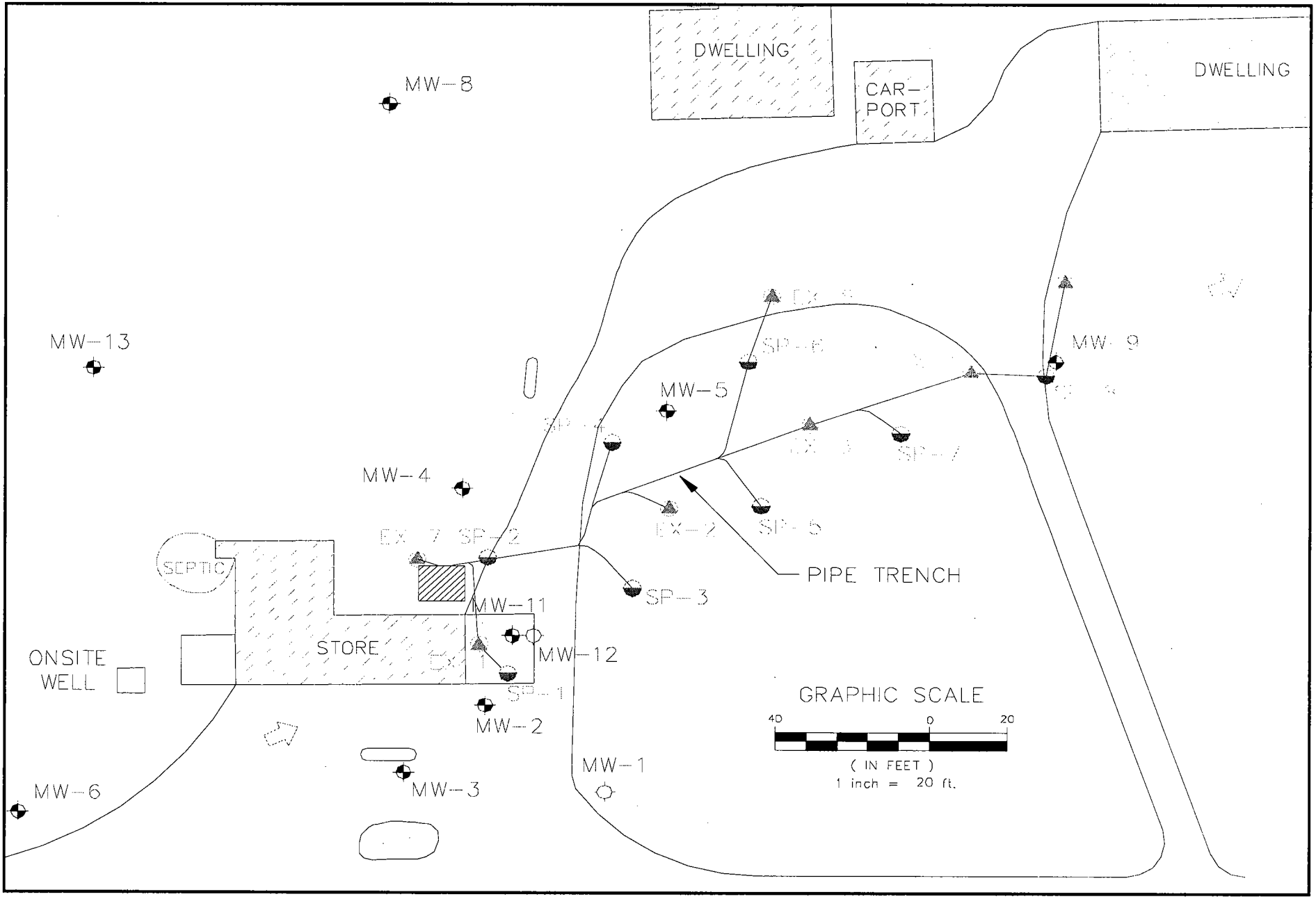
SSWM installed eight (8) bio-sparge wells within the plume area and six (6) vapor extraction wells outside and within the plume area to collect vapors generated by the bio-sparge wells. Water recovered by the SVE blower is treated and augmented with microbes and nutrients, and then injected into the plume area through the sparge wells to create an in-situ bioreactor to degrade the BTEX, MTBE and naphthalene compounds.

SSWM completed the system installation in July of 2003. The results of the above-described system are summarized in Table 1. A map of the site and well locations is presented as Figure 1. As can be seen in Table 1, overall contaminant concentrations were reduced by 62 percent within 5 months, and by 96 percent within 17 months. In MW-5, benzene has been reduced from 4,300 ug/L to less than 5 ug/L. In MW-9, benzene has been reduced from 450 ug/L to less than 5 ug/L. Wells MW-2 and MW-4 are located slightly upgradient of the treatment system have been slower to clean up. Well locations must be selected carefully to prevent accidentally "pushing" the plume in unintended directions and to achieve a quick clean up.

Table 1

Chemical of Concern		Benzene	Toluene	Ethylbenzene	Xylenes	MTBE	Naphthalene
		(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
MW-1	08/13/02	4.2	4	44	205	< 2	19
	12/29/03	< 1	2.2	66	154	< 1	3.5
	07/05/04	< 5	< 5	69	44	< 5	9.8
	12/07/04	< 5	< 5	50	25	< 5	6.7
MW-2	08/13/02	55	62	< 10	60	< 10	< 10
	12/29/03	150	1,600	100	2,340	< 5	39
	07/05/04	34	120	11	312	< 5	< 5
	12/07/04	39	190	23	400	< 5	15
MW-3	08/13/02	19	34	1	61	7.6	< 1
	12/29/03	43	280	42	1,170	< 2	3.5
	07/05/04	440	56	47	695	15	7.8
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5
MW-4	08/13/02	240	250	89	329	< 10	19
	12/29/03	550	720	340	1,980	40	36
	07/05/04	54	89	31	790	91	33
	12/07/04	170	290	77	374	140	36
MW-5	08/13/02	4,300	9,500	1,200	2,001	< 500	< 500
	12/29/03	43	19	4	8	6.2	< 1
	07/05/04	18	12	< 5	23.6	7.4	< 5
	12/07/04	< 5	< 5	< 5	< 10	8.3	< 5
MW-6	08/13/02	< 1	< 1	< 1	< 1	< 1	< 1
	12/29/03	< 1	< 1	< 1	< 2	< 1	< 1
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5
MW-8	08/13/02	< 1	< 1	< 1	< 1	< 1	< 1
	12/29/03	< 1	< 1	< 1	< 2	< 1	< 1
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5
MW-9	08/13/02	450	2,700	1,100	5,200	31	310
	12/29/03	4.9	3.5	3	< 2	< 1	< 1
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5
MW-11	08/13/02	870	4,800	640	5,100	< 200	< 200
	12/29/03	39	310	52	1,310	< 1	64
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	12	60	5	260	< 5	10
MW-12	08/13/02	< 1	< 1	< 1	< 1	< 1	< 1
	12/29/03	< 1	1.5	< 1	< 2	< 1	< 1
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5
MW-13	08/13/02	< 1	< 1	< 1	< 1	< 1	< 1
	12/29/03	< 1	1.3	< 1	< 2	< 1	< 1
	07/05/04	< 5	< 5	< 5	< 10	< 5	< 5
	12/07/04	< 5	< 5	< 5	< 10	< 5	< 5

Figure 1


DWELLING
CAR-
PORT
DWELLING
MW-8
MW-13
MW-9
MW-5
SP-6
MW-4
EX-2
SP-5
SP-2
SP-3
PIPE TRENCH
SEPTIC
MW-11
STORE
MW-12
ONSITE
WELL
SP-1
MW-2
MW-1
MW-3
MW-6
GRAPHIC SCALE
40
0
20
(IN FEET)
1 inch = 20 ft.

COSTS

Costs for this type of system depend on the number of wells installed, the ease of installing extraction and sparge piping from the treatment system to the wells, the size and quality of the equipment and controls installed, the availability of qualified system operators and the frequency of site visits, utility costs, and other regulatory costs associated with obtaining permits, sampling requirements, air treatment, etc. **The capital costs for the bio component for this type of system are typically $10,000 to $20,000**. We typically add nutrients once per week (during the weekly site visit) and microbes once per month. **The cost for nutrients and microbes is typically $1,500 to $3,000 per month.**

It is very difficult to estimate clean-up times due to the number of variables involved not only in the hydraulic and subsurface conditions, but in the factors that effect biological processes. However, as you can see in the above example, SSWM has had very good results with our microbial blends and system designs in treating benzene and other hydrocarbons, especially when compared to traditional pump-and-treat or AS/SVE systems. We have even been able to eliminate up to 12 inches or more of free product (gasoline) in less than two years at several sites and achieve non-detect concentrations of benzene in dozens of monitoring wells where part-per-million concentrations were present. **Although contaminant destruction rates typically drop as concentrations reach non-detect levels, non-detect concentrations of benzene are very achievable with bioaugmentation within two or three years when starting at low ppb concentrations**. Finally, once the beneficial microbes are populated in the ground, "natural attenuation" is enhanced as the microbes continue to work after the system is turned off.

SSWM appreciates the opportunity to assist you with this project in Virginia, and we look forward to talking with you about how to move forward with the engineering design phase of the project. We will be available for any questions or comments that you may have at (303) 347-6390 (office) or at (303) 908-1557 (cell).

Sincerely,

Behzad Mirzayi, P.E.

Vice President
SSWM
303-347-6388 x1

Jason Nesseth

Project Manager
SSWM
303-347-6388 x3

A.4 - ALTERNATIVE 5 AIR SPARGING

Tetra Tech NUS		STANDARD CALCULATION SHEET	
CLIENT: EFANE CLEAN	FILE No: 1612 1110	BY:	PAGE: 1 OF 2
SUBJECT: Wallops Flight Facility – WOD Site Groundwater Alternative 5 AS Treatment – Entire Plume		CHECKED BY:	DATE: 1/28/05

1.0 TREATMENT SCHEME

The option of Groundwater Alternative 5 would consist of an air sparging (AS) system. The AS system would feature the following elements:

- AS well array
- AS blower system

Typical remedial action duration for AS systems ranges from one to five years. For the purpose of this FS, it is assumed that remedial action duration would be 2 years.

2.0 AS WELL ARRAY

Based upon results of pilot tests at a similar Wallops Flight Facility site (Old Aviation Fuel Tank Farm), the typical radius of influence (ROI) of AS wells is approximately 15 to 17.5 ft. This ROI is used for the WOD site.

Area of influence per AS well: $(30)^2 \times \pi/4 = 707\ ft^2$, rounded down to $650\ ft^2$ for overlap
$(35)^2 \times \pi/4 = 961\ ft^2$, rounded down to $900\ ft^2$ for overlap

AS wells will be installed at one depth, screened from 15 to 20 feet below the water table (total depth of the wells will be approximately 35 to 40 feet below ground surface) in the area of the VOC plume.

Number of wells in the AS Well Array: $(8{,}400\ ft^2) \div 700\ ft^2$ = approximately 12 wells

3.0 AS BLOWER SYSTEMS

Based upon results of pilot tests at a similar Wallops Flight Facility site (Old Aviation Fuel Tank Farm), the typical air sparging flow is approximately 6 to 12 cfm per well.

For the AS System, an individual AS Blower System would supply air to the AS Well Array installed at a given depth.

AS Blower System would feature 1 blower. The blower would provide air to the 12 wells of the AS Well

Discharge rate of AS Blower: 12 wells x 6 cfm/well = 72, say 75 cfm
Discharge rate of AS Blower: 12 wells x 12 cfm/well = 144, say 150 cfm

Static head required for the AS Blower: 20 ft H_2O x 0.433 ft/psi = 8.7 psi

To accommodate line friction losses, design blower discharge pressure is approximately twice the required static head. The AS Blower would be designed for a discharge head of 17 psi.

$\Rightarrow$ AS Blower System would feature 1 blower. The AS Blower would be rated for 150 cfm @ 17 psi.

4.0 FUGITIVE EMISSIONS

As per computations presented in Appendix A.1 (Section 2.5), the total quantities of VOC COCs for the WOD site are estimated as follows:

Benzene: 0.0125 pounds in groundwater
Petroleum: 31 pounds in soil

Total: 31 + 0.0125 = 31 pounds

Of these, it is assumed that 100% of the benzene in groundwater and 33% of the Petroleum in soil will eventually be removed by stripping and generate fugitive emissions:

Total Fugitive Emissions
0.0125 + (0.33 x 31) = 10.2, say 10 pounds

It is assumed that 75% of these emissions will occur during the first year of operation of the AS treatment systems and that, within, that first year, half of the emissions would occur during the first 30 days:

Maximum Daily Rate of Fugitive Emissions:
10 pounds x 0.75 x 0.5 ÷ 30 = 0.125 pounds per day

Based on the calculated fugitive emission, this is below the VDEQs deminimis level of 15 pounds per day. Therefore, the AS system can be operated without fugitive emissions controls.

APPENDIX B

BIOSCREEN GROUNDWATER FATE AND TRANSPORT MODELING

BIOSCREEN MODELING
WASTE OIL DUMP
FEASIBILITY STUDY
NASA WALLOPS FLIGHT FACILITY
WALLOPS ISLAND, VIRGINIA
FEBRUARY 1, 2005

MODEL SELECTION

Groundwater fate and transport modeling was performed for the Waste Oil Dump (WOD) site at the NASA Wallops Flight Facility in Wallops Island, Virginia, to develop a screening-level assessment of future benzene concentrations in shallow groundwater where stained soils are currently observed. BIOSCREEN was selected to perform the modeling and it is a screening-level tool that is based on a simple analytical model and a series of assumptions. One of the basic assumptions is that groundwater flow conditions at the modeled site are simple, where flow is predominantly horizontal. The model should not be used to evaluate a complex groundwater flow system where vertical and horizontal components of groundwater flow play a key role in the transport of the contaminants. Analysis of the groundwater flow data for the WOD site indicates the following:

- Groundwater flow is both downward and horizontal in the upland areas (WOD Source Area at WWF-15-GW7).

- From the upland source area to the unnamed tributary, groundwater flow is predominantly horizontal, as evidenced in the occurrence of contaminants at WWF16-GW2D.

- Groundwater flow is generally upward in the lowland areas and discharges to the unnamed tributary.

Although there are vertical components of groundwater flow, overall the groundwater flow regime is simple and typical for shallow, unconfined aquifers near a shallow tributary. Transport of contaminants occurs predominantly in a horizontal groundwater flow regime between the uplands and lowlands and although vertical components of groundwater flow occur at the site, the extent is limited and its impact on the transport of contaminants is minimal. Therefore, a simple groundwater flow regime is present at the WOD and the use of the BIOSCREEN model is justified.

MODEL SCENARIOS

The site-specific calibrated BIOSCREEN model was used to evaluate viable remedial actions necessary to reduce current benzene concentrations to below preliminary remediation goals (PRGs). BIOSCREEN is a Microsoft Excel-based spreadsheet model that was developed by the Air Force Center for Environmental Excellence [AFCEE, 1997 (version 1.4)] as a screening-level tool for use in evaluating the natural attenuation of petroleum hydrocarbons in groundwater. Benzene, toluene, ethylbenzene and total xylenes can be modeled together as BTEX or each individual parameter can be modeled. The model predicts contaminant concentrations at various distances downgradient from the source area at user-selected time frames based on the input parameters used. Concentration trends with distance along the centerline of the plume for the selected time are developed for 1st order decay (most typically observed) and instantaneous reaction models of contaminant degradation, along with a no-degradation simulation for comparison purposes. The model also has the ability to estimate the lateral distribution of contamination and the remaining source mass and plume mass at user-selected times.

Two series of BIOSCREEN simulations were performed; one utilizing an average hydraulic conductivity of 140 feet/day based on aquifer tests performed at the Wallops site (observed range was 80 to 200 feet/day), while the other utilized an average hydraulic conductivity of 1.42 feet/day based on aquifer tests conducted in 2001 during the Remedial Investigation phase at two wells (WFF15-GW1 and WFF15-GW2) adjacent to the impacted area of the WOD. It was theorized in the Supplemental Remedial Investigation that the removal actions and subsequent filling activities at the WOD may have created a heterogeneous aquifer with areas of low hydraulic conductivity that could affect contaminant fate and transport. This theory was tested during the modeling by considering both hydraulic conductivities. For each series of simulations, the spreadsheet model was calibrated to existing conditions, then predictive simulations were run to estimate future concentration trends based on a no further action scenario and two supplemental source removal scenarios at both 50 percent and 90 percent mass removals.

MODEL SETUP

BIOSCREEN requires that the user input a number of site-specific and chemical-specific parameters during the model setup and calibration process. The following are the fixed inputs used in the setup of the various BIOSCREEN model runs for the site:

- Hydraulic conductivity = 4.9E-2 cm/sec (140 feet/day) and 5.0E-4 cm/sec (1.42 feet/day). *Source*: Aquifer tests conducted at the WFF (Occu-Health, Inc., 1999) and aquifer tests conducted at the WOD during the 2001 Remedial Investigation (Versar, Inc., 2001a).

- Hydraulic gradient = 0.008964. *Source*: Water level elevations measured by TtNUS during March 19, 2003. Gradient was calculated from potentiometric surface map along primary flow path from source well WFF15-GW7.

- Porosity = 0.25. *Source*: Consistent with referenced literature values (Freeze and Cherry, 1979) given for lithologies observed by TtNUS.

- Estimated plume length = 160 feet. *Source*: Estimated distance along the primary flowpath from the source well WFF15-GW7 from various figures including plan and cross-sections of the site showing extent of impacted groundwater.

- Dispersion = Automatically calculated by BIOSCEEN. *Source*: Calculated automatically by BIOSCREEN based on the estimated plume length.

- Soil bulk density = 1.98 kg/L. *Source*: Assumption that is consistent with the assumed porosity and a specific gravity for the soil grains of 2.65.

- Partition coefficient (Koc) = 38 L/kg. *Source*: Reference value of Koc of benzene provided by BIOSCREEN (ASTM, 1995). When BTEX was considered during model calibration, 127 L/Kg was used, which is the average of the Koc's for the individual BTEX compounds Koc reference values (ASTM, 1995).

- Fraction organic carbon (foc) = 0.001. *Source*: Value used at other Wallops Island sites (average value based on observed laboratory data). Only two locations near the impacted groundwater at the WOD had foc determined, WFF15-GW3 at 2 mg/L and WFF15-GW at <1 mg/L. Use of value of 0.001 based on other areas of Wallops is justified.

- Delta oxygen = 0.5625 mg/L. *Source*: Site-specific calculated value based on a comparison of average DO for uncontaminated (background) groundwater monitoring wells versus lowest observed DO for source area wells from the TtNUS March 2003 sampling round. Value used is 25% of the calculated amount to account for only benzene being modeled (adjustment of total biodegradation capacity to account for electron acceptor utilization by other constituents present in the groundwater plume).

- Delta nitrate = 0.44305 mg/L. *Source*: Site-specific analytical data from the March 2003 sampling round performed by TtNUS as the difference between average nitrate values detected at uncontaminated (background) locations versus the lowest observed value (non-detection) from the source well. Value

used is 25% of the calculated amount to account for only benzene being modeled (adjustment of total biodegradation capacity to account for electron acceptor utilization by other constituents present in the groundwater plume).

- Observed ferrous iron = 1.5 mg/L. *Source*: Observed site-specific analytical result for WFF15-GW7 (groundwater monitoring well at impacted source) from the sampling round of TtNUS during March 2003. Assumes that all dissolved iron is ferrous (analysis was not species-specific). Value used is 25% of the observed amount to account for only benzene being modeled (adjustment of total biodegradation capacity to account for electron acceptor utilization by other constituents present in the groundwater plume).

- Delta sulfate = 2.5625 mg/L. *Source*: Site-specific analytical data from the March 2003 sampling round performed by TtNUS as the difference between average sulfate values detected at uncontaminated (background) locations versus the lowest observed value from the source well. Value used is 25% of the calculated amount to account for only benzene being modeled (adjustment of total biodegradation capacity to account for electron acceptor utilization by other constituents present in the groundwater plume).

- Observed methane = 0.132425 mg/L. *Source*: Observed site-specific analytical result for WFF15-GW7 (groundwater monitoring well at impacted source) from the sampling round of TtNUS during March 2003. Value used is 25% of the observed amount to account for only benzene being modeled (adjustment of total biodegradation capacity to account for electron acceptor utilization by other constituents present in the groundwater plume).

- Model area length = 160 feet. *Source*: Set equal to the estimated plume length (see above) so that evaluation of the source and downgradient well concentrations could be performed.

- Model area width = 50 feet. *Source*: Estimated to encompass the lateral extent of contamination. Estimated distance perpendicular to the primary flowpath from the source well WFF15-GW7 from various figures including plan and cross-sections of the site showing extent of impacted groundwater.

- Simulation time for calibration = Variable based on modeling runs. Time is in years. Model calibration runs were six years (1997 to 2000), while future scenarios were in multiples of 1 year increments.

- Source thickness in saturated zone = 5 feet. *Source*: Estimated thickness of smear zone (area of groundwater fluctuation) specific to the WOD and WFF15-GW7 based on historical data. This value is also consistent with other petroleum related impacts at Wallops Island.

- Source zone width = 50 feet. *Source*: Set equal to the modeled area width (see above) so that evaluation of the source and downgradient well concentrations could be performed.

- Source zone concentration = Variable based on analytical results.

Other input parameters, solute half-life and soluble mass, were established during the model calibration process, as described below.

HIGH HYDRAULIC CONDUCTIVITY (140 FEET/DAY)

Model Calibration

During model calibration, two primary input parameters were determined based on site, time and chemical specific data. The two primary input parameters were solute half-life and soluble mass. BIOSCREEN calculates a first order decay coefficient based on the solute half-life and other chemical and physical properties entered. Similarly, BIOSCREEN calculates a source half-life for both the instantaneous reaction model and first order decay model based on the soluble mass and other chemical and physical properties entered. These two parameters are typically determined through a trial-and-error methodology during model calibration of BIOSCREEN since they are site-specific and literature values may not adequately match field conditions to accurately employ predictive runs. When available, soluble mass may be estimated from site data (based on soil analytical results and impacted area) and average literature values for solute half lives are used as initial input for model calibration.

For the calibration of benzene for the WOD, all available historical data was analyzed to determine the most representative, long term conditions for calibration (BIOSCREEN assumes that the petroleum impacted groundwater is at steady-state conditions). Based on the available data, the BIOSCREEN model was calibrated with chemical data from April 1997 and March 2003. This yielded a total simulation time of 6 years, with 1997 being year 0. Benzene was observed to be 42 ug/L in April 1997 and 11 ug/L in March 2003 at the source well WFF15-GW7. In March 2003, benzene was observed to be 8 ug/L at the downgradient well WFF15-GW2D. Based on measurements from various site figures of the WOD, these two well are approximately 100 feet apart.

Calibration was performed by matching the model calculated benzene results for Year 6 (March 2003) to the observed March 2003 data for the two primary calibration points: the source well WFF15-GW7 and the downgradient well WFF15-GW2D. The soluble mass was varied until the resultant time dependent benzene concentration was consistent with the first order decay model results at the source well WFF15-GW7. Similarly, the solute half-life was varied until the resultant time dependent benzene concentration was consistent with the first order decay model results at the downgradient well WFF15-GW2D. As can be seen in the BIOSCREEN results, a very tight fit of the first order decay model was achieved to the observed field data. The calibrated soluble mass is 0.610 kg, resulting in a first order decay source half life of 3 years and the calibrated solute half life is 0.20 year, resulting in a first order decay coefficient of 3.5 per year. Both of these calibrated results are consistent with general site conditions in a similar geologic/lithologic setting.

As a verification of this calibration, calibration of benzene was also performed for chemical data from February 2000 to March 2003. This yielded a total simulation time of 3 years, with 2000 being year 0. Benzene was observed to be 58 ug/L in February 2000 and 11 ug/L in March 2003 at the source well WFF15-GW7. In March 2003, benzene was observed to be 8 ug/L at the downgradient well WFF15-GW2D. Results of this verification of calibration modeling were a soluble mass of 0.335 kg and a solute half life of 0.15 year. The solute half life is nearly identical, being 0.15 versus 0.20 year. The soluble mass has decreased, as expected, since the total model time is half of the original time. However, the resultant first order decay source half life has been decreased to 1 year. This ultimately results in a higher source removal rate and less conservative site-specific results. Therefore, the calibration of benzene from 1997 to 2003 will be used as the base case for the future predictive runs.

As a further verification, calibration of total BTEX was also performed for chemical data from April 1997 to March 2003. This yielded a total simulation time of 6 years, as with the primary benzene calibration. Total BTEX was observed to be 2822 ug/L in April 1997 and 739 ug/L in March 2003 at the source well WFF15-GW7. In March 2003, total BTEX was observed to be 16 ug/L at the downgradient well WFF16-GW2D. Data input for the instantaneous reaction model was adjusted to appropriately account for the four parameters composing BTEX, as well as the partition coefficient was also adjusted to reflect the average literature values for BTEX. Results of this verification of calibration modeling were a soluble mass of 41 kg and a solute half-life of 0.02 year. Soluble mass was significantly higher for total BTEX at 41 kg compared to the calibrated soluble mass for benzene at 0.610 kg. However, the first order decay source half life was determined to be exactly the same, being 3 years. The solute half life was approximately one-tenth, being 0.02 for total BTEX versus 0.20 year for benzene. The change in solute half life was reflective of the four components in BTEX. The concentration of total BTEX predicted was too high using a solute half life of 0.02; however, further deceases do not significantly change the predicted concentrations and fit is

reasonable. Overall, the identical result of the first order decay source half life further verifies the appropriateness and representative nature of the calibrated benzene results.

Results of the primary calibration of benzene from April 1997 to March 2003 are as follows:

1997 - 2003 Calibration with K_h = 140 feet/day		
Soluble Mass	First Order Decay Source Half Life	Solute Half Life
0.61 kg	3 years	0.20 years

Predictive Simulations

The 1997 to 2003 benzene calibrated BIOSCREEN model was used as a basis for additional simulations of benzene concentrations at pre-determined yearly time steps in the future from March 203. Three time steps were examined, 1 year, 3 years, and 5 years in the future. For these time steps, no remedial action was considered (i.e. no removal of source). The only changes made to the calibrated BIOSCREEN model were: the adjustment of the source concentration to be consistent with March 2003 data, the soluble mass was decreased to be consistent with March 2003 data, and the starting time was re-set to March 2003. The source concentration was adjusted to 11 ug/L, as observed in March 2003 at WFF15-GW7. The soluble mass was decreased to 0.175 Kg, with special emphasis placed on maintaining the calibrated first order decay source half life of 3 years.

As indicated by the model output sheets, the source area and downgradient concentrations are predicted to drop steadily in the future. Based on the predictive BIOSCREEN modeling, it will take approximately 4 years from March 2003 for benzene concentrations to decline to less than 5 ug/L (PRG) throughout the entire plume (source well to downgradient location).

Additional Source Removal Simulations

Additional simulations were performed in order to estimate the beneficial effects of performing supplemental source remediation activities to remove the remaining contaminant mass from the subsurface. For these simulations, the re-baselined benzene BIOSCREEN model (1997 to 2003 calibrated benzene BIOSCREEN model re-set to March 2003 data, as described above) was used as the base case scenario. Two primary cases were examined, one where 50% of the source mass (soluble mass) was removed, and one where 90% of the source mass was removed. These two cases are considered reasonable remedial goals based on existing technologies and the type of contamination. For each of these cases, the soluble mass was decreased by 50% and 90%, as appropriate. The predictive runs were then run yearly until benzene

concentrations of less than 5 ug/L (PRG) throughout the entire plume were observed. As can be seen in the model output sheets, reducing the mass will decrease the amount of time needed to attain benzene concentrations below the PRG of 5 ug/L. With 50% source removal, benzene levels will be at or below the PRG in approximately 2 years, and with 90% source removal, benzene levels will be below the PRG in less than 1 year.

LOW HYDRAULIC CONDUCTIVITY (1.42 FEET/DAY)

The entire process of calibration and analysis of predictive runs were repeated (as described above) utilizing a lower hydraulic conductivity of 1.42 feet/day, versus the 140 feet/day used in the first series of calibrations and modeling runs. Since only one area of input changed during the model calibration and predictive runs, only the resulting changes due to this input will be described.

Model Calibration

By decreasing the hydraulic conductivity by a factor of 100, the resultant soluble mass was also decreased by a factor of 100 (0.0061 kg versus previous calibrated amount of 0.610 kg). The resultant first order decay source half life remains unchanged at 3 years. The solute half-life has increased to 4 years, which results in a 0.17 per year first order decay coefficient. This is a considerable change from the previous solute half life of 0.2 years and 3.5 per year first order decay coefficient. Consistent with the previous scenario, a tight match to the observed March 2003 data was achieved. Similar results (soluble mass decreased by factor of 100 and solute half-life increased to 4 years) were achieved when the verification of calibration (February 2000 to March 2003) was run. Additionally, similar results for the total BTEX verification were also observed, where the first order decay source half life remained unchanged at 3 years while the solute half-life decreased (from 4 years to 1 year).

Results of the primary calibration of benzene from April 1997 to March 2003 are as follows:

1997 - 2003 Calibration with K_h = 1.42 feet/day		
Soluble Mass	First Order Decay Source Half Life	Solute Half Life
0.0061 kg	3 years	4 years

Predictive Simulations

The predictive simulations utilizing a lower hydraulic conductivity resulted in a time of 3 years from March 2003 for benzene concentrations to decline to less than 5 ug/L (PRG) throughout the entire plume (source

well to downgradient location) as compared to 4 years with a higher hydraulic conductivity when no remedial action is taken at the WOD site.

Additional Source Removal Simulations

Similar to the predictive simulations, the results when 50% and 90% of the source was removed produced nearly identical results as the high hydraulic conductivity benzene BIOSCREEN modeling.

SUMMARY AND CONCLUSIONS

Overall, site, time and chemical data was accurately and appropriately modeled using BIOSCREEN. Modeled concentrations of benzene very strongly matched recent observed concentrations utilizing site-specific input parameters.

Though two scenarios are presented, results from the scenarios utilizing the higher hydraulic conductivity of 140 feet/day are considered to be more representative and accurate of the WOD site. The primary reasons for selecting this scenario is:

- Hydraulic conductivity is consistent with observed lithologies and previous site investigations (including previous modeling – both MODFLOW and 2-D analytical)

- Soluble mass of 0.0061 kg is relatively low. Calculations of the site-specific soluble mass (see calculations in Appendix A) are consistent with the calibrated soluble mass using a hydraulic conductivity of 140 feet/day of 0.61 kg.

- Solute half-life of 4 years exceeds the typical higher end of the observed range of laboratory defined values (2 is typical upper limit, [ASTM, 1995]).

Summary of Predictive Simulations:

Scenario	Kh = 140 feet/day	Kh = 1.42 feet/day
No Action	4 years	3 years
50% Source Removal	2 years	2 years
90% Source Removal	< 1.0 year	< 1.0 year

GENERAL REFERENCES

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Versar, Inc. 2001b. Remedial Investigation/Feasibility Study Sites 14 and 15. NASA Goddard Space Flight Center, Wallops Flight Facility, Wallops Island, VA. April.

HIGH HYDRAULIC CONDUCTIVITY (140 FEET/DAY)
BASELINE SIMULATIONS
(MODEL CALIBRATION)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Calibration 1997-2003

Data Input Instructions:

115 ↑ or 0.02 *

1. *Enter value directly...or*
2. *Calculate by filling in grey cells below. (To restore formulas, hit button below).*

Variable* — *Data used directly in model.*

20 — *Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

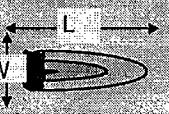
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	6	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.042
4	0	0
5	0	0

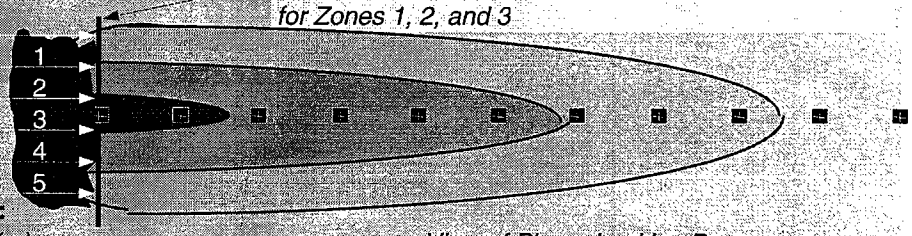
Source Halflife (see Help): <1 | 3 *(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.610 *(Kg)*

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	.011						.008					
Dist. from Source (ft)	0	16	32	48	64	80	96	112	128	144	160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

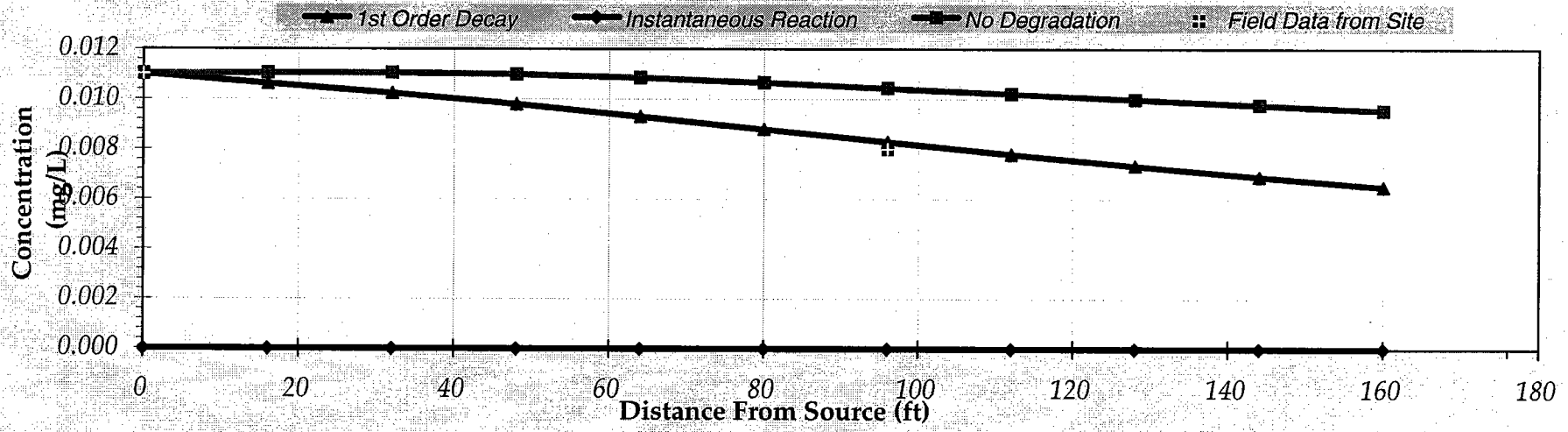
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010
1st Order Decay	0.011	0.011	0.010	0.010	0.009	0.009	0.008	0.008	0.007	0.007	0.006
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.011						0.008				



Calculate Animation

Time: 6 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is. / Waste Oil Dump / Calibration 2000-2003

Data Input Instructions:

1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

* Data used directly in model.
* Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

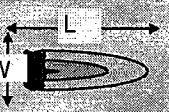
1st Order Decay Coeff*	*lambda*	4.6E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.15	*(year)*

or Instantaneous Reaction Model

Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	3	*(yr)*



Variable*
20

6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.058
0	0
0	0

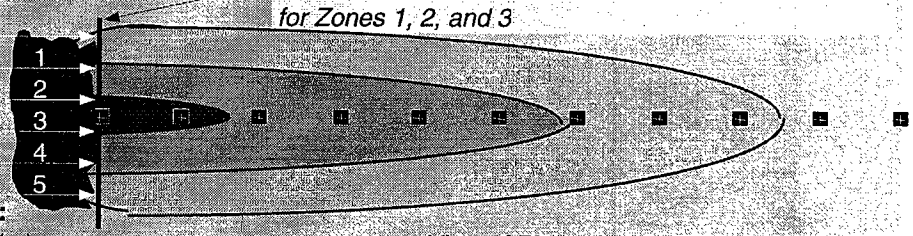
Source Halflife (see Help):

<1	1	*(yr)*

Inst. React. ↖ ↑ 1st Order

Soluble Mass In Source NAPL, Soil: 0.335 *(Kg)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	.011
16	
32	
48	
64	
80	
96	.008
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

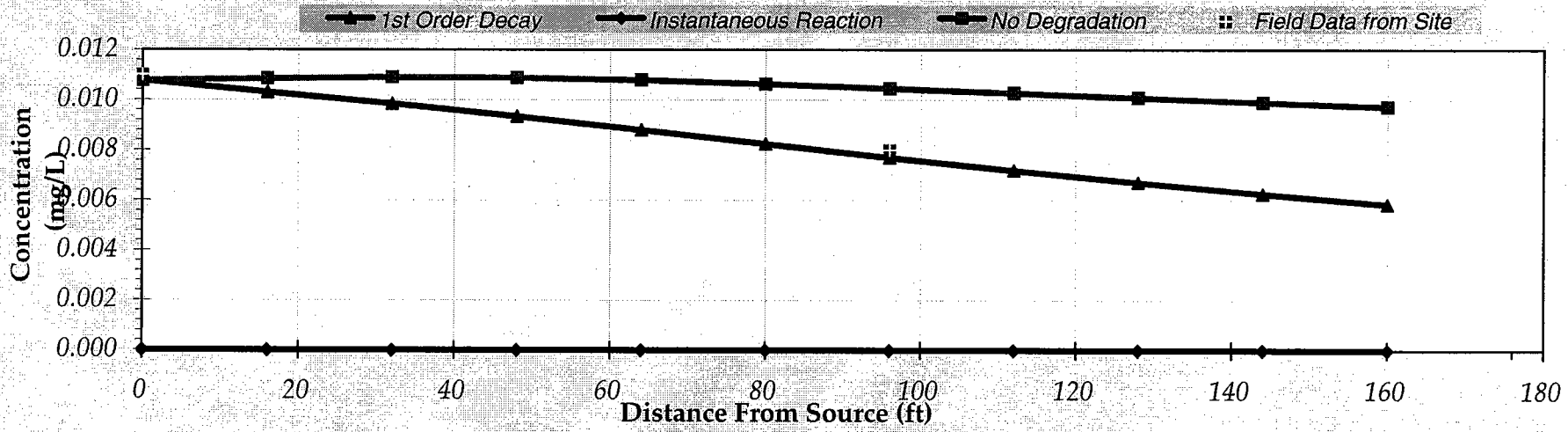
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010
1st Order Decay	0.011	0.010	0.010	0.009	0.009	0.008	0.008	0.007	0.007	0.006	0.006
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.011						0.008				



Calculate Animation

Time:
3 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence

Version 1.4

NASA Wallops Is.
Waste Oil Dump
Calibration 1997-2003

Data Input Instructions:

115 ↑ or 0.02

1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.
20 ▸ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

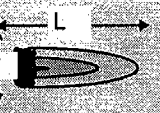
Retardation Factor*	*R*	2.0	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	127	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.02	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	2.25	*(mg/L)*
Delta Nitrate*	*NO3*	1.7722	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	6	*(mg/L)*
Delta Sulfate*	*SO4*	10.25	*(mg/L)*
Observed Methane*	*CH4*	0.5297	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	6	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

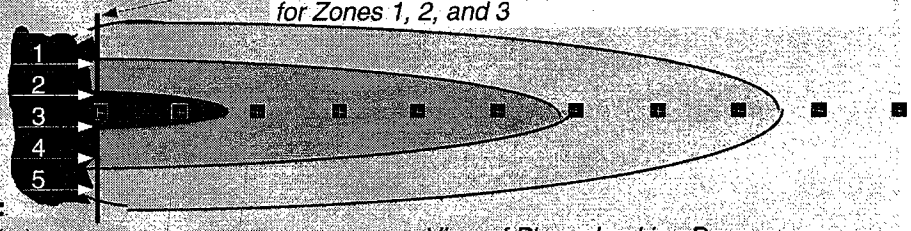
Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	2.822
0	0
0	0

Source Halflife (see Help):

1	3	*(yr)*
Inst. React.	↑ 1st Order	

Soluble Mass 41 *(Kg)*
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	.739
16	
32	
48	
64	
80	
96	.016
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

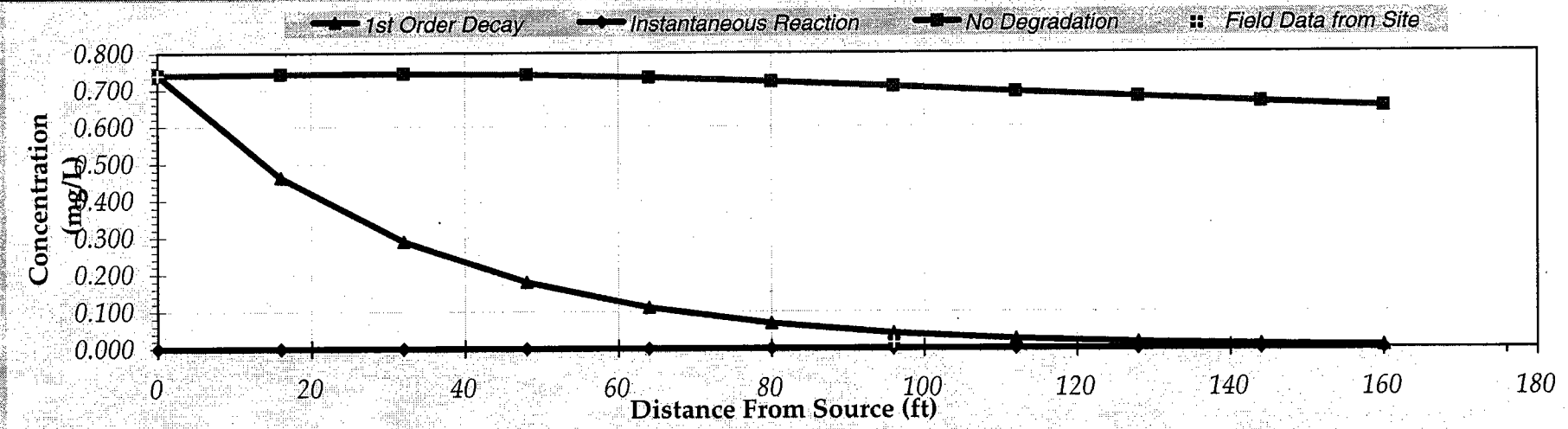
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.740	0.743	0.745	0.742	0.733	0.721	0.708	0.693	0.678	0.664	0.651
1st Order Decay	0.740	0.463	0.290	0.180	0.111	0.068	0.042	0.025	0.015	0.009	0.006
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.739						0.016				



Calculate Animation

Time: 6 Years

Return to Input

Recalculate This Sheet

HIGH HYDRAULIC CONDUCTIVITY (140 FEET/DAY)
PREDICTIVE SIMULATIONS
(NO ACTION – NO SOURCE REMOVAL)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

1. Enter value directly...or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.
▸ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

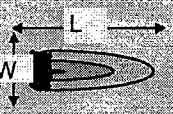
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*



115
↑ or
0.02

Variable*
20

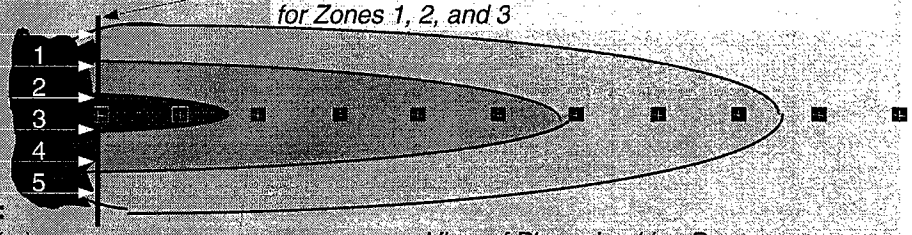
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1 | 3 *(yr)*

Inst. React. ↖ ↑ 1st Order

Soluble Mass 0.175 *(Kg)*
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

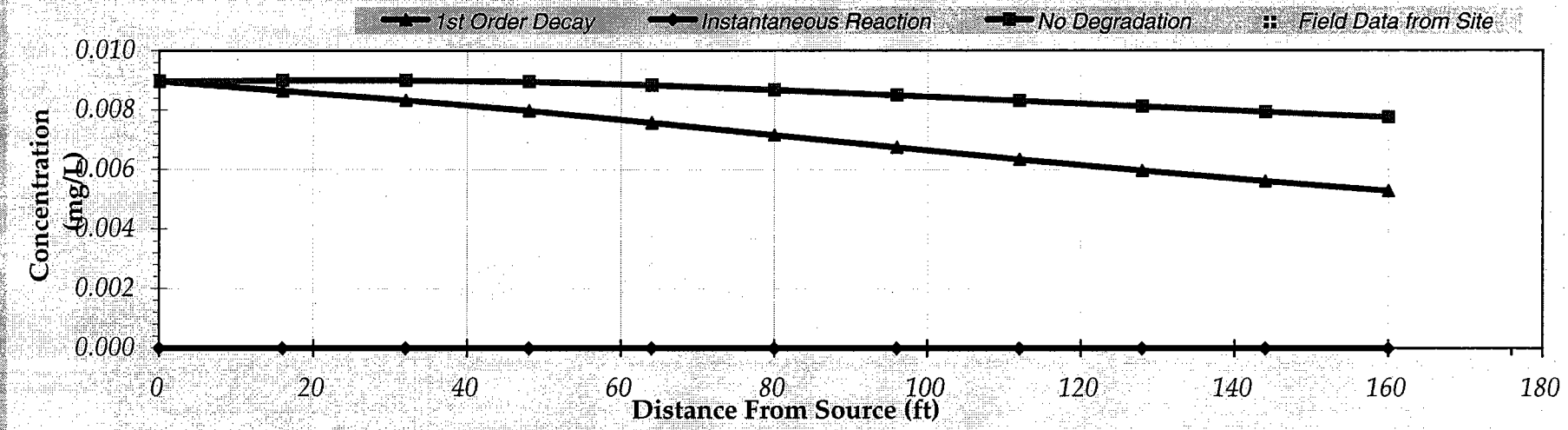
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.009	0.009	0.009	0.009	0.009	0.009	0.008	0.008	0.008	0.008	0.008
1st Order Decay	0.009	0.009	0.008	0.008	0.008	0.007	0.007	0.006	0.006	0.006	0.005
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 1 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

1. Enter value directly...or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable ▸ Data used directly in model.*
▸ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ *or*	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ *or*	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

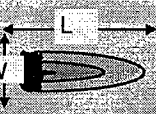
Retardation Factor*	*R*	1.3	*(-)*
or		↑ *or*	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ *or*	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	3	*(yr)*



115	
↑ *or*	
0.02	
Variable*	▸ *Data used directly in model.*
20	▸ *Value calculated by model. (Don't enter any data).*

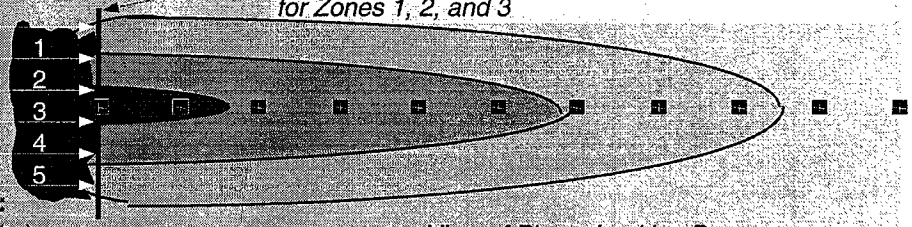
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0



View of Plume Looking Down

Source Halflife (see Help):

<1	3	*(yr)*
Inst. React. ↖ ↑ 1st Order		
Soluble Mass	0.175	*(Kg)*

In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	0	16	32	48	64	80	96	112	128	144	160
Concentration (mg/L)											

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

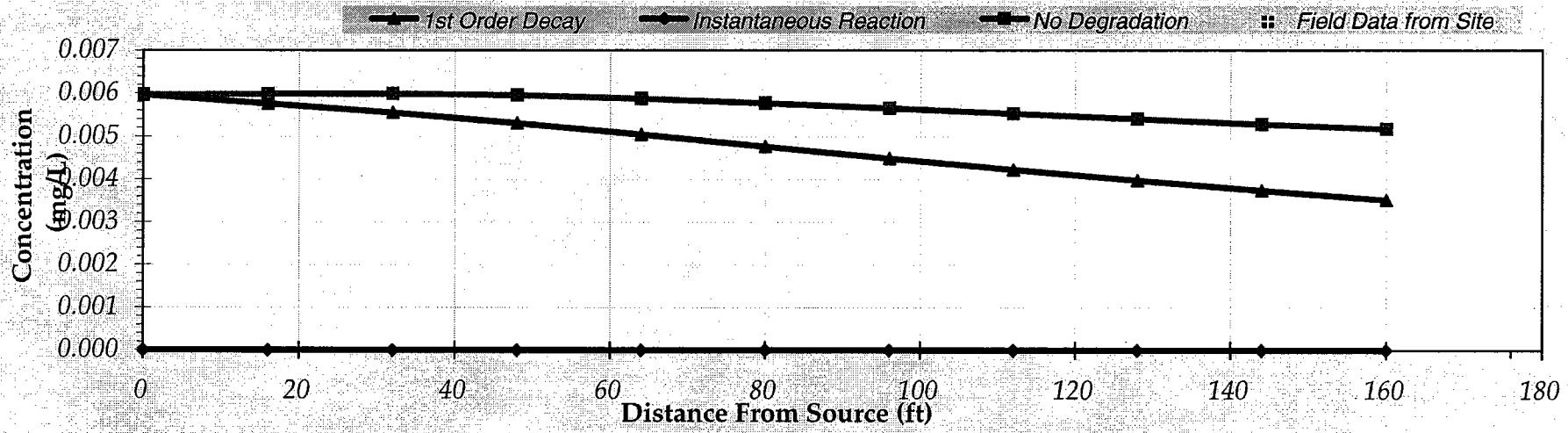
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.005	0.005	0.005
1st Order Decay	0.006	0.006	0.006	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 3 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

115 ← 1. Enter value directly...or
↑ or
0.02 ← 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ← Data used directly in model.
20 ← Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

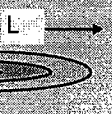
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	5	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

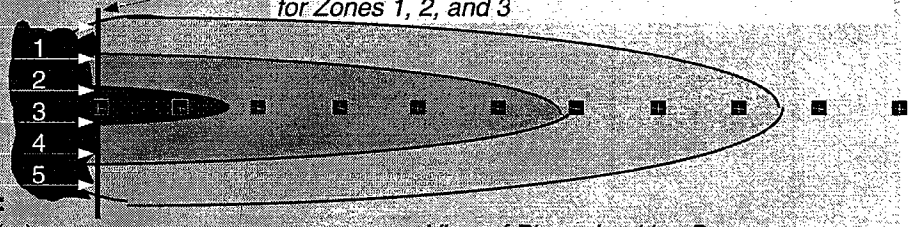
Source Halflife (see Help):

<1 | 3 *(yr)*

Inst. Reactor ↑ ↑ 1st Order

Soluble Mass In Source NAPL, Soil: 0.175 *(Kg)*

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

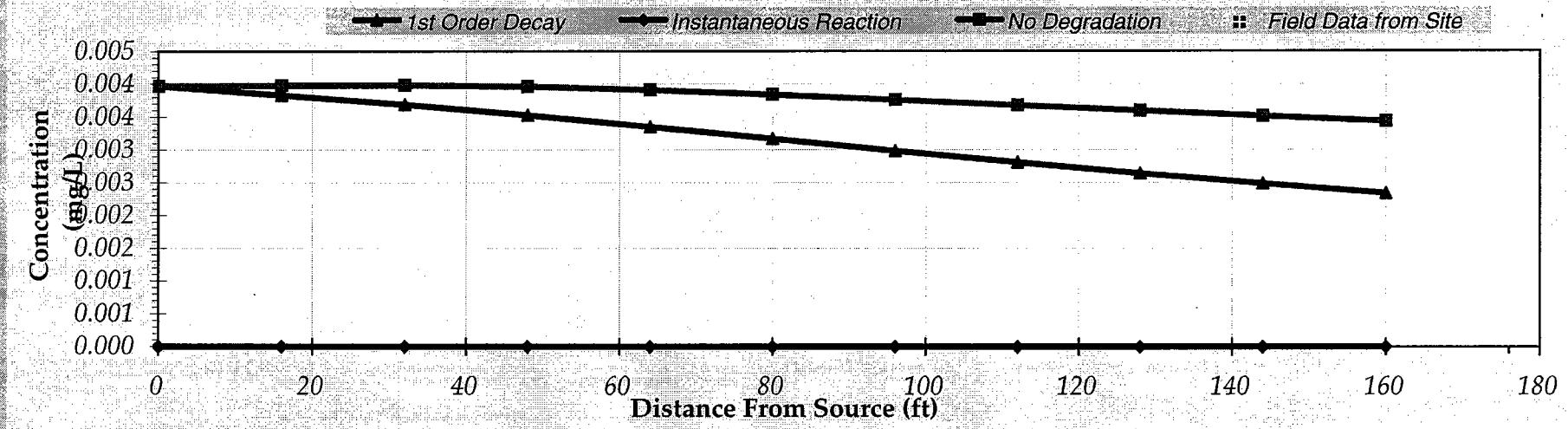
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003
1st Order Decay	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.003	0.002	0.002
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 5 Years

Return to Input

Recalculate This Sheet

HIGH HYDRAULIC CONDUCTIVITY (140 FEET/DAY)

PREDICTIVE SIMULATIONS

(ASSUMES ADDITIONAL REMEDIAL ACTIVITIES REMOVE 50% OF REMAINING SOURCE MASS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - 50% Source Removed

Data Input Instructions:

115 — 1. Enter value directly....or
↑ or — 2. Calculate by filling in grey
0.02 — cells below. (To restore formulas, hit button below).

Variable* — Data used directly in model.
20 — Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

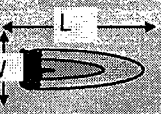
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*



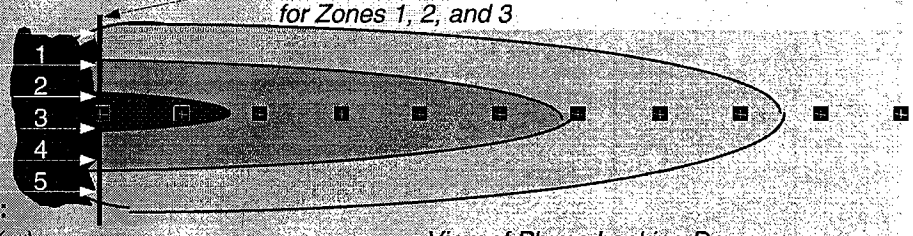
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1 | 2 *(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.088 *(Kg)*
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This Sheet

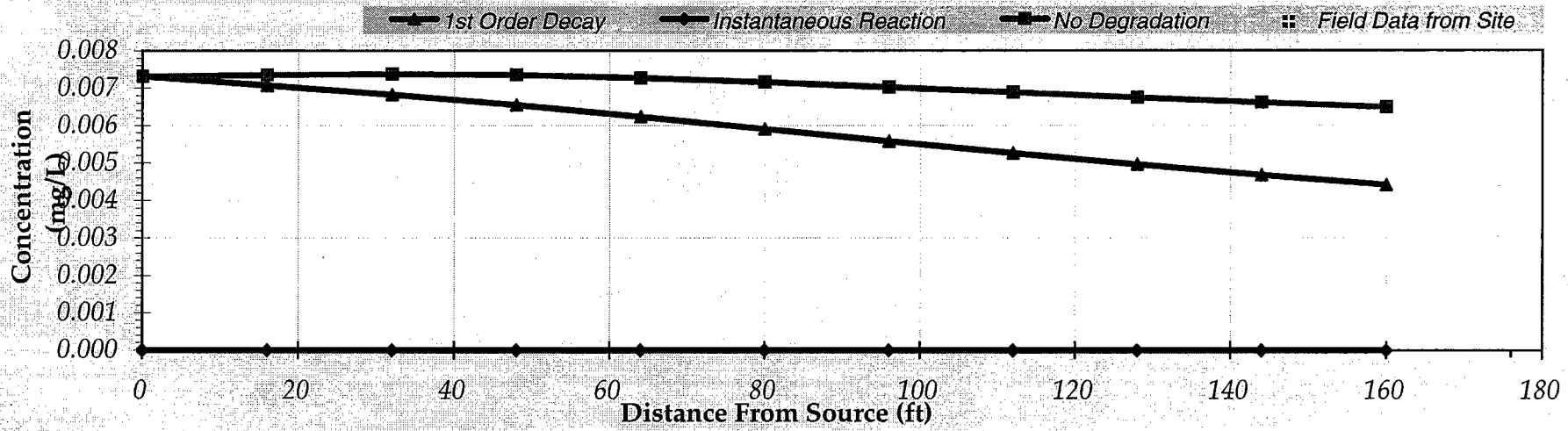
Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.006
1st Order Decay	0.007	0.007	0.007	0.007	0.006	0.006	0.006	0.005	0.005	0.005	0.004
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time:
1 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - 50% Source Removed

Data Input Instructions:
1. Enter value directly... or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

115 ↑ or 0.02

Variable* — * Data used directly in model.
20 — * Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

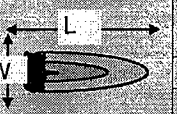
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	2	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

Source Halflife (see Help):

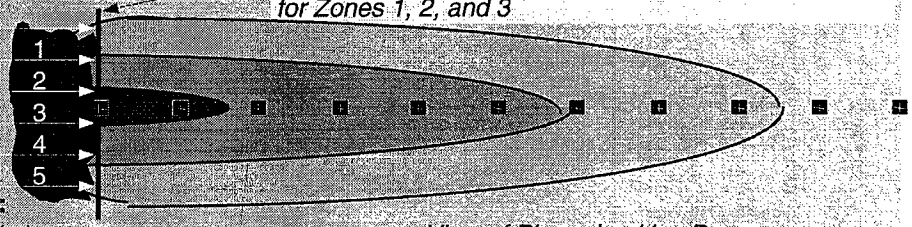
<1 | 2 *(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.088 *(Kg)*

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

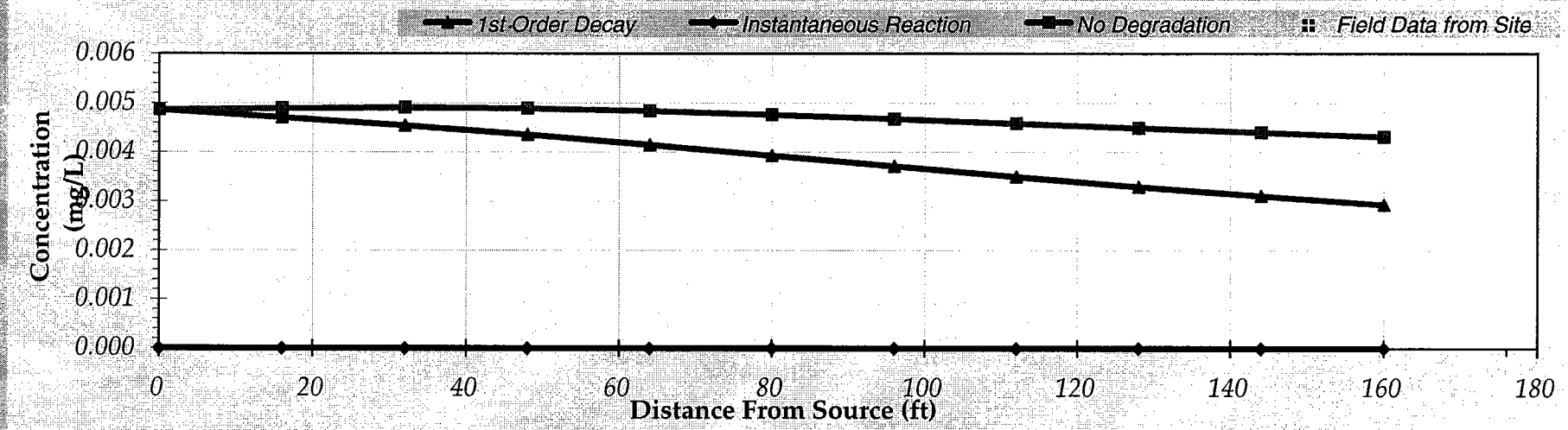
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004
1st Order Decay	0.005	0.005	0.005	0.004	0.004	0.004	0.004	0.004	0.003	0.003	0.003
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 2 Years

Return to Input

Recalculate This Sheet

HIGH HYDRAULIC CONDUCTIVITY (140 FEET/DAY)

PREDICTIVE SIMULATIONS

(ASSUMES ADDITIONAL REMEDIAL ACTIVITIES REMOVE 90% OF REMAINING SOURCE MASS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - 90% Source Removed

Data Input Instructions:

1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

* Data used directly in model.
* Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	1832.3	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	4.9E-02	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

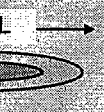
1st Order Decay Coeff*	*lambda*	3.5E+0	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	0.20	*(year)*

or Instantaneous Reaction Model

Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*



	115
	↑ or
	0.02
Variable*	
	20

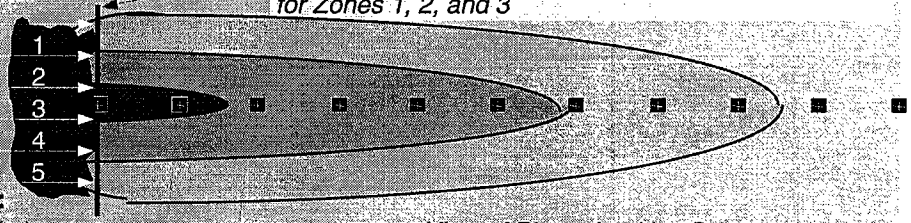
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1	<1	*(yr)*
Inst. React. ↑	↑ 1st Order	

Soluble Mass 0.018 *(Kg)*
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This Sheet

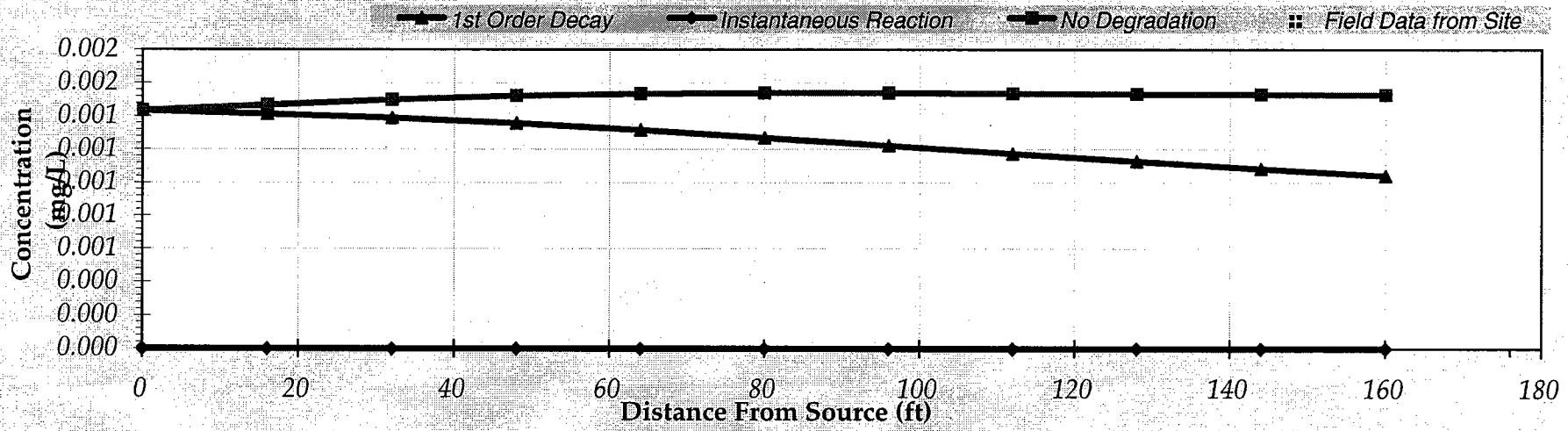
Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.001	0.001	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
1st Order Decay	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time:
1 Years

Return to Input

Recalculate This Sheet

LOW HYDRAULIC CONDUCTIVITY (1.42 FEET/DAY)
BASELINE SIMULATIONS
(MODEL CALIBRATION)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is. / Waste Oil Dump / Calibration 1997-2003

Data Input Instructions:
1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.
Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

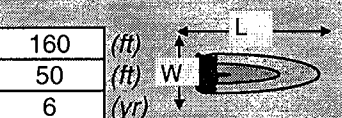
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	6	*(yr)*



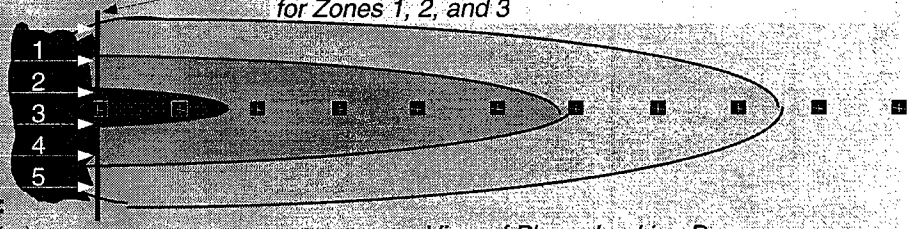
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.042
4	0	0
5	0	0

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1	3	*(yr)*
Inst. React.	↑ 1st Order	

Soluble Mass 0.0061 *(Kg)* In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	.011
16	
32	
48	
64	
80	
96	.008
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This Sheet

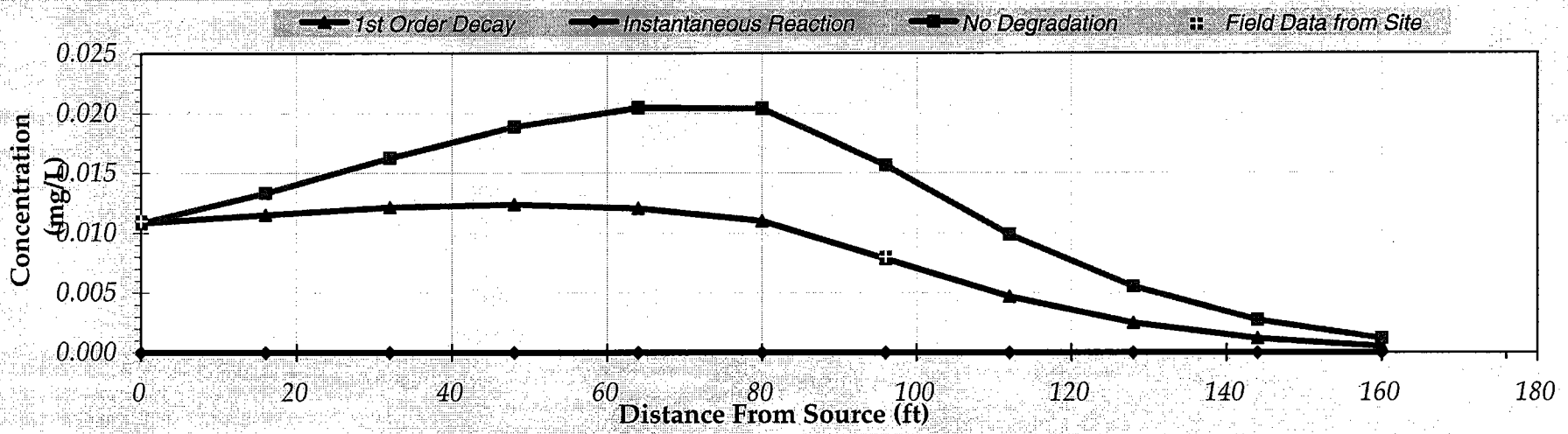
Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.011	0.013	0.016	0.019	0.020	0.020	0.016	0.010	0.006	0.003	0.001
1st Order Decay	0.011	0.012	0.012	0.012	0.012	0.011	0.008	0.005	0.003	0.001	0.001
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.011						0.008				



Calculate Animation

Time: 6 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Calibration 2000-2003

Data Input Instructions:

115 ← 1. Enter value directly....or
↑ or
0.02 ← 2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ← Data used directly in model.
20 ← Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

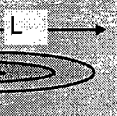
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	3	*(yr)*



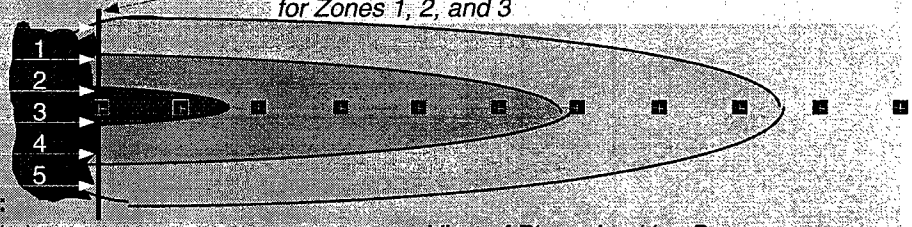
6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.058
4	0	0
5	0	0

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Source Halflife (see Help):

<1 | 1 *(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.0035 *(Kg)*
In Source NAPL, Soil

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Concentration (mg/L)	.011						.008				
Dist. from Source (ft)	0	16	32	48	64	80	96	112	128	144	160

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

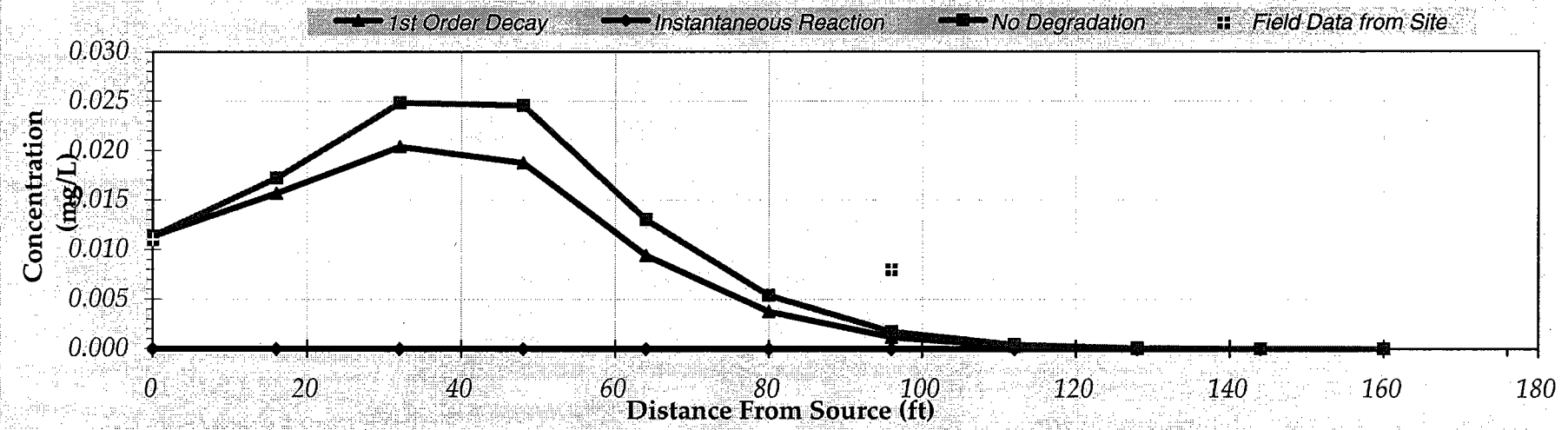
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.011	0.017	0.025	0.025	0.013	0.005	0.002	0.000	0.000	0.000	0.000
1st Order Decay	0.011	0.016	0.020	0.019	0.009	0.004	0.001	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.011						0.008				



Calculate Animation

Time:
3 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Calibration 1997-2003

Data Input Instructions:

115 ↑ or ↓ 0.02

1. *Enter value directly....or*
2. *Calculate by filling in grey cells below. (To restore formulas, hit button below).*

Variable* — *Data used directly in model.*
20 — *Value calculated by model. (Don't enter any data).*

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	2.0	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	127	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	6.9E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	1.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	2.25	*(mg/L)*
Delta Nitrate*	*NO3*	1.7722	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	6	*(mg/L)*
Delta Sulfate*	*SO4*	10.25	*(mg/L)*
Observed Methane*	*CH4*	0.5297	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	6	*(yr)*

6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	2.822
0	0
0	0

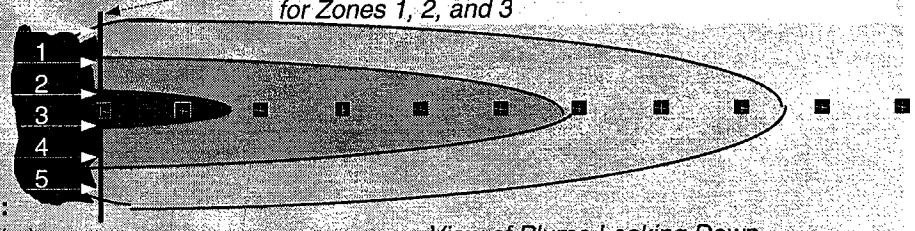
Source Halflife (see Help):

1	3	*(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.410 *(Kg)*
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	.739
16	
32	
48	
64	
80	
96	.016
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

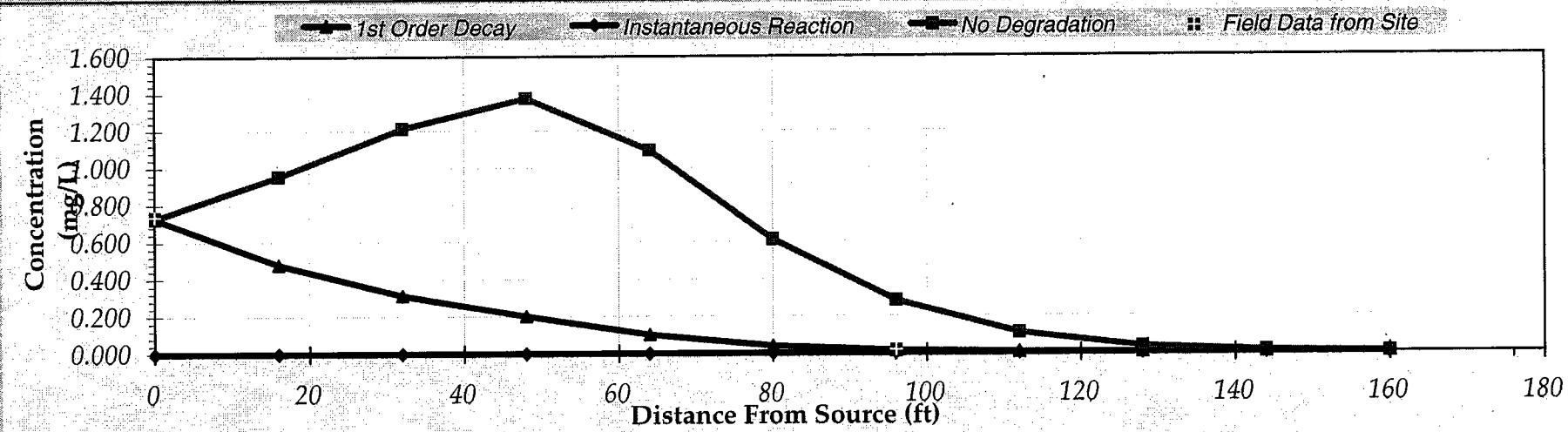
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.728	0.954	1.213	1.375	1.094	0.612	0.284	0.108	0.033	0.008	0.002
1st Order Decay	0.728	0.479	0.313	0.201	0.100	0.039	0.014	0.004	0.001	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site	0.739						0.016				



Calculate Animation

Time: 6 Years

Return to Input

Recalculate This Sheet

LOW HYDRAULIC CONDUCTIVITY (1.42 FEET/DAY)
PREDICTIVE SIMULATIONS
(NO ACTION – NO SOURCE REMOVAL)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

1. Enter value directly...or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.
▸ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ *or*	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ *or*	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

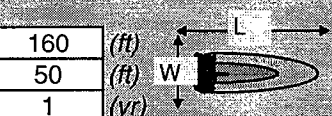
Retardation Factor*	*R*	1.3	*(-)*
or		↑ *or*	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ *or*	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*



115
↑ *or*
0.02

6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

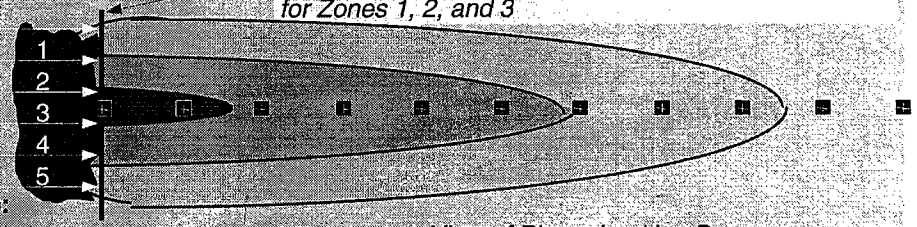
Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.011
0	0
0	0

Source Halflife (see Help):

<1	3	*(yr)*
Inst. React.	↑ 1st Order	

Soluble Mass 0.0015 *(Kg)*
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This Sheet

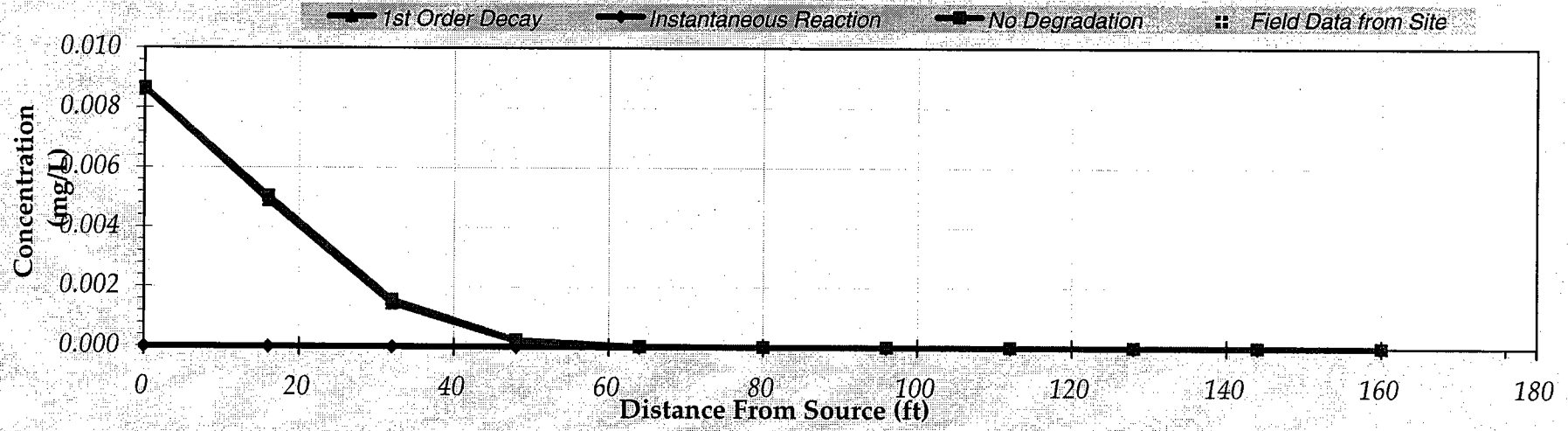
Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.009	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.009	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 1 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

1. Enter value directly...or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* = Data used directly in model.
Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

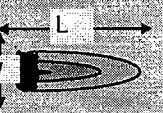
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	3	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

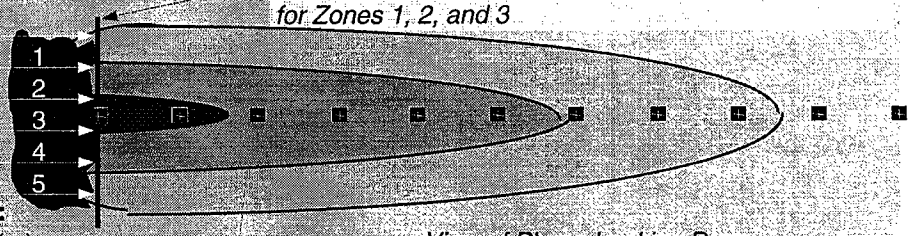
Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.011
0	0
0	0

Source Halflife (see Help): <1 | 3 *(yr)*

Inst. React. ↖ ↑ 1st Order

Soluble Mass 0.0015 *(Kg)*
In Source NAPL Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

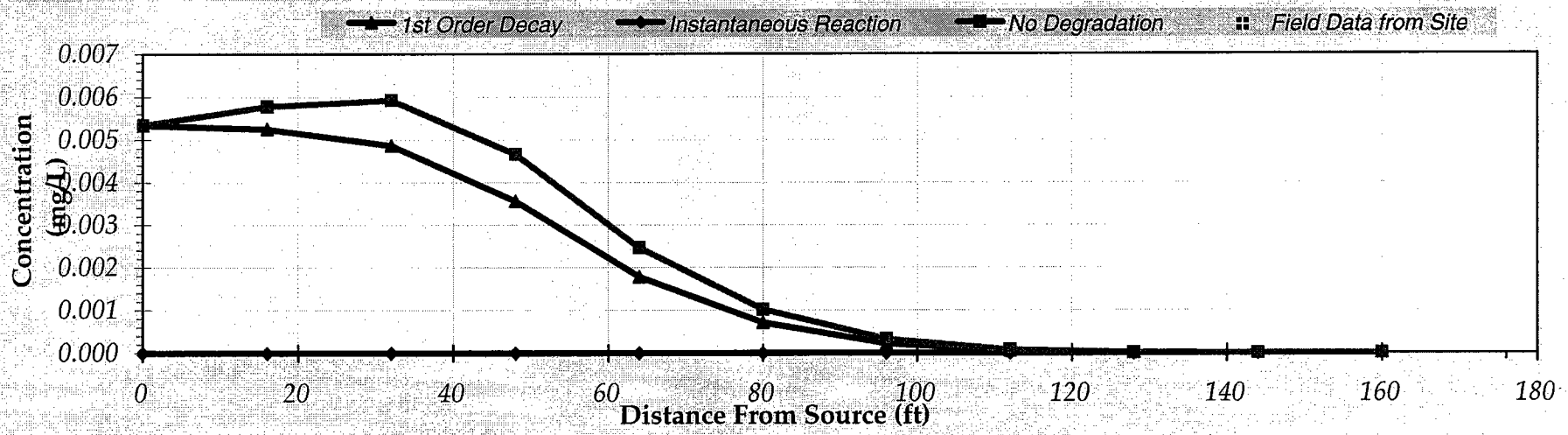
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.005	0.006	0.006	0.005	0.002	0.001	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.005	0.005	0.005	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 3 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - No Action

Data Input Instructions:

1. Enter value directly...or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

* Data used directly in model.
* Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	18.5	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	5.0E-04	(cm/sec)
Hydraulic Gradient	i	0.008964	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	9.6	(ft)
Transverse Dispersivity*	alpha y	1.0	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		↑ or	
Estimated Plume Length	Lp	160	(ft)

3. ADSORPTION

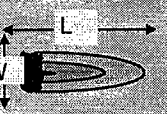
Retardation Factor*	R	1.3	(-)
or		↑ or	
Soil Bulk Density	rho	1.98	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	1.0E-3	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.7E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	4.00	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0.5625	(mg/L)
Delta Nitrate*	NO3	0.44305	(mg/L)
Observed Ferrous Iron*	Fe2+	1.5	(mg/L)
Delta Sulfate*	SO4	2.5625	(mg/L)
Observed Methane*	CH4	0.132425	(mg/L)

5. GENERAL

Modeled Area Length*	160	(ft)
Modeled Area Width*	50	(ft)
Simulation Time*	5	(yr)



Variable*
20

6. SOURCE DATA

Source Thickness in Sat.Zone* 5 (ft)

Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.011
0	0
0	0

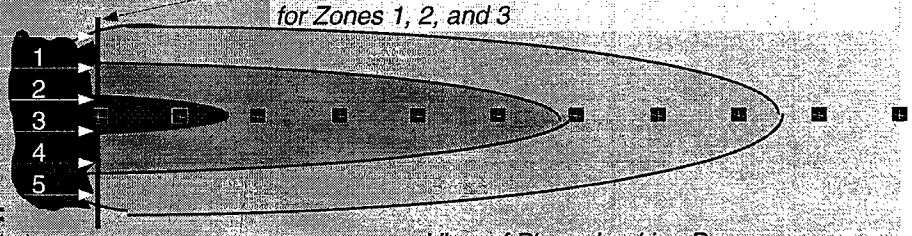
Source Halflife (see Help): <1 | 3 (yr)

Inst. React. ↖ ↑ 1st Order

Soluble Mass 0.0015 (Kg)

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

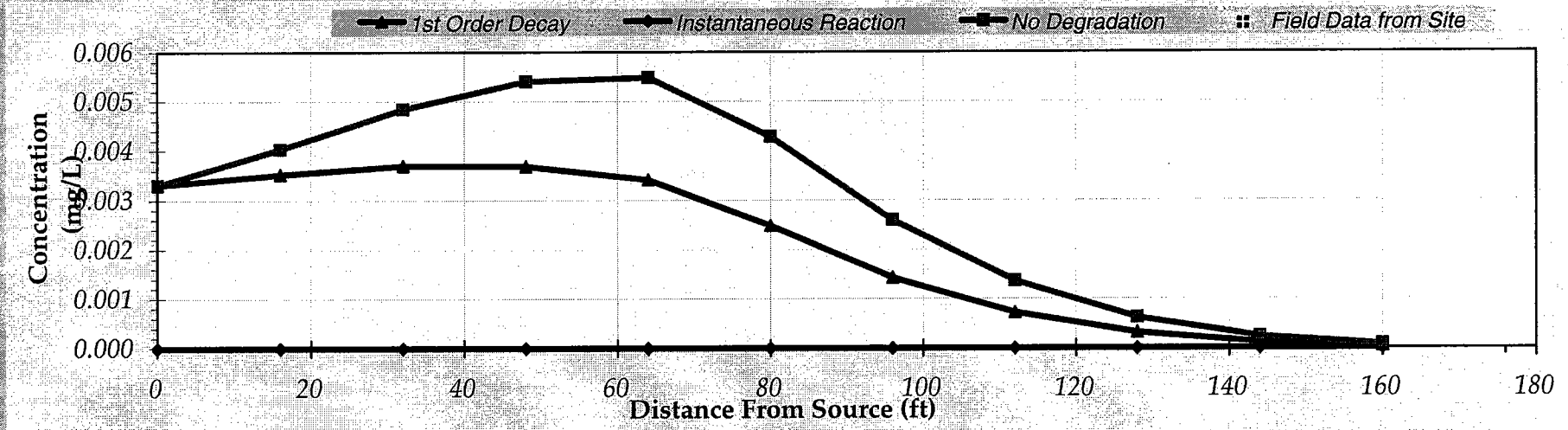
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

TYPE OF MODEL	Distance from Source (ft) 0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.003	0.004	0.005	0.005	0.005	0.004	0.003	0.001	0.001	0.000	0.000
1st Order Decay	0.003	0.004	0.004	0.004	0.003	0.002	0.001	0.001	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 5 Years

Return to Input

Recalculate This Sheet

LOW HYDRAULIC CONDUCTIVITY (1.42 FEET/DAY)

PREDICTIVE SIMULATIONS

(ASSUMES ADDITIONAL REMEDIAL ACTIVITIES REMOVE 50% OF REMAINING SOURCE MASS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is. / Waste Oil Dump / Future - 50% Source Removal

Data Input Instructions:

1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.

20 ◂ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ or	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ or	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

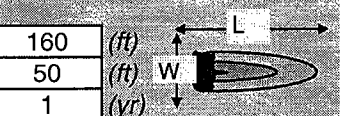
Retardation Factor*	*R*	1.3	*(-)*
or		↑ or	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ or	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

	Width* (ft)	Conc. (mg/L)*
1	0	0
2	0	0
3	50	0.011
4	0	0
5	0	0

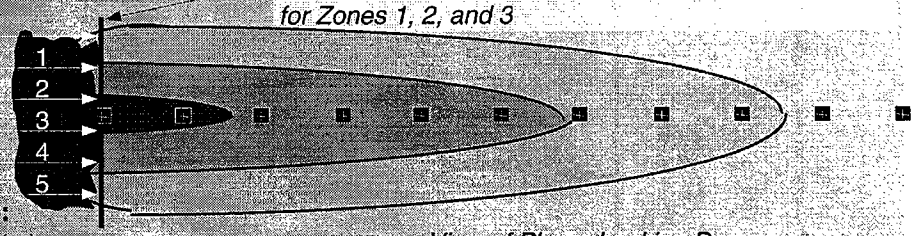
Source Halflife (see Help): <1 | 1 *(yr)*

Inst. React. ↑ ↑ 1st Order

Soluble Mass 0.0008 *(Kg)*

In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

Recalculate This Sheet

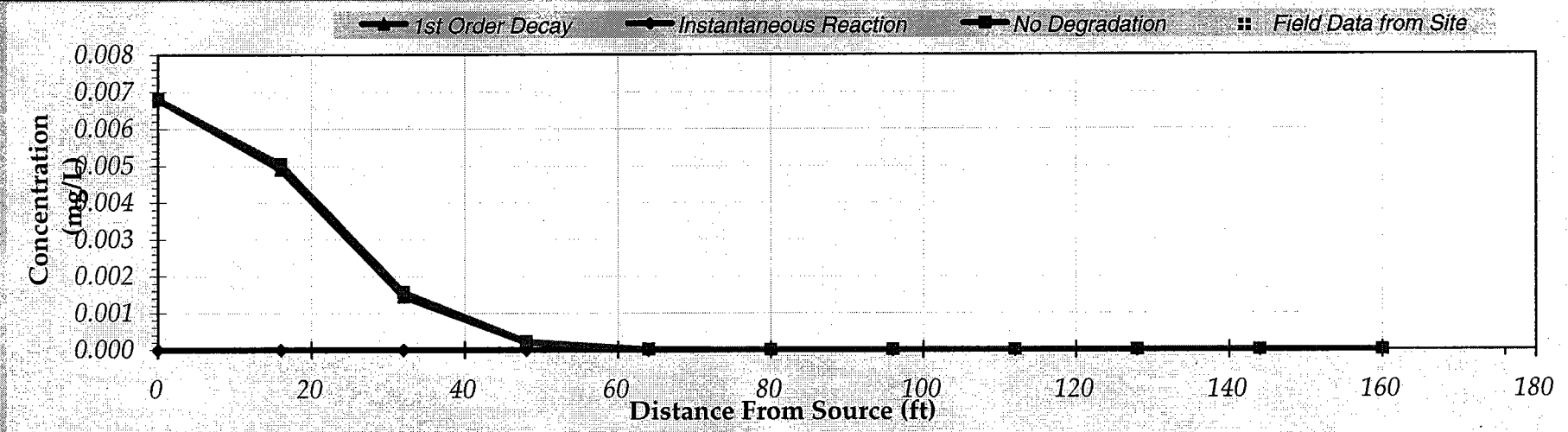
Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.007	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.007	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time:

1 Years

Return to Input

Recalculate This Sheet

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - 50% Source Removal

Data Input Instructions:

1. Enter value directly... or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* ▸ Data used directly in model.
20 ▸ Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	Vs	18.5	(ft/yr)
or		↑ or	
Hydraulic Conductivity	K	5.0E-04	(cm/sec)
Hydraulic Gradient	i	0.008964	(ft/ft)
Porosity	n	0.25	(-)

2. DISPERSION

Longitudinal Dispersivity*	alpha x	9.6	(ft)
Transverse Dispersivity*	alpha y	1.0	(ft)
Vertical Dispersivity*	alpha z	0.0	(ft)
or		↑ or	
Estimated Plume Length	Lp	160	(ft)

3. ADSORPTION

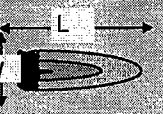
Retardation Factor*	R	1.3	(-)
or		↑ or	
Soil Bulk Density	rho	1.98	(kg/l)
Partition Coefficient	Koc	38	(L/kg)
FractionOrganicCarbon	foc	1.0E-3	(-)

4. BIODEGRADATION

1st Order Decay Coeff*	lambda	1.7E-1	(per yr)
or		↑ or	
Solute Half-Life	t-half	4.00	(year)
or Instantaneous Reaction Model			
Delta Oxygen*	DO	0.5625	(mg/L)
Delta Nitrate*	NO3	0.44305	(mg/L)
Observed Ferrous Iron*	Fe2+	1.5	(mg/L)
Delta Sulfate*	SO4	2.5625	(mg/L)
Observed Methane*	CH4	0.132425	(mg/L)

5. GENERAL

Modeled Area Length*	160	(ft)
Modeled Area Width*	50	(ft)
Simulation Time*	3	(yr)



6. SOURCE DATA

Source Thickness in Sat.Zone* 5 (ft)

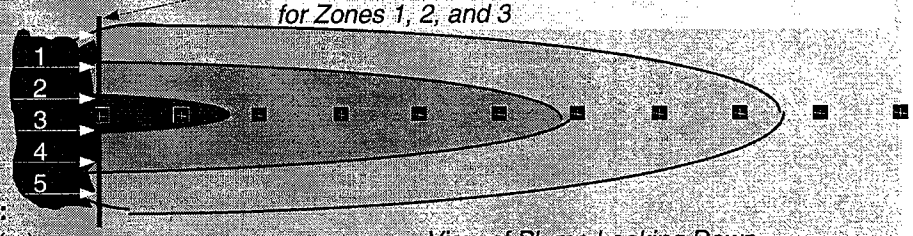
Source Zones:

Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.011
0	0
0	0

Source Halflife (see Help): <1 | 1 (yr)
Inst. React. ↑ 1st Order

Soluble Mass 0.0008 (Kg)
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

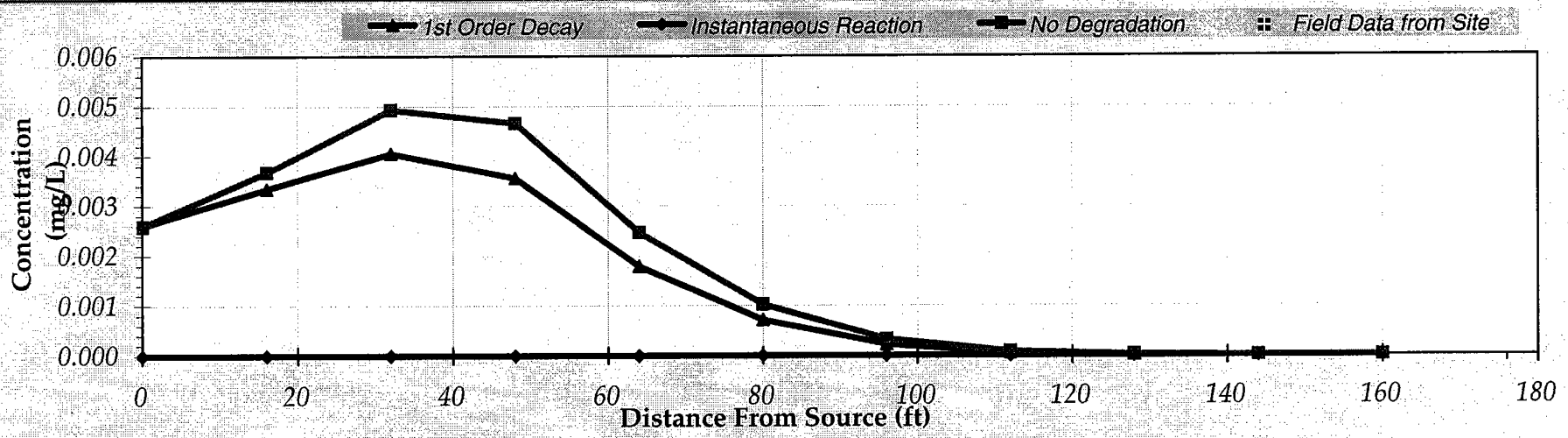
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.003	0.004	0.005	0.005	0.002	0.001	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.003	0.003	0.004	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 3 Years

Return to Input

Recalculate This Sheet

LOW HYDRAULIC CONDUCTIVITY (1.42 FEET/DAY)

PREDICTIVE SIMULATIONS

(ASSUMES ADDITIONAL REMEDIAL ACTIVITIES REMOVE 90% OF REMAINING SOURCE MASS)

BIOSCREEN Natural Attenuation Decision Support System

Air Force Center for Environmental Excellence — *Version 1.4*

NASA Wallops Is.
Waste Oil Dump
Future - 90% Source Removal

Data Input Instructions:

1. Enter value directly....or
2. Calculate by filling in grey cells below. (To restore formulas, hit button below).

Variable* = Data used directly in model.
Value calculated by model. (Don't enter any data).

1. HYDROGEOLOGY

Seepage Velocity*	*Vs*	18.5	*(ft/yr)*
or		↑ *or*	
Hydraulic Conductivity	*K*	5.0E-04	*(cm/sec)*
Hydraulic Gradient	*i*	0.008964	*(ft/ft)*
Porosity	*n*	0.25	*(-)*

2. DISPERSION

Longitudinal Dispersivity*	*alpha x*	9.6	*(ft)*
Transverse Dispersivity*	*alpha y*	1.0	*(ft)*
Vertical Dispersivity*	*alpha z*	0.0	*(ft)*
or		↑ *or*	
Estimated Plume Length	*Lp*	160	*(ft)*

3. ADSORPTION

Retardation Factor*	*R*	1.3	*(-)*
or		↑ *or*	
Soil Bulk Density	*rho*	1.98	*(kg/l)*
Partition Coefficient	*Koc*	38	*(L/kg)*
FractionOrganicCarbon	*foc*	1.0E-3	*(-)*

4. BIODEGRADATION

1st Order Decay Coeff*	*lambda*	1.7E-1	*(per yr)*
or		↑ *or*	
Solute Half-Life	*t-half*	4.00	*(year)*
or Instantaneous Reaction Model			
Delta Oxygen*	*DO*	0.5625	*(mg/L)*
Delta Nitrate*	*NO3*	0.44305	*(mg/L)*
Observed Ferrous Iron*	*Fe2+*	1.5	*(mg/L)*
Delta Sulfate*	*SO4*	2.5625	*(mg/L)*
Observed Methane*	*CH4*	0.132425	*(mg/L)*

5. GENERAL

Modeled Area Length*	160	*(ft)*
Modeled Area Width*	50	*(ft)*
Simulation Time*	1	*(yr)*

115
↑ *or*
0.02

Variable*
20

6. SOURCE DATA

Source Thickness in Sat.Zone* 5 *(ft)*

Source Zones:

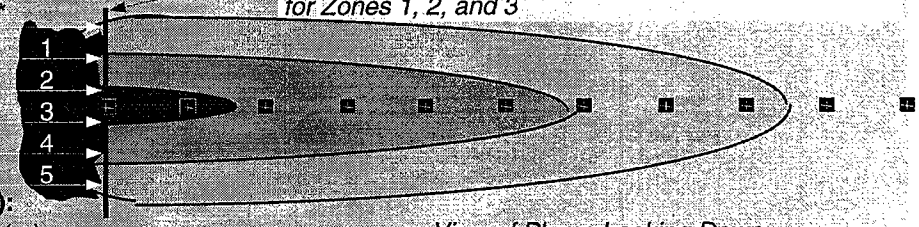
Width* (ft)	Conc. (mg/L)*
0	0
0	0
50	0.011
0	0
0	0

Source Halflife (see Help):

<1	<1	*(yr)*
Inst. React.	↑ 1st Order	

Soluble Mass 0.0002 *(Kg)*
In Source NAPL, Soil

Vertical Plane Source: Look at Plume Cross-Section and Input Concentrations & Widths for Zones 1, 2, and 3



View of Plume Looking Down

Observed Centerline Concentrations at Monitoring Wells
If No Data Leave Blank or Enter "0"

7. FIELD DATA FOR COMPARISON

Dist. from Source (ft)	Concentration (mg/L)
0	
16	
32	
48	
64	
80	
96	
112	
128	
144	
160	

8. CHOOSE TYPE OF OUTPUT TO SEE:

RUN CENTERLINE — **View Output**

RUN ARRAY — **View Output**

Help

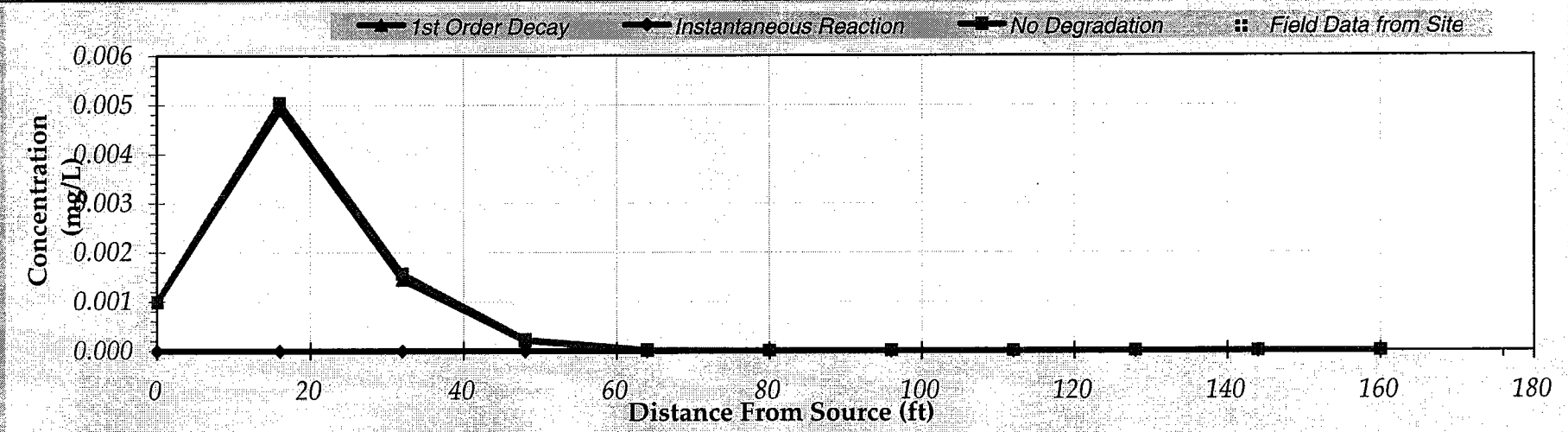
Recalculate This Sheet

Paste Example Dataset

Restore Formulas for Vs, Dispersivities, R, lambda, other

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

	Distance from Source (ft)										
TYPE OF MODEL	0	16	32	48	64	80	96	112	128	144	160
No Degradation	0.001	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1st Order Decay	0.001	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Field Data from Site											



Calculate Animation

Time: 1 Years

Return to Input

Recalculate This Sheet

APPENDIX C

COST ESTIMATES

- **C.1 - ALTERNATIVE 2 NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING**
- **C.2 - ALTERNATIVE 3 IN-SITU BIOREMEDIATION (BIOSTIMULATION)**
- **C.3 - ALTERNATIVE 4 IN-SITU BIOREMEDIATION (BIOAUGMENTATION)**
- **C.4 - ALTERNATIVE 5 AIR SPARGING**

CLIENT:	NASA Wallops Flight Facility		JOB NUMBER:	1612 1110
SUBJECT:	Waste Oil Dump			
BASED ON:			DRAWING NUMBER:	
BY: TJR Date: 2-3-2005		CHECKED BY: Date:	APPROVED BY:	DATE:

Alternative 2: Natural Attenuation, Institutional Controls and Monitoring

Monitoring Well Installation

Install two wells (15 to 20 feet & 25 to 30 feet).

Assume cost:

Drill Rig mob/demob of $3000.

$30.00 per lf of well.

Include IDW disposal, well development & oversite.

Annual Inspection

Assume 1 day to inspect with 2 people

2 people @ $55.00 per hour for 10 hours =	$1,100
car for one day =	$100
report @ $55.00 per hour for 4 hours =	$220
well maintenance (material & labor) =	$1,000
Misc supplies, copying, etc. =	$150
	$2,570

Sampling

Labor & Materials, per round

Assume 4 days to sample with 2 people

2 people @ $55.00 per hour for 10 hours per for 3 days =	$3,300
car for 3 days =	$300
report @ $55.00 per hour for 4 hours =	$220
Misc supplies, copying, etc. =	$200
	$4,020

Analytical, per round

Collect 9 water samples from wells and analyze for VOCs, SVOCs, metals

type	cost each	number	total
water VOCs	$100	9	$900
water SVOCs	$200	9	$1,800
water arsenic (total & dissolved)	$40	9	$360
			$3,060
		40% QA/QC & Data Validation	$1,224
			$4,284

Analytical, per round

Collect 9 water samples from wells and analyze for Natural Attenuation

CLIENT:	NASA Wallops Flight Facility		JOB NUMBER:	1612 1110
SUBJECT:	Waste Oil Dump			
BASED ON:			DRAWING NUMBER:	
BY: TJR Date: 2-3-2005		CHECKED BY: Date:	APPROVED BY:	DATE:

	type	cost each	number	total
Natural Attenuation parameters		$340	9	$3,060
				$3,060
40% QA/QC & Data Validation				$1,224
				$4,284

5-Year Review
Assume 5-year review includes review of past data

5-year review & report	$15,000

Alternative 3: In-situ Biological Treatment (Biostimulation), Institutional Controls and Monitoring

Capital Cost
Based on Regenesis ORC Design Software

3-month Monitoring Event

1. Mob/demob one (1) DPT rig for one day.	$3,000
2. Include technical labor (consultant): $ 30/hr unburdened for 5 days including mob/demob and travel time.	$1,200
3. Include field material costs: $ 500 (tygon tubing, Chemetrics kits, monitoring instruments and peristaltic pump rental)	$500
4. Include per diem for 2 days	$240
5. Include car rental (2 days) + gas and tolls	$150
	$5,090

Monitoring Well Installation
same as Alternative 2
Annual Inspection
same as Alternative 2, but for only three years
Sampling
same as Alternative 2, but for only three years
5-Year Review
same as Alternative 2

Alternative 4: In-situ Biological Treatment (Bioaugmentation), Institutional Controls and Monitoring

Capital Cost
Based on SSWM/U.S. Microbics proposal of 2/7/05.
Installation
assume 12 DPT wells to depth of 40 feet
initial microbes and nutrients cost $20,000

CLIENT:	NASA Wallops Flight Facility		JOB NUMBER:	1612 1110
SUBJECT:	Waste Oil Dump			
BASED ON:			DRAWING NUMBER:	
BY: TJR Date: 2-3-2005		CHECKED BY: Date:	APPROVED BY:	DATE:

SSWM/U.S. Microbics weekly visits for two years

(1-3 day and 3-2 day visits per month)

once per month - 3 day visit		24	hours for one person	
		$60	per hour	
		$1,440		$1,440
three times per month - 2 day visit		16	hours for one person	
		$60	per hour	
		$960	times 3 visits =	$2,880

vehicle for visits

3 day visit	3	days	
2 day visit	6	days	
	9	days	
	$65	per day	
	$585		$585

per diem

from above	9	days	
	$110	per day	
	$990		$990

additional microbes/nutrients/supplies	$3,000	$3,000
	monthly cost for system treatment	$8,895
	yearly cost for system treatment	$106,740

Monitoring Well Installation
same as Alternative 2
Annual Inspection
same as Alternative 2, but for only three years
Sampling
same as Alternative 2, but for only three years
5-Year Review
same as Alternative 2

CLIENT:	NASA Wallops Flight Facility		JOB NUMBER:	1612 1110
SUBJECT:	Waste Oil Dump			
BASED ON:			DRAWING NUMBER:	
BY: TJR Date: 2-3-2005		CHECKED BY: Date:	APPROVED BY:	DATE:

Alternative 5: In-situ Air Sparging, Institutional Controls, & Monitoring

Capital Cost

Wells: Install 12 wells to depth of 40'

Depth:	40	ft
Wells:	12	
	480	lf

Cost to install from D. Brayack (2/05) at $30 per lf, complete.

Piping: Assume 2" & 4" PVC underground
120 lf of 2" & 120 lf of 4"
in addition, include steel pipe inside building

O & M Cost

One blower @ 15 hp

15	hp
1	ea
15	hp
0.746	kW/hp/hr
11	kW/hr
24	hours/day
269	kW/day
365	day/year
98,024	kW/year

Assume maintenance per year @ 5% of installation cost.

Monitoring Well Installation
same as Alternative 2

Annual Inspection
same as Alternative 2, but for only three years

Sampling
same as Alternative 2, but for only three years

5-Year Review
same as Alternative 2

C.1 - ALTERNATIVE 2 NATURAL ATTENUATION, INSTITUTIONAL CONTROLS, AND MONITORING

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 2: Natural Attenuation, Institutional Controls and Monitorin
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
1 PROJECT PLANNING AND OVERSITE											
1.1 Prepare Remedial Action Plar	100	hr			$35.00		$0	$0	$3,500	$0	$3,500
1.2 Professional Oversight (1p * 5 days/week	1	wk			$1,000.00		$0	$0	$1,000	$0	$1,000
2 MONITORING WELL INSTALLATION											
2.1 Mobilize/Demobilize Drill Rig	1	ls	$3,000.00				$3,000	$0	$0	$0	$3,000
2.2 Install Monitoring Well	45	lf	$30.00				$1,350	$0	$0	$0	$1,350
2.3 Well Development	8	hr	$35.00				$280	$0	$0	$0	$280
2.4 Collect/Containerize IDW	2	ea	$50.00				$100	$0	$0	$0	$100
2.5 Transport/Dispose IDW Off Site	2	drum	$150.00				$300	$0	$0	$0	$300
3 INSTITUTIONAL CONTROLS											
3.1 Prepare Land Use Control (LUC	200	hr			$35.00		$0	$0	$7,000	$0	$7,000
Subtotal							$5,030	$0	$11,500	$0	$16,530
Local Area Adjustments							100.0%	104.8%	85.6%	85.6%	
							$5,030	$0	$9,844	$0	$14,874
Overhead on Labor Cost @ 30%									$2,953		$2,953
G & A on Labor Cost @ 10%									$984		$984
G & A on Material Cost @ 10%								$0			$0
G & A on Equipment Cost @ 10%										$0	$0
G & A on Subcontract Cost @ 10%							$503				$503
Total Direct Cost							$5,533	$0	$13,782	$0	$19,315
Indirects on Total Direct Cost @ 20%											$3,863
Profit on Total Direct Cost @ 10%											$1,931
Subtotal											$25,109
Health & Safety Monitoring @ 5%											$1,255
Total Field Cost											$26,364
Contingency on Total Field Costs @ 20%											$5,273
Engineering on Total Field Cost @ 20%											$5,273
TOTAL COST											**$36,910**

NASA WALLOP FLIGHT FACILIT'
Wallops Island, Virginia
Waste Oil Dump
Alternative 2: Natural Attenuation, Institutional Controls and Monitorir
ANNUAL COST

Item	Item Cost Year 1	Item Cost Years 2 & 3	Item Cost Years 4 - 5	Item Cost Every 5 Years	Notes
Site Inspection & Report	$2,570	$2,570	$2,570		One-day inspection with 2 people for LUC
Sampling	$16,080	$8,040	$4,020		Labor, Field Supplies (local
Analysis	$17,136	$8,568	$4,284		Analyze 9 water samples for VOCs, SVOCs, and arsenic. Quarterly year 1, semi-annually years 2 & 3, annually years 4 & 5
Analysis	$17,136	$8,568	$4,284		Analyze 9 water samples for natural attenuation. Quarterly year 1, semi-annually years 2 & 3, annually years 4 & 5
Sampling & Analysis Report	$20,000	$10,000	$5,000		Document sampling events and results
Site Review				$15,000	Perform 5-year review
TOTALS	$72,922	$37,746	$20,158	$15,000	

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 2: Natural Attenuation, Institutional Controls and Monitoring
PRESENT WORTH ANALYSIS

Year	Capital Cost	Annual Cost	Annual Discount Rate at 3.5%	Present Worth
0	$36,910		1.000	$36,910
1		$72,922	0.966	$70,443
2		$37,746	0.934	$35,255
3		$37,746	0.902	$34,047
4		$20,158	0.871	$17,558
5		$35,158	0.842	$29,603
			TOTAL PRESENT WORTH	**$223,815**

C.2 - ALTERNATIVE 3 IN-SITU BIOREMEDIATION (BIOSTIMULATION)

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 3: In-situ Biological Treatment (Biostimulation), Institutional Controls and Monitorir
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
1 PROJECT DOCUMENTS/INSTITUTIONAL CONTROLS											
1.1 Prepare Documents & Plans including Permits	150	hr			$35.00		$0	$0	$5,250	$0	$5,250
1.2 Prepare Land Use Control (LUC	200	hr			$35.00		$0	$0	$7,000	$0	$7,000
2 MOBILIZATION/DEMOBILIZATION AND FIELD SUPPOR											
2.1 Office Trailer	1	mo				$286.00	$0	$0	$0	$286	$286
2.2 Office Trailer Mob/Demc	1	ea				$225.00	$0	$0	$0	$225	$225
2.3 Field Office Support	1	mo		$143.00			$0	$143	$0	$0	$143
2.4 Utility Connection/Disconnection (phone/electric	1	ls	$1,500.00				$1,500	$0	$0	$0	$1,500
2.5 Site Utilities (phone & electric)	1	mo		$302.00			$0	$302	$0	$0	$302
2.6 Drill Rig Mobilization/Demobilizatior	1	ls	$3,000.00				$3,000	$0	$0	$0	$3,000
2.7 Professional Oversight (2p * 5 days/week	3	wk			$1,600.00		$0	$0	$4,800	$0	$4,800
3 DECONTAMINATION											
3.1 Decontamination Services	1	mo		$375.00	$1,200.00	$900.00	$0	$375	$1,200	$900	$2,475
3.2 Pressure Washer	1	mo				$1,100.00	$0	$0	$0	$1,100	$1,100
3.3 Equipment Decon Pad	1	ls		$500.00	$450.00	$155.00	$0	$500	$450	$155	$1,105
3.4 Decon Water	1	kgal		$200.00			$0	$200	$0	$0	$200
3.5 Decon Water Storage Tank, 6,000 gallor	1	mo				$645.00	$645	$0	$0	$645	$1,290
3.6 Clean Water Storage Tank, 4,000 gallor	1	mo				$580.00	$580	$0	$0	$580	$1,160
3.7 Disposal of Decon Waste (liquid & solid	1	mo	$900.00				$900	$0	$0	$0	$900
4 MONITORING WELL INSTALLATION											
4.1 Install Monitoring Well	45	lf	$30.00				$1,350	$0	$0	$0	$1,350
4.2 Well Development	8	hr	$35.00				$280	$0	$0	$0	$280
4.3 Collect/Containerize IDW	2	ea	$50.00				$100	$0	$0	$0	$100
4.4 Transport/Dispose IDW Off Site	2	drum	$150.00				$300	$0	$0	$0	$300
5 BIOREMEDIATION											
5.1 Bench-Scale Treatability Study	1	ls	$10,000.00				$10,000	$0	$0	$0	$10,000
5.2 Drill 12 1-inch DPT Points to 30' bgs	360	ft	$30.00				$10,800	$0	$0	$0	$10,800
5.3 ORC Materials (5430 lbs. + 5%)	5,700	lbs		$9.30			$0	$53,010	$0	$0	$53,010
5.4 Supplier Technical Oversite	1	ls	$2,000.00				$2,000	$0	$0	$0	$2,000
6 SITE RESTORATION											
6.1 Vegetate Disturbed Areas	1	ls		$300.00	$500.00	$200.00	$0	$300	$500	$200	$1,000
Subtotal							$31,455	$54,830	$19,200	$4,091	$109,576
Local Area Adjustments							100.0%	104.8%	85.6%	85.6%	
							$31,455	$57,462	$16,435	$3,502	$108,854
Overhead on Labor Cost @ 30%									$4,931		$4,931
G & A on Labor Cost @ 10%									$1,644		$1,644
G & A on Material Cost @ 10%								$5,746			$5,746
G & A on Equipment Cost @ 10%										$350	$350
G & A on Subcontract Cost @ 10%							$3,146				$3,146
Total Direct Cost							$34,601	$63,208	$23,009	$3,852	$124,670

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 3: In-situ Biological Treatment (Biostimulation), Institutional Controls and Monitorir
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
Indirects on Total Direct Cost @ 35%											$43,634
Profit on Total Direct Cost @ 10%											$12,467
Subtotal											$180,771
Health & Safety Monitoring @ 2%											$3,615
Total Field Cost											$184,387
Contingency on Total Field Costs @ 20%											$36,877
Engineering on Total Field Cost @ 10%											$18,439
TOTAL COST											**$239,703**

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 3: In-situ Biological Treatment (Biostimulation), Institutional Controls and Monitorir
ANNUAL COST

Item	Item Cost Year 1	Item Cost Years 2 & 3	Item Cost Every 5 Years	Notes
Site Inspection & Report	$2,570	$2,570		One-day inspection with 2 people for LUC
3-month Monitoring	$5,090			Monitoring oxygen and carbon dioxide in treatment area 3 months following injection.
Sampling	$16,080	$8,040		Labor, Field Supplies (local
Analysis	$17,136	$8,568		Analyze 9 water samples for VOCs, SVOCs, and arsenic. Quarterly year 1, semi-annually years 2 & 3
Analysis	$17,136	$8,568		Analyze 9 water samples for natural attenuation. Quarterly year 1, semi-annually years 2 & 3
Sampling & Analysis Report	$20,000	$10,000		Document sampling events and results
Site Review			$15,000	Perform 5-year review
TOTALS	$78,012	$37,746	$15,000	

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 3: In-situ Biological Treatment (Biostimulation), Institutional Controls and Monitorir
PRESENT WORTH ANALYSIS

Year	Capital Cost	Annual Cost	Annual Discount Rate at 3.5%	Present Worth
0	$239,703		1.000	$239,703
1		$78,012	0.966	$75,360
2		$37,746	0.934	$35,255
3		$37,746	0.902	$34,047
4			0.871	$0
5		$15,000	0.842	$12,630
			TOTAL PRESENT WORTH	**$396,994**

C.3 - ALTERNATIVE 4 IN-SITU BIOREMEDIATION (BIOAUGMENTATION)

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 4: In-situ Biological Treatment (Bioaugmentation), Institutional Controls and Monitorir
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
1 PROJECT DOCUMENTS/INSTITUTIONAL CONTROLS											
1.1 Prepare Documents & Plans including Permits	150	hr			$35.00		$0	$0	$5,250	$0	$5,250
1.2 Prepare Land Use Control (LUC	200	hr			$35.00		$0	$0	$7,000	$0	$7,000
2 MOBILIZATION/DEMOBILIZATION AND FIELD SUPPOR											
2.1 Office Trailer	1	mo				$286.00	$0	$0	$0	$286	$286
2.2 Office Trailer Mob/Demo	1	ea				$225.00	$0	$0	$0	$225	$225
2.3 Field Office Support	1	mo		$143.00			$0	$143	$0	$0	$143
2.4 Utility Connection/Disconnection (phone/electric	1	ls	$1,500.00				$1,500	$0	$0	$0	$1,500
2.5 Site Utilities (phone & electric)	1	mo		$302.00			$0	$302	$0	$0	$302
2.6 Drill Rig Mobilization/Demobilizatior	1	ls	$3,000.00				$3,000	$0	$0	$0	$3,000
2.7 Professional Oversight (2p * 5 days/week	4	wk			$1,600.00		$0	$0	$6,400	$0	$6,400
3 DECONTAMINATION											
3.1 Decontamination Services	1	mo		$375.00	$1,200.00	$900.00	$0	$375	$1,200	$900	$2,475
3.2 Pressure Washer	1	mo				$1,100.00	$0	$0	$0	$1,100	$1,100
3.3 Equipment Decon Pad	1	ls		$500.00	$450.00	$155.00	$0	$500	$450	$155	$1,105
3.4 Decon Water	1	kgal		$200.00			$0	$200	$0	$0	$200
3.5 Decon Water Storage Tank, 6,000 gallor	1	mo				$645.00	$645	$0	$0	$645	$1,290
3.6 Clean Water Storage Tank, 4,000 gallor	1	mo				$580.00	$580	$0	$0	$580	$1,160
3.7 Disposal of Decon Waste (liquid & solid)	1	mo	$900.00				$900	$0	$0	$0	$900
4 BIOREMEDIATION											
4.1 Bench-Scale Treatability Study	1	ls	$10,000.00				$10,000	$0	$0	$0	$10,000
4.2 Drill 12 1-inch DPT Points to 20' bgs	480	ft	$30.00				$14,400	$0	$0	$0	$14,400
4.3 Biological Materials	1	ls		$20,000.00			$0	$20,000	$0	$0	$20,000
4.4 Supplier Technical Oversite	1	ls	$2,000.00				$2,000	$0	$0	$0	$2,000
5 SITE RESTORATION											
5.1 Vegetate Disturbed Areas	1	ls		$300.00	$500.00	$200.00	$0	$300	$500	$200	$1,000
Subtotal							$33,025	$21,820	$20,800	$4,091	$79,736
Local Area Adjustments							100.0%	104.8%	85.6%	85.6%	
							$33,025	$22,867	$17,805	$3,502	$77,199
Overhead on Labor Cost @ 30%									$5,341		$5,341
G & A on Labor Cost @ 10%									$1,780		$1,780
G & A on Material Cost @ 10%								$2,287			$2,287
G & A on Equipment Cost @ 10%										$350	$350
G & A on Subcontract Cost @ 10%							$3,303				$3,303
Total Direct Cost							$36,328	$25,154	$24,927	$3,852	$90,260
Indirects on Total Direct Cost @ 35%											$31,591
Profit on Total Direct Cost @ 10%											$9,026
Subtotal											$130,878

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 4: In-situ Biological Treatment (Bioaugmentation), Institutional Controls and Monitorir
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
Health & Safety Monitoring @ 3%											$3,926
Total Field Cost											$134,804
Contingency on Total Field Costs @ 20%											$26,961
Engineering on Total Field Cost @ 10%											$13,480
TOTAL COST											**$175,245**

NASA WALLOP FLIGHT FACILIT'
Wallops Island, Virginia
Waste Oil Dump
Alternative 4: In-situ Biological Treatment (Bioaugmentation), Institutional Controls and Monitori
ANNUAL COST

Item	Item Cost Year 1	Item Cost Year 2	Item Cost Year 3	Item Cost Every 5 Years	Notes
Site Inspection & Report	$2,570	$2,570	$2,570		One-day inspection with 2 people for LUC
Supplier Inspection	$106,740	$106,740			Supplier visits to add microbes and nutrients to treatment area. Weekly for years 1 & 2.
Sampling	$16,080	$8,040	$8,040		Labor, Field Supplies (local
Analysis	$17,136	$8,568	$8,568		Analyze 9 water samples for VOCs, SVOCs, and arsenic. Quarterly year 1, semi-annually years 2 & 3
Analysis	$17,136	$8,568	$8,568		Analyze 9 water samples for natural attenuation. Quarterly year 1, semi-annually years 2 & 3
Sampling & Analysis Report	$20,000	$10,000	$10,000		Document sampling events and results
Site Review				$15,000	Perform 5-year review
TOTALS	$179,662	$144,486	$37,746	$15,000	

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 4: In-situ Biological Treatment (Bioaugmentation), Institutional Controls and Monitc
PRESENT WORTH ANALYSIS

Year	Capital Cost	Annual Cost	Annual Discount Rate at 3.5%	Present Worth
0	$175,245		1.000	$175,245
1		$179,662	0.966	$173,553
2		$144,486	0.934	$134,950
3		$37,746	0.902	$34,047
4		$0	0.871	$0
5		$15,000	0.842	$12,630
			TOTAL PRESENT WORTH	**$530,425**

C.4 - ALTERNATIVE 5 AIR SPARGING

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 5: In-situ Air Sparging, Institutional Controls and Monitorin
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
1 PROJECT PLANNING AND DOCUMENTS											
1.1 Prepare Documents & Plans including Permits	150	hr			$35.00		$0	$0	$5,250	$5,250	$10,500
1.2 Prepare Land Use Control (LUC	200	hour			$35.00		$0	$0	$7,000	$0	$7,000
2 MOBILIZATION/DEMOBILIZATION AND FIELD SUPPOR											
2.1 Office Trailer	2	mo				$286.00	$0	$0	$0	$572	$572
2.2 Office Trailer Mob/Demc	1	ea				$225.00	$0	$0	$0	$225	$225
2.3 Field Office Support	2	mo		$143.00			$0	$286	$0	$0	$286
2.4 Utility Connection/Disconnection (phone/electric	1	ls	$1,500.00				$1,500	$0	$0	$0	$1,500
2.5 Site Utilities (phone & electric)	2	mo		$302.00			$0	$604	$0	$0	$604
2.6 Drill Rig Mobilization/Demobilizatior	1	ls	$3,000.00				$3,000	$0	$0	$0	$3,000
2.7 Mobilization/Demobilization Construction Equipmen	2	ea			$141.00	$336.00	$0	$0	$282	$672	$954
2.8 Professional Oversight (2p * 5 days/week	8	wk			$3,200.00		$0	$0	$25,600	$0	$25,600
3 DECONTAMINATION											
3.1 Decontamination Services	2	mo		$375.00	$1,200.00	$900.00	$0	$750	$2,400	$1,800	$4,950
3.2 Pressure Washer	2	mo				$1,100.00	$0	$0	$0	$2,200	$2,200
3.3 Equipment Decon Pad	1	ls		$500.00	$450.00	$155.00	$0	$500	$450	$155	$1,105
3.4 Decon Water	2	kgal		$200.00			$0	$400	$0	$0	$400
3.5 Decon Water Storage Tank, 6,000 gallor	2	mo				$645.00	$0	$0	$0	$1,290	$1,290
3.6 Clean Water Storage Tank, 4,000 gallor	2	mo				$580.00	$0	$0	$0	$1,160	$1,160
3.7 Disposal of Decon Waste (liquid & solid	2	mo	$900.00				$1,800	$0	$0	$0	$1,800
4 AIR SPARGING SYSTEM											
4.1 Air Sparging Well Install, 1" PVC, 12 wells, 40' bgs	480	lf	$30.00				$14,400	$0	$0	$0	$14,400
4.2 Air Sparging Piping, 2" PVC, Buried	120	lf		$1.88	$3.96	$1.64	$0	$226	$475	$197	$898
4.3 Air Sparging Piping, 4" PVC, Buried	120	lf		$5.83	$5.17	$1.64	$0	$700	$620	$197	$1,517
4.4 Air Sparging Piping, steel	1	ls		$800.00	$400.00		$0	$800	$400	$0	$1,200
4.5 Moisture Removal Tank, 500 gal	1	ea		$2,200.00	$300.00		$0	$2,200	$300	$0	$2,500
4.6 Blower, 15 HP, 163 cfm, 150 psi	1	ea		$4,825.00	$1,147.00		$0	$4,825	$1,147	$0	$5,972
4.7 Electric Service	1	ea		$1,532.00	$1,750.00		$0	$1,532	$1,750	$0	$3,282
4.8 Plumb & Test System	1	ls		$500.00	$8,000.00		$0	$500	$8,000	$0	$8,500
4.9 Treatment System Building	1	ls		$16,000.00	$16,000.00		$0	$16,000	$16,000	$0	$32,000
5 MISCELLANEOUS											
5.1 Post Construction Documents	100	hr			$35.00		$0	$0	$3,500	$0	$3,500
5.2 Vegetate Disturbed Areas	1	ls		$300.00	$500.00	$200.00	$0	$300	$500	$200	$1,000
Subtotal							$20,700	$29,622	$73,675	$13,918	$137,914
Local Area Adjustments							100.0%	104.8%	85.6%	85.6%	
							$20,700	$31,044	$63,065	$11,913	$126,723
Overhead on Labor Cost @ 30%									$18,920		$18,920
G & A on Labor Cost @ 10%									$6,307		$6,307
G & A on Material Cost @ 10%								$3,104			$3,104
G & A on Equipment Cost @ 10%										$1,191	$1,191
G & A on Subcontract Cost @ 10%							$2,070				$2,070
Total Direct Cost							$22,770	$34,148	$88,292	$13,105	$158,315

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 5: In-situ Air Sparging, Institutional Controls and Monitorin
CAPITAL COST

Item	Quantity	Unit	Unit Cost				Extended Cost				Subtotal
			Subcontract	Material	Labor	Equipment	Subcontract	Material	Labor	Equipment	
Indirects on Total Direct Cost @ 35%											$55,410
Profit on Total Direct Cost @ 10%											$15,831
Subtotal											$229,557
Health & Safety Monitoring @ 3%											$6,887
Total Field Cost											$236,443
Contingency on Total Field Costs @ 20%											$47,289
Engineering on Total Field Cost @ 10%											$23,644
TOTAL COST											**$307,376**

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 5: In-situ Air Sparging, Institutional Controls and Monitoring
Operation and Maintenance Costs per Year

	Item	Qty	Unit	Unit Cost	Subtotal Cost	Notes
1	Energy - Electric	98,050	kWh	$0.07	$6,864	
2	Maintenance	1	ls	$1,488.42	$1,488	5% of Installation Cost
3	Labor, Per Diem, Supplies	52	day	$350.00	$18,200	1 visit per week - 1 day
4	Semi-Annual Reports	2	ea	$4,000.00	$8,000	
	Subtotal Cost for One Year Operation				$34,552	

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 5: In-situ Air Sparging, Institutional Controls and Monitorin
ANNUAL COST

Item	Item Cost Year 1	Item Cost Years 2 & 3	Item Cost Every 5 Years	Notes
Site Inspection & Report	$2,570	$2,570		One-day inspection with 2 people for LUC
Sampling	$16,080	$8,040		Labor, Field Supplies (local
Analysis	$17,136	$8,568		Analyze 9 water samples for VOCs, SVOCs, and arsenic. Quarterly year 1, semi-annually years 2 & 3
Sampling & Analysis Report	$20,000	$10,000		Document sampling events and results
Site Review			$15,000	Perform 5-year review
TOTALS	$55,786	$29,178	$15,000	

NASA WALLOP FLIGHT FACILITY
Wallops Island, Virginia
Waste Oil Dump
Alternative 5: In-situ Air Sparging, Institutional Controls and Monitoring
PRESENT WORTH ANALYSIS

Year	Capital Cost	Operation and Maintenance	Annual Cost	Annual Discount Rate at 3.5%	Present Worth
0	$307,376			1.000	$307,376
1		$34,552	$55,786	0.966	$87,266
2		$34,552	$29,178	0.934	$59,524
3			$29,178	0.902	$26,319
4			$0	0.871	$0
5			$15,000	0.842	$12,630
				TOTAL PRESENT WORTH	**$493,115**