FINAL
CLOSURE REPORT/DECISION DOCUMENT
102-52 ACID PIT
SWMU B24

HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

September 2009

Prepared for:

U.S. Army Environmental Command

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Contract No. W91ZLK-05-D-0011
Delivery Order No. 0002

CLOSURE DECISION DOCUMENT SWMU B24

September 2009

The selected remedy is protective of human health and the environment. It has been shown that a complete pathway to human health and the environment does not exist, and there is no potential for an exposure pathway to be completed in the future.

U.S. Army

28 September 2009
DATE

Kimberly L. Gilbert-Mason
Lieutenant Colonel, U.S. Army Commanding

State of Nevada

Oct 6, 2009
DATE

Jim Najima
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Executive Summary

This decision document presents the rationale for the closure of solid waste management unit (SWMU) B24, 102-52 acid impoundment, at the Hawthorne Army Depot (HWAD) located in Hawthorne, Nevada. A site evaluation was performed at SWMU B24 in accordance with NAC 445A.22705: *Contamination of soil: Evaluation of Site by Owner or Operator; Review of Evaluation by Division and as described in ASTM Standard E1739-95 – Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (ASTM 2002).*

Following ASTM E1739-95 guidance, the Nevada Division of Environmental Protection (NDEP) agreed to use the U.S. EPA Region IX Preliminary Remediation Goals (PRGs) for industrial soil as Tier 1 risk-based screening levels (RBSLs). For petroleum, the NDEP has established an action level of 100 milligrams per kilogram (mg/kg) total petroleum hydrocarbons for petroleum substances.

Site History

SWMU B24 is located southeast of Building 102-52 and has been identified as an inactive unlined surface impoundment measuring 30 by 100 by 5 feet deep, that has been eroded and partially filled with windblown sand (Figures 2-2 and 2-3). A soil berm consisting of material believed to have been dredged from the pit occupied the north and east sides of the pit. Three soil piles, also believed to have been dredged from the pit, occupied the southern edge of the pit.

Site Conditions

The impoundment reportedly received worn out battery electrolyte waste fluid, battery acid spills, and wash down water from the Battery Shop from circa 1950 to 1980. Acid and large quantities of water flowed into the pit from the Battery Shop, Building 102-52. Based on the historical use of the pit, semivolatile organic compounds (SVOCs), pesticides, PCBs, TPH, nitrate, picric acid, explosives, and pH were investigated. Volatile organic compounds (VOCs) were investigated in the subsurface. Groundwater is at approximately 100 feet below ground surface (bgs).

Investigations

The investigatory history of the Acid Pit (SWMU B24) began in 1987 with an investigation of solid waste management units by the United States Army Environmental Hygiene Agency (USAEHA). Both a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) (1994) and Facility Investigation (RFI) (1997) have been conducted at the site. At the direction of the NDEP, additional site characterization occurred in January 2008.

Investigation Results

Compounds detected in previous investigations included arsenic, lead, PCB Aroclor-1260, RDX, and TPH. Compounds above current RBSLs consist of lead, Aroclor-1260, RDX and TPH. Concentrations above the RBSLs were limited to the three soil piles on the southern edge of the pit, the southern end of the berm, and the pit bottom. Lead was detected in several of the surface and subsurface soil samples but only exceeded the RBSL of 800 mg/kg within the pit at 0-0.5 feet bgs. Aroclor-1260 was detected at several sample locations and depths. Two surface samples (0-0.5 feet), in the western portions of the pit bottom and the southern end of the berm,

exceeded the RBSL of 0.74 mg/kg. In addition, three soil pile samples on the southern edge of pit and three samples on the pit bottom exceed RBSLs. RDX was detected in two samples collected from the pit bottom at concentrations of 150 mg/kg and 55 mg/kg, respectively. Both samples were collected at a depth of 0.5-1.0 feet bgs and exceed the current RBSL of 16 mg/kg. Both TPH-D and TPH-G were detected at this site. However, only TPH-D exceeded the action level of 100 mg/kg. Locations of TPH-D exceedances included the pit bottom at the surface and subsurface (5 feet), the southern end of the berm, and three soil piles at the southern end of the pit. The maximum detection of TPH-D was 14,000 mg/kg was taken from the southern end of the berm. The vertical extent of contamination is 12.5 feet bgs.

Remediation

In 2008, an Interim Removal Action (IRA) was conducted, removing 244 tons (approximately 160 cubic yards) of soil from the site over the course of two excavation events. The soil piles and soil from the pit floor were removed and disposed of as non-hazardous waste.

Remediation Results

Confirmation soil samples collected at the conclusion of the IRA indicate that residual soil contains PCBs above the U.S. EPA Region IX Preliminary Remediation Goals (PRG) at the site. A site-specific cleanup goal for PCBs was developed. Concentrations in residual soils are below that cleanup goal, and the site has been backfilled.

Public Involvement

It is the policy of both the U.S. Department of Defense and the U.S. Army to involve the local community throughout the investigation process at an installation. To initiate this involvement, HWAD has established and maintains a repository library that contains final copies of all past studies and other documents regarding environmental issues at HWAD.

HWAD has solicited community participation in the establishment of a restoration and advisory board (RAB). Because there has been insufficient response, HWAD has not yet formed a RAB. It has, however, held open houses to inform the public of ongoing environmental issues. HWAD will continue to solicit community involvement and will establish a RAB when there is sufficient community interest.

Conclusions

The following conclusions regarding SWMU B24 are based on available information and an evaluation of the site:

- The exposure pathways identified are ingestion of soil, dermal contact with soil, and inhalation of soil dust or soil gas.
- The vertical and horizontal migration of site contaminants is limited to the impoundment and to within five feet of the impoundment. Groundwater has not been impacted.
- 244 tons (160 cubic yards) of impacted soil were removed between August 18 and October 10, 2008.

- Final soil cleanup goals for PCBs at SWMU B24, which are protective of human health and the environment, have been met.
- The SWMU B24 pit was backfilled on March 23, 2009.

SWMU B24 is recommended for closure based on the conclusions presented above.

TABLE OF CONTENTS

1.0 INTRODUCTION 1-1
1.1 Purpose and Scope 1-1
1.2 Overview 1-1
1.3 Regulatory Setting 1-1
1.4 Site Evaluation Process 1-1
1.4.1 Site Characterization 1-2
1.4.2 Tier 1 Evaluation 1-2
1.4.3 Tier 2 Evaluation 1-2
1.4.4 Conclusions and Recommendations 1-3
2.0 FACILITY AND SITE DESCRIPTION 2-1
2.1 General Facility Location 2-1
2.2 General Facility Description 2-1
2.3 Geology and Hydrology 2-2
2.3.1 Soils and Geology 2-2
2.3.2 Surface Waters 2-2
2.3.3 Groundwater 2-3
2.4 General SWMU Description 2-3
3.0 INVESTIGATIVE SITE HISTORY 3-1
3.1 Previous Investigations Summary 3-1
3.2 RCRA Facility Assessment Summary 3-1
3.2.1 Soil Assessment 3-1
3.2.2 Chemicals of Concern 3-2
3.3 RCRA Facility Investigation Summary 3-2
3.3.1 Surface Soil Samples 3-2
3.3.2 Berm Soil Samples 3-3
3.3.3 Soil Pile Samples 3-3
3.3.4 Subsurface Soil Samples 3-4
3.3.5 Field Screening Results 3-4
3.4 Additional Characterization 3-4
3.5 Previous Investigation Conclusions 3-5
4.0 SITE EVALUATION 4-1
4.1 Introduction 4-1
4.2 Tier 1 Evaluation Summary 4-1
4.3 Conceptual Site Model 4-1
4.4 Nature and Extent of Contamination 4-2
4.4.1 Total Petroleum Hydrocarbons 4-2
4.4.2 Polychlorinated Biphenyls 4-3
4.5 Ecological Risk Screening 4-3
4.6 Exposure Scenario Development 4-3
4.7 Development of Site-Specific Target Levels 4-4
4.7.1 Evaluation of SSTL 4-6
4.7.2 Selection of SSTL 4-7
5.0 CORRECTIVE ACTIONS 5-1
5.1 Interim Removal Action 5-1
5.2 Confirmation Sampling 5-1
6.0 CONCLUSIONS 6-1
7.0 REFERENCES 7-1

Figures

2-1 Hawthorne Army Depot Location Map
2-2 SWMU Location Map
2-3 SWMU B24 Acid Pit
3-1 RFA Sample Location SWMU B24
3-2 RFI Sample Location SWMU B24
3-3 Cross-Section Map SWMU B24 Acid Pit
3-4 Additional Characterization Sampling Locations
4-1 Conceptual Site Model
4-2 Sample Locations and Results from First Removal Action SWMU B24
4-3 Sample Locations and Results from Second Removal Action SWMU B24

Tables

3-1 Additional Characterization Analytical Results
4-1 Chemicals of Potential Concern for SWMU B24
4-2 SSTLs—Exposure Parameters
4-3 SSTLs—COPC-Specific Data
4-4 SSTLs—Calculation Results
5-1 Confirmation Sampling Results

Appendices

Appendix A Excerpt from Final RCRA Facility Investigation
Appendix B American Petroleum Institute (API) Bulletin No. 9
Appendix C Photo Documentation

ACRONYMS AND ABBREVIATIONS

ACA	Army Contracting Agency
ASTM	American Society for Testing & Materials
BGMP	Basewide Groundwater Monitoring Program
bgs	Below Ground Surface
COPC	Chemicals of Potential Concern
CPT	Cone Penetrometer
CSM	Conceptual Site Model
DOD	Department of Defense
DZB	Day and Zimmerman/Basil Corporation
DZHC	Day & Zimmerman Hawthorne Corporation
E&E	Ecology and Environment
ELISA	Enzyme-Linked Immunosorbant Assay
GO/CO	Government-Owned/Contractor-Operated
HMX	High Melting Explosive
HSWA	Hazardous Solid Waste Amendments
HWAAP	Hawthorne Army Ammunition Plant
HWAD	Hawthorne Army Depot
mg/kg	Milligrams per Kilograms
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
PCB	Polychlorinated Biphenyls
PRG	Preliminary Remediation Goals
RBSL	Risk-Based Screening Levels
RCRA	Resource Conservation and Recovery Act
RDX	Cyclotrimethylenetrinitramine
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
SSTL	Site Specific Target Levels
SVOC	Semi-Volatile Organic Compound
SWMU	Solid waste Management Unit
TPH	Total Petroleum Hydrocarbons
USAEHA	U.S. Army Environmental Hygiene Agency
USEPA	U.S. Environmental Protection Agency
VOC	Volatile Organic Compound

1.0 INTRODUCTION

1.1 Purpose and Scope

Plexus Scientific Corporation was awarded a performance-based delivery order (Delivery Order 0002) to implement environmental remediation services and the Basewide Groundwater Monitoring Program (BGMP) at the Hawthorne Army Depot (HWAD) in Hawthorne, Nevada. The delivery order was issued by the Army Contracting Agency (ACA) under contract W91ZLK-05-D-0011. This document provides an assessment of Solid Waste Management Unit B24, also known as the SWMU B24 Acid Pit, after the implementation of the interim removal action which was performed in accordance with *Final Interim Removal Plan, SWMU B24*, dated July 2008. This document also develops site specific target levels (SSTLs) for compounds where the removal goals of the interim removal were not achieved. Following the assessment of site conditions, closure of SWMU B24, is recommended.

1.2 Overview

Section 1.0 of this document provides an introduction, presents the purpose of the document, discusses the regulatory setting, and details the site evaluation process. Section 2.0 describes the physical setting at HWAD and of SWMU B24. Section 3.0 provides a summary of past investigations at SWMU B24. Section 4.0 provides an evaluation of the site following the interim removal action, develops SSTLs for compounds remaining above the goals set in the Final Interim Removal Plan (Plexus, 2008), and compares existing data to those SSTLs. Section 5.0 describes the interim removal action. Section 6.0 provides the conclusions of the report and the NDEP required a-k assessment. Section 7.0 provides a list of references used in this document.

1.3 Regulatory Setting

The U.S. Environmental Protection Agency (USEPA) provides regulatory oversight of contamination assessment and corrective measures at Resource Conservation and Recovery Act (RCRA) SWMUs, under Section 3004(u) of the 1984 Hazardous and Solid Waste Amendments (HSWA) to RCRA. Corrective action for releases of hazardous wastes or constituents is required under 40 CFR Part 264.101 (a), (b), and (c).

The HWAD also maintains RCRA Permit No. NEV HW0017, which was renewed in August 2005 and which requires corrective actions for any hazardous waste or hazardous constituents released from any SWMUs at the facility.

Authority and responsibility for the implementation of RCRA has been delegated by USEPA to the State of Nevada, designating the Nevada Division Environment Protection (NDEP) as the lead regulatory agency for all RCRA corrective actions at HWAD. Sections NAC 445A.226 through 445A.22755 (inclusive) of Nevada Administrative Code (NAC) are applicable to SWMU B24.

1.4 Site Evaluation Process

In accordance with NAC 445A.22705: *Contamination of soil: Evaluation of site by owner or operator; review of evaluation by Division, a* site evaluation was performed at SWMU B24.

NAC 445A.22705 stipulates that site evaluations be performed as described in American Society for Testing and Materials (ASTM) Standard E1739-95 – *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. Although ASTM E1739-95 was developed for petroleum sites, the principles and process are applicable to sites and chemicals other than those that are petroleum-based.

ASTM E1739-95 provides a stepped approach to evaluating risk at a site and in determining the need for a corrective action. Part of the ASTM process is reviewing existing investigation documents and determining whether the site has been adequately characterized. If additional investigation is deemed necessary, the additional investigation must be performed prior to recommending a final remedy for the site. However, if adequate data is available, a Tier 1, Tier 2 and Tier 3 evaluation may be performed. A Tier 3 evaluation is currently not envisioned and is therefore not addressed in this document.

1.4.1 Site Characterization

In determining whether the site has been adequately characterized, the following general questions were posed:

- Were the recommended actions provided in previous investigation completed?
- Are there an adequate number of samples to reflect the distribution of contaminants across the site?
- Has the horizontal limit of any impacted soils been delineated?
- Has the vertical limit of impacted soils been delineated?
- Has groundwater been impacted?
- Have the boundaries of the impacted groundwater been delineated?

Existing investigation reports were considered acceptable if issued as final documents.

1.4.2 Tier 1 Evaluation

This evaluation consists of comparing existing site analytical data to risk-based screening levels (RBSLs). The RBSLs are risk-based values derived from non-site-specific assumptions for direct and indirect exposure pathways. They use conservative exposure factors and conservative fate and transport assumptions for potential pathways and property uses (residential, industrial, etc.). The RBSLs do not represent site-specific conditions.

The RBSLs that are used in the Tier 1 evaluation for SWMU B24 consist of the USEPA Region IX preliminary remediation goals (PRGs) and NDEP's action level of 100 mg/kg for petroleum substances. Site constituents that exceed the RBSLs in the Tier 1 Evaluation were considered chemicals of potential concern (COPC) and, if performed, were included in a Tier 2 evaluation.

1.4.3 Tier 2 Evaluation

The Tier 2 evaluation develops SSTLs that are risk-based remedial action target levels for chemicals of concern. In the Tier 2 evaluation, the non-site-specific assumptions used for the RBSLs are replaced with site-specific factors. The values calculated from inputting site-specific

factors are the SSTLs. The maximum concentrations of COPCs are then compared to the SSTL to determine the recommendation for closure.

1.4.4 Conclusions and Recommendations

Conclusions are based on the results of the Tier 1 and Tier 2 evaluations.

2.0 FACILITY AND SITE DESCRIPTION

2.1 General Facility Location

HWAD is located in Mineral County, Nevada, approximately 140 miles southeast of Reno, Nevada (Figure 2-1). The depot covers an area of approximately 150,000 acres and encloses three sides of the town of Hawthorne.

2.2 General Facility Description

HWAD's current mission is to receive issue, store, renovate, inspect, demilitarize, and dispose of conventional ammunition. The depot is a government-owned/contractor-operated (GO/CO) facility that is presently operated by Day & Zimmermann Hawthorne Corporation (DZHC) (U.S. Army 2001).

The installation was originally constructed in 1928 as a U.S. Naval Ammunition Depot. Its original mission was to store, service, and issue ammunition to the Pacific Area. Following World War II, the depot was actively involved in the demolition of various types of allied and enemy ammunition. Its role was also expanded to include receiving, renovating, loading, maintaining, storing, and issuing ammunition, explosives, expendable ordnance items, and/or weapons and technical ordnance materials. It was also used to test weapons and dispose of unserviceable and/or dangerous ammunition and explosives. In 1977, the depot was transferred to the U.S. Army and renamed Hawthorne Army Ammunition Plant (HWAAP).

After the transfer, HWAAP was re-designated as a GO/CO Plant in 1980 and operated under the direction of the former Day and Zimmermann/Basil Corporation (DZB). Its mission from 1980-1994 was to:

- Receive, produce, assemble, load, issue, store, renovate, inspect, test demilitarize, and dispose of conventional ammunition
- Operate and/or maintain in operational readiness cast and fuel-air explosive loading plants, rocket assemble plants, and medium/major caliber assembly lines
- Provide special/experimental high-explosive casting, extruding, and pressing, and fuel air explosive loading and support services to designated research and development activities
- Provide storage facilities for war reserve ammunition, and maintain designated ammunition in a state of readiness for mobilization, including assembling or otherwise providing base unit materials
- Conduct testing of solid propelled munitions, high explosive warheads, mechanical and electronic fuses, cartridge cases, primers, rocket motors, and other ballistic devices (U.S. Army 2001)

In 1994, HWAAP was renamed the HWAD and was designated as a Tier II, or caretaker, ammunition facility that was used to store war reserve ammunition to be used after the first 30 days (NDEP 2006, U.S. Army 2001). HWAD has continued to fulfill its revised mission (shipping, storage and recycling of munitions) and operating under the direction of DZHC.

HWAD is not on the National Priority List. Studies and investigations have been conducted in coordination with the NDEP. Releases of various hazardous constituents have been located and classified as cleanup sites to be addressed pursuant to applicable cleanup authorities. Remediation efforts have been ongoing with the Army Installation Restoration Program since 1974, initially pursuant to the Comprehensive Environmental Response, Compensation and Liability Act. Following issuance of the RCRA Hazardous Waste Storage and Treatment Permit (Permit Number NEV HW0017, Revision 1, August 2005) for HWAD, remediation of all delivery order sites is being conducted pursuant to the Part VI, Corrective Division of Environmental Action, of the permit, with regulatory coordination, as appropriate, from the NDEP. Groundwater monitoring is required as a part of corrective action activities at the facility.

2.3 Geology and Hydrology

HWAD is located in west-central Nevada within the Whiskey Flat-Hawthorne sub area of Walker Lake Valley in the Great Basin section of the Basin and Range physiographic province. Geographically, HWAD is bounded on three sides by mountains: the Wassuk Mountain Range on the west, the Gillis Range on the east, and the Excelsior Mountains on the south. Walker Lake bounds the depot on the north (E & E 1997).

2.3.1 Soils and Geology

The valley floor, alluvial fans and aprons, and the weathered parent material in the higher elevations are composed of Quaternary and Tertiary unconsolidated sedimentary deposits. The surficial deposits on the installation can be divided into four broad depositional and soil types based on topographic position. The first soil type occupies the mountains/hills, canyons, mountain slopes, and foothills. These deposits are characterized by silty sand, gravel, sand-silt mixtures, silt, and sand and gravel in a clay matrix. Cobbles and boulders are not uncommon. Depth of the overburden is very shallow and interrupted by rock outcrops. The second type consists of deposits forming the alluvial fans and aprons. These are silty sands and gravelly silt-sand mixtures. Fluvial processes have also transported detritus to the lower elevations. The thicknesses of these units are reported to be at least 850 feet in the installation area. Lacustrine deposits, which are predominantly clays deposited from the Pleistocene-Age Lake Lahontan, comprise the final deposit (E & E 1997).

2.3.2 Surface Waters

The installation occupies the Walker Lake drainage basin. The Wassuk Mountains on the western boundary of the installation are the primary watershed for the installation, with the majority of surface drainage originating there. The installation captures surface water in a series of basins located on major creeks above HWAD for use as drinking water. There are no perennial surface streams on the valley floor. Surface overflow occurs only after a major rainfall or snow melt. After the drainage paths reach the valley floor, the gradient decreases abruptly and the stream becomes influent. Therefore, surface flow rarely reaches Walker Lake, the only lake on the installation (E & E, 1997).

2.3.3 Groundwater

Depths to the water table increase with distance from Walker Lake and toward the apexes of the alluvial fans. The shallow groundwater regime flows northwest toward Walker Lake at an approximate seepage rate of one foot per year (U.S. Army Environmental Hygiene Agency [USAEHA] 1988). Recharge occurs along the mountain front near the apex of the alluvial fans.

Groundwater is present in several productive zones located at various depths at HWAD. The plant's drinking water is currently obtained from surface catch basins and reservoirs in the Wassuk Mountains and several groundwater wells upgradient and cross-gradient from the SWMU. The town of Hawthorne currently obtains drinking water from groundwater wells in the Whiskey Flats area 12 miles south of town. However, the town formerly used local municipal wells that have not been abandoned. On-site production wells are maintained in a state of readiness to provide water to the firefighting system or to produce water for non-potable use at the plant (USAEHA 1988). During periods of high water demand, the HWAD production well #1 is used to provide water to blend with water from reservoirs for use as potable water. HWAD production well #3 is non-operational but can be used to produce water for potable uses.

The depth to groundwater in the vicinity of SWMU B24 has been estimated at 100 bgs, although no monitoring wells have been installed in the vicinity of the site to specifically investigate SWMU B24.

2.4 General SWMU Description

SWMU B24 was an inactive, unlined surface impoundment located southeast of Building 102-52 (Figures 2-2 and 2-3). The impoundment measured 30 by 100 by 5 feet deep, but was eroded and partially filled with windblown sand. A soil berm consisting of material believed to have been dredged from the pit occupied the north and east sides of the pit. Three soil piles, also believed to have been dredged from the pit, occupied the southern edge of the pit.

The impoundment reportedly was in operation from circa 1950 to 1980 and was used for worn out battery electrolyte waste fluid, battery acid spills, and wash-down water from the Battery Shop. Acid and large quantities of water flowed into the pit from the Battery Shop, Building 102-52. Effluent reportedly flowed into the impoundment from two pipes on the northeast side. These effluent pipes were not located during E & E's 1994 RCRA Facility Assessment (RFA) investigation of the SWMU. SWMU B24 has never been permitted and has not gone through a formal RCRA closure.

3.0 INVESTIGATIVE SITE HISTORY

3.1 Previous Investigations Summary

The investigatory history of the Acid Pit (SWMU B24) began in 1987. The following is a synopsis of significant dates and events associated with previous investigations at SWMU B24. Excerpts from the previous investigations are provided in Appendix A.

- In 1987 and 1988, USAEHA conducted a groundwater contamination survey and evaluation of SWMUs at HWAD. The survey team identified 82 SWMUs on the installation, including SWMU B24.
- Between April and June 1994, E & E conducted an RFA at 33 of the Group A site SWMUs. The objective was to characterize the soils within and beneath each impoundment to determine whether a release of contaminants to the underlying soils had occurred. At SWMU B24, RFA investigation activities included the collection and analysis of surface and subsurface soil samples. A Final RFA Report was prepared in 1995.
- A RCRA Facility Investigation (RFI) was performed in 1996 based on results of the RFA, which recommended that additional surface and subsurface soil sampling be conducted to determine the extent of soil contamination. A Final RFI Report was prepared in 1997. Because soil remediation criteria were exceeded, the RFI recommended that corrective action measures at the site be evaluated.
- An additional site characterization was performed on January 14, 2008 at the direction of the NDEP to confirm the extent of total petroleum hydrocarbons (TPH) and polychlorinated biphenyls (PCB) impacted soil in the soil berm. A letter report, detailing the results, was issued on February 19, 2008.

3.2 RCRA Facility Assessment Summary

3.2.1 Soil Assessment

The 1994 RFA investigation at SWMU B24 included collection and analysis of surface and subsurface soil samples. Table 3-11 of the RFI (RFI excerpts are provided in Appendix A) summarizes the samples collected. All soil samples were analyzed for semivolatile organics compounds (SVOCs), pesticides, polychlorinated biphenyls (PCBs), total petroleum hydrocarbons (TPH), nitrate, picric acid, metals, explosives (nitroaromatics), and pH. Subsurface soil samples were also analyzed for volatile organic compounds (VOCs) (E & E, 1997).

Two surface soil samples and two hand auger samples (5 feet bgs) were collected from the bottom of the impoundment. These surface and near-surface samples were collected from the lowest elevation in the impoundment where liquids tended to accumulate. The subsurface investigation of SWMU B24 was performed adjacent to the impoundment and on its downgradient side closest to the reported location of the effluent discharge pipes. Two subsurface soil samples (11 and 22 feet bgs) were collected from a cone penetrometer (CPT) boring installed on the northwest side of the impoundment. To characterize the potential for contaminated surface soils outside of the impoundment, two surface soil samples were collected

from areas adjacent to the impoundment (E & E, 1997) (Figure 3-1).

3.2.2 Chemicals of Concern

Table 3-12 of the RFI (Appendix A) presents a summary of the compounds detected during the RFA. Five metals (arsenic, barium, cadmium, chromium, and lead) were detected in all of the surface soil samples collected from within and on the perimeter of the impoundment. With the exception of cadmium, these same metals were also found at low levels in the subsurface soil samples. Silver was detected in two further surface samples and mercury and selenium were detected in two surface samples. Of all the metals, only lead concentrations exceeded the soil remediation criteria (100 milligrams per kilogram (mg/kg)).

Royal demolition explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine) (RDX) was detected in two surface soil samples at concentrations of 55 mg/kg and 150 mg/kg from within the impoundment. Only one of the samples exceeded the soil remediation criteria of 63.6 mg/kg. All other detected nitroaromatics were present at concentrations below the soil remediation criteria. Nitroaromatics were not detected in subsurface soil samples above this criteria.

Organic compounds detected in the impoundment included TPH as gasoline and diesel, phenanthrene, pyrene, di-n-butyl-phthalate, and bis (2-ethylhexyl) phthalate. TPH as diesel exceeded the soil remediation criteria of 100 mg/kg in all of the surface and near-surface soil samples, with concentrations ranging from 1,300 mg/kg to 34,000 mg/kg.

PCB compound Aroclor-1260 (Aroclor-1260) was detected in three samples collected at the SWMU. The concentrations detected in two of the samples (1.6 mg/kg and 36 mg/kg) exceed the soil remediation criteria of 0.09 mg/kg. Both samples were collected at the surface.

3.3 RCRA Facility Investigation Summary

Based on results of the RFA, it was recommended that additional surface and subsurface soil sampling be conducted at SWMU B24 to determine the extent of soil contamination associated with the impoundment. The results of the May 1997 RFI are presented below (E & E 1997). Tables 3-11 and 3-14 of the RFI (Appendix A) summarize the samples collected and the analytical results for RFI sampling, respectively. Figure 3-2 illustrates the sample locations.

3.3.1 Surface Soil Samples

A total of five surface soil samples were collected during the RFI. As shown on Figure 3-2, three samples were collected from the bottom of the pit and two were collected from the bermed area along the northern edge of the pit.

TPH-diesel was detected in the three samples collected from the bottom of the impoundment at concentrations ranging from 18 to 98 mg/kg, which is less than the soil remediation criteria of 100 mg/kg. In addition, one of these samples contained TPH-gasoline at 33 mg/kg.

Lead was detected in all five surface soil samples at concentrations ranging from 5.7 to 1,700 mg/kg. The lead concentration in three of the samples exceeded the soil remediation criteria of 100 mg/kg. These three soil samples were collected from the bottom of the impoundment.

The only nitroaromatic detected in the surface soil samples was High Melting Explosive (cyclotetramethylene-tetranitramine) (HMX), which was detected in one sample at 7.5 mg/kg,

which is less than the soil remediation criteria of 4,000 mg/kg. This sample was collected from the west end of the impoundment bottom. Aroclor-1260 was detected in four of the surface soil samples at concentrations ranging from 0.014 to 2.8 mg/kg. Three of the samples, which were above the soil remediation criteria of 0.09 mg/kg, were collected from the bottom of the impoundment.

Bis(2-ethylhexy1) phthalate and di-n-butyl-phthalate were detected in all five of the surface soil samples at concentrations ranging from 0.034 to 96 mg/kg and 0.4 to 32 mg/kg, respectively. The three surface soil samples collected from the bottom of the impoundment contained bis(2-ethylhexy1) phthalate concentrations that exceeded the soil remediation criteria of 50 mg/kg. None of the remaining detections were above respective soil remediation criteria and no other SVOCs were detected in any of the surface soil samples.

3.3.2 Berm Soil Samples

Six soil samples were collected from the center line of the soil berm bordering the impoundment on the north and east side. TPH-diesel was detected in one sample collected from the west end of the berm on the north side of the impoundment, at 50 mg/kg which is less than the soil remediation criteria of 100 mg/kg. TPH-gasoline was not detected in any of the berm samples. Lead was detected in all of the berm soil samples at concentrations ranging from 3.7 to 63 mg/kg, all of which are less than the soil remediation criteria of 100 mg/kg.

Aroclor-1260 was detected at 0.01 mg/kg, 0.093 mg/kg, and 0.29 mg/kg in samples collected from the west end and southeast corner of the berm on the north side of the impoundment, respectively. Two of these Aroclor-1260 concentrations exceed the soil remediation criteria of 0.09 mg/kg.

Benzo(a)pyrene and chrysene were the only two SVOCs detected in the berm soil samples. These compounds were detected at concentrations of 0.057 mg/kg and 0.041 mg/kg in samples collected from the west end of the berm on the north side of the impoundment. These concentrations do not exceed their respective soil remediation criterion of 0.096 mg/kg and 95.9 mg/kg. No other SVOCs were detected in any of the berm soil samples.

3.3.3 Soil Pile Samples

Three soil samples were collected from the center of the soil piles along the southern edge of the impoundment. TPH-diesel was detected in all of the soil pile samples at concentrations ranging from 310 to 4,700 mg/kg which exceed the soil remediation criteria of 100 mg/kg. TPH-gasoline was detected in one soil pile samples at a concentration of 6.7 mg/kg, which does not exceed the soil remediation criteria of 100 mg/kg.

Lead was detected in all of the soil pile samples at concentrations ranging from 49 to 170 mg/kg. The eastern-most soil pile sample contained 170 mg/kg lead, which exceeds the soil remediation criteria of 100 mg/kg. All other detected lead concentrations were less than the soil remediation criteria.

Arolcor-1260 was detected in all of the soil pile samples at concentrations ranging from 1.8 to 13 mg/kg, with the highest concentration detected in the eastern-most sample. All of these detected concentrations exceed the soil remediation criteria of 0.09 mg/kg. Chrysene and pyrene were detected in two of the soil pile samples at concentrations less than the soil remediation criteria.

3.3.4 Subsurface Soil Samples

Thirty subsurface soil samples were collected from five soil borings installed to a total depth of 60 feet bgs. As shown on Figure 3-3, two borings were drilled through the bottom of the impoundment and three borings were drilled outside of the impoundment along the southern edge. Soil samples were collected for laboratory analysis from 5-, 10-, 20-, 30-, 40-, and 60-foot depths in each boring.

TPH-diesel was detected at concentrations exceeding the soil remediation criteria (100 mg/kg) in two of the subsurface soil samples (5 and 10 feet bgs) from the borings at the bottom of the impoundment at concentrations of 130 mg/kg and 130.1 mg/kg. TPH-diesel was also detected in samples collected at 30 feet bgs but only at a concentration of 5.6 mg/kg. TPH-gasoline was not detected in any of the subsurface soil samples.

Lead was analyzed for and detected in ten of the subsurface soil samples. The lead concentrations ranged from 1.4 to 10 mg/kg, which is below the soil remediation criteria of 100 mg/kg and within the natural background range established in the Final Technical Memorandum Background Soil Sampling, Hawthorne Army Depot, Hawthorne, Nevada (Tetra Tech, 1997).

Aroclor-1260 was analyzed for in ten of the subsurface soil samples and detected in only one sample, collected from boring SB1-4 at five feet bgs, at 0.021 mg/kg which is below the soil remediation criteria of 0.09 mg/kg. No nitroaromatic compounds were detected in any of the subsurface soil samples.

Bis(2-ethylhexy1)phthalate was detected in four subsurface soil samples at concentrations ranging from 0.037 to 0.130 mg/kg. Di-n-butyl-phthalate was detected in two subsurface soil samples at concentrations ranging from 0.550 to 0.580 mg/kg. These concentrations were well below their soil remediation criteria of 50 mg/kg and 8,000 mg/kg, respectively.

3.3.5 Field Screening Results

Fourteen surface and near-surface soil samples were field screened for TNT and RDX. A total of 30 subsurface soil samples, collected from depths of 5-, l0-, 20-, 30-, 40-, and 60-feet bgs, were also screened for TNT and RDX.

The soil samples were screened for TNT and RDX using Enzyme-Linked Immunosorbant Assay (ELISA) test kits to determine a general range of concentrations for safe handling and shipment. Field screening results are provided in Table 3-13 of the RFI (Appendix A). TNT was detected in two of the field screened soil samples at ranges 1.5 to 3.0 ppm and 0.5 to 1.5 ppm. RDX was detected in seven of the field screened soil samples at ranges of 1.5 to 2.5 ppm and 2.5 to 4.5 ppm.

3.4 Additional Characterization

At the direction of the NDEP, two soil samples and a duplicate were collect on January 14, 2008 from the southern termination of the soil berm to confirm the extent of impacted soil in that portion of the berm. Additional characterization sampling locations are illustrated in Figure 3-4 The samples were analyzed for PCBs, TPH-diesel, TPH-gasoline, and metals. Arsenic, barium, chromium (total), lead, and Aroclor-1260 were all detected above the detection limit. The analytical results are provided in Table 3-1. Evaluation of the analytical results concluded that

the southern portion of the berm did not require removal.

Table 3-1 – Additional Characterization Analytical Results

Analyte	Unit	B24-011408-S-001	B24-011408-S-002	B24-011408-S-002-Z	PRG
Arsenic	mg/kg	**5.5**	**5.3**	**4.9**	1.6
Barium	mg/kg	51	74	68	67,000
Cadmium	mg/kg	0.046 J	ND	ND	450
Chromium	mg/kg	4.4	5.5	5.5	450
Lead	mg/kg	15	22	8.7J	800
Selenium	mg/kg	0.92J	ND	ND	5,100
Mercury	mg/kg	ND	ND	0.018J	310
Aroclor 1260	mg/kg	ND	0.051	0.054	0.74

Bold, underlined, and shaded results exceed the Region IX PRG
J – Estimated
ND – Not detected above the detection limit
Sample B24-011408-S-002-Z is a duplicate of B24-011408-S-002

3.5 Previous Investigation Conclusions

The RFA concluded that low pH levels and lead in soil support the reported historic use of the site, but went on to indicate that the presence of VOCs, SVOCs, PCBs, and nitroaromatics indicated other releases. The RFA also concluded that the vertical and horizontal extent of contamination was limited but recommended further investigation.

The RFI satisfied the recommendations of the RFA and concluded that vertical and horizontal migration of site contaminants was limited to the impoundment and to within five feet of the impoundment. Laboratory results for surface and subsurface sample indicated that lead, TPH-diesel, RDX, and PCBs exceeded the soil remediation criteria in place at the time. The volume of impacted material was estimated at 800 cubic yards. The recommendation was made to develop an engineering cost analysis to be used to evaluate the appropriate corrective measure. An engineering cost analysis developed in 2005, for the excavation and disposal of 1,000 cubic yards of impacted material from SWMU B24 indicated that such a removal action would cost $919,000 (US Army 2005).

The additional characterization performed in February 2008 concluded that excavation and disposal of the soil berm was not necessary. However, due to the presence of elevated lead and PCBs in the pit and soil piles, an interim removal action was deemed necessary.

4.0 SITE EVALUATION

4.1 Introduction

Consistent with the requirements of NAC 445A.22705, an evaluation of SWMU B24 was performed using the risk-based corrective action approach outlined in ASTM Standard E1739-95 – *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*. This section provides a summary of the site evaluation and details the development and selection of site-specific cleanup goals.

4.2 Tier 1 Evaluation Summary

To establish the COPCs, the results of the excavation confirmation sampling were merged with the data from the RI. Data points from the RI that were collected from areas that were removed during the interim removal action were not considered. The resulting dataset was compared to the U.S. EPA Region IX PRGs for industrial soils or the NDEP action level for petroleum as applicable. Compounds that exceeded their respective PRGs are considered COPCs for this site. Table 4-1 lists the compounds identified from the pre-remediation soils analyses as COPCs, and their respective EPA Region IX PRG. All other site constituents were found to be below their respective PRG.

Table 4-1. Chemicals of Potential Concern for SWMU B24

COPC	Max. Detection (mg/kg)	PRG (mg/kg)/AL[1]
TPH-D (diesel)	780	100
TPH-G (gasoline)	440	100
Aroclor-1260	1.7	0.74
Aroclor-1254	1.2	0.74

[1] The action level for TPH is defined in NAC 445A.2272. For PCB, the EPA Region IX PRG for "PCBs (unspecified mixture, high risk, e.g. Aroclor-1254)" was used.

4.3 Conceptual Site Model

The process of the Tier 1 evaluation included the development of a conceptual site model (CSM) that depicts both complete and incomplete pathways of exposure. The CSM is presented in Figure 4-1. For a pathway to be complete, a potential human receptor must be present that can come in contact with the contaminant.

The pathways that are identified in the CSM as being complete for these receptors are ingestion of soil, dermal contact with soil, and inhalation of soil dust. The groundwater pathway was determined to be incomplete because drinking water for the installation is obtained primarily from surface water originating in the surrounding mountains west of HWAD. On occasion, the surface waters contained in reservoirs are supplemented with groundwater; however, the wells used for this purpose are located upgradient or cross-gradient to the site. Water supply well #7 is located approximately 0.6 miles downgradient of SWMU B24. Well #7 is not a potable water source due to naturally high levels of fluoride and nitrate that exceed drinking water standards. Additionally, the annual precipitation rate for the HWAD area (approximately 4.5 inches) is exceeded by the evapotranspiration rate.

The nearest surface water body to the site is Walker Lake, located approximately 4.8 miles down gradient from SWMU B24. Due to the distance from SWMU B24 and the generally flat surface topography gradient, surface water is not considered an exposure pathway. The current and foreseeable future use of SWMU B24 is in an industrial capacity.

4.4 Nature and Extent of Contamination

Chemicals of potential concern (COPCs) that remained above RBSLs after the interim removal actions were limited to TPH-D (diesel range) and PCB Aroclors-1260 and -1254. Confirmation sampling locations and results from the first and second excavation events are illustrated in Figure 4-2 and Figure 4-3, respectively. Impacted soil was limited to the shallow soils in the footprint of the pit, and at the location of the former soil piles. Analytical data collected during the RFI from soil borings advanced through the pit bottom to a depth of 60 feet did not indicate any COPCs present at depth. The deepest detection of a COPC above the RBSL was TPH-D at a concentration of 130 mg/kg (2-B24-SB1-2-010), 10-12.5 feet below ground surface. Analytical data from soil borings advanced outside the pit did not indicate any impact to soil.

Confirmation sampling following the second interim removal action indicated that Aroclor-1260 was present in surface soil samples at concentrations ranging up to 1.7 mg/kg (B24-091508-S-PF10) with four samples exceeding the Industrial PRG for an unspecific mixture of high risk Aroclors (e.g., Aroclor-1254) of 0.74 mg/kg. Three of the four sample locations were taken from the pit floor. The fourth sample was taken in the location of the former middle soil pile. Of the four Aroclor-1260 samples that exceeded the PRG two also exceeded the Aroclor-1254 PRG.

Confirmation sampling following the second interim removal action indicated that TPH-D exceeded the NDEP action level of 100 mg/kg at three surface soil sample location in the pit floor. TPH-D exceedances ranged from 290 J mg/kg (B24-100707-S-PF08) to 780 J mg/kg (B24-091508-S-PF10). TPH-D was also detected during the RFI at a concentration of 130 J mg/kg (2-B24-SB1-2-010) from a sample collected from 10-12.5 feet below the original bottom of the pit (Figure 3-3), which represents the deepest extent of TPH contamination at the site.

Although not specifically investigated during any of the previous investigations, groundwater is not believed to have been impacted. The nature of the contaminants and the diminishing concentrations of compounds with depth indicate that there would be minimal or no impact to groundwater.

4.4.1 Total Petroleum Hydrocarbons

During a July 2, 2007 teleconference, NDEP provided an overview of the TPH action level framework acceptable to the state. For surface soils, direct exposure, and protection of groundwater, the state accepts a risk-based approach. For subsurface soils, the saturation value for given soil type and petroleum distillate was used as a Tier 2 site-specific target level.

For surface soils where direct exposure is a concern, none of the sample locations exceeded the action level for TPH. Therefore, only a comparison to saturation values was necessary.

For subsurface soils where direct contact is not the primary pathway, cleanup levels (Tier 2 SSTLs) will be fuel saturation values based on soil and fuel type. The application of fuel saturation values was broken down into three zones:

- Zone 1—This zone was defined as areas that can reasonably be excavated if TPH levels exceed fuel saturation values with significant mass present.
- Zone 2—Areas below Zone 1 and above 10 feet of groundwater. Exceedances of the fuel saturation values with significant mass present in Zone 2 may require additional groundwater monitoring for the presence of product.
- Zone 3—Areas within 10 feet of groundwater. If fuel saturation values are exceeded, additional actions need to be assessed.

The fuel saturation values used are those established by the American Petroleum Institute (API) Soil & Groundwater Research Bulletin No. 9 (June, 2000), entitled "Non-Aqueous Phase Liquid (NAPL) Mobility Limits in Soil" (Appendix B). Table 2 of the API Bulletin provides the points at which soils begin to release free product (known as the fuel saturation value). Fuel saturation varies with fuel and soil type.

In the case of SWMU B24, both gasoline range TPH and diesel range TPH were detected in the subsurface. The middle distillate best represents the diesel range TPH that was detected. The most conservative saturation value is for a gravel material. That RBSL is 1,000 for gasoline range TPH and 2,286mg/kg for diesel range TPH. Both are well above the respective highest detection of TPH.

4.4.2 Polychlorinated Biphenyls

Concentrations of Aroclor-1260 and -1254 in soils within the pit remain above the Tier 1 RBSL of 0.74mg/kg. Since the Tier 1 values were exceeded, site-specific clean up goals were calculated for the current and foreseeable future Industrial use of the facility.

4.5 Ecological Risk Screening

A screening ecological risk assessment was considered for SWMU B24. The SWMU was evaluated with the information available to determine the extent to which the SWMU was sufficiently large and had habitat suitable to support ecologically significant floral and faunal populations. The existing information was used as basis for the inclusion or exclusion of a screening ecological assessment.

SWMU B24 was excluded from a screening level ecological risk assessment for the following reasons:

- Small size of site (relative to adjacent landscape) limits ecological significance
- Site soils are highly disturbed
- Site is located near an area of human activity
- No indication of the presence of threatened and endangered floral or faunal species
- No indication that the site contains or is part of regionally critical habitat

4.6 Exposure Scenario Development

Three different exposure scenarios were developed for SWMU B24: current and future Standard Workers, On-Site Workers, and potential future Construction Workers. As HWAD is a secure industrial military installation, other receptors, including residential inhabitants and trespassers,

were not considered as potential receptors.

The On-Site Worker and Standard Worker scenarios assume potential exposure to surface soils and shallow subsurface soils to a depth of 2 feet below ground surface. The potential future Construction Worker scenario assumes potential exposure to soils to a depth of 10 feet, a typical depth for general construction.

On-Site Worker

The On-Site Worker represents the current and future worker working specifically at SWMU B24 under its current specific use. The SWMU itself is currently unused for any purpose and has no intended future use, as indicated by HWAD personnel. There are no buildings associated with the SWMU. The nearest occupied building to the SWMU is Building 102-52, the battery repair shop, which lies approximately 110 feet to the north. The building is separated from the SMWU by Building 102-53, the tire shed where old tires and used empty drums are stored. Approximately 30 workers occupy Building 102-52 year-round, performing diesel engine repairs and tire changes.

Although the SWMU was identified by HWAD as having no significant activity, a more conservative approach was taken when considering exposure factors. For example, there is no current reason for site workers to visit the SWMU. However, the assumption used for developing the exposure factors for the On-Site Worker was that site workers would visit the site one full day each week.

Construction Worker

The Construction Worker represents the potential future construction worker who may become exposed to site soils while demolishing or constructing structures at the site. This is more conservative than a construction worker performing activities such as installing or repairing utilities, which would be a more likely scenario.

Standard Worker

The Standard Worker scenario assumes that an individual works outside and contacts site soils on a regular basis as part of his or her normal job. A groundskeeper would be an example of this category. This scenario applies the same exposure parameters as the worker scenario used to develop the EPA Region IX PRGs but modified to specific to the HWAD.

4.7 Development of Site-Specific Target Levels

After exposure factors were developed for each exposure scenario previously described, COPC-specific SSTLs were calculated. For each COPC that is a known or suspected carcinogen, a range of acceptable SSTLs was calculated. The exposure parameters used to estimate COPC intakes included exposure frequency, exposure duration, body weight, averaging time, soil ingestion rate, fraction ingested, exposed skin surface area, soil-to-skin adherence factor, dermal absorption factor, exposure time, inhalation rate and particulate emission factor (Table 4-2).

A range of similarly protective SSTLs for each exposure scenario was then calculated for the COPCs applying the site-specific exposure parameters previously identified. The cancer slope factor and reference dose results for the identified COPCs are listed in Table 4-3. The

subsequent cancer and non-cancer SSTL ranges are listed in Table 4-4. With the use of conservative exposure parameters, all provided ranges are protective of human health and the environment.

Table 4-2. SSTLs—Exposure Parameters

	Exposure Parameters		
	Standard Worker	**On-Site Worker**	**Construction Worker**
Target Cancer Risk (unitless)	1E-04	1E-04	1E-04
	1E-05	1E-05	1E-05
	1E-06	1E-06	1E-06
Target Hazard Quotient (unitless)	1.0	1.0	1.0
Averaging Time – cancer (days)	25,550	25,550	25,550
Averaging Time – non-cancer (days)	9,125	9,125	365
Incidental Soil Ingestion Rate (mg/day)	100	100	330
Exposure Frequency (days/year)	250	50	130
Exposure Duration (year)	25	25	1
Fraction Ingested (unitless)	1	0.25	1
Exposed Skin Surface Area (cm^2)	3,300	3,300	3,300
Soil-to-Skin Adherence Factor (mg/cm^2)	0.2	0.2	0.3
Dermal Absorption Factor (unitless)	see below		
Air Inhalation Rate (m^3/hour)	2.5	1.5	2.5
Particulate Emission Factor (m^3/kg)	3.81E+10	3.81E+10	3.81E+10
Exposure Time (hour/day)	8	2	8
Body Weight (kg)	70	70	70
Units Conversion Factor (mg/kg)	1,000,000	1,000,000	1,000,000

Table 4-3. SSTLs—COPC-Specific Data

	COPC-Specific Data						
COPC	**Dermal Absorption Factor (unitless)**	**Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$**			**Reference Dose (mg/kg-day)**		
		Oral	**Dermal**	**Inhalation**	**Oral**	**Dermal**	**Inhalation**
PCB	0.14	2	2	2	0.00002	0.00002	0.00002

Table 4-4. SSTLs—Calculation Results

COPC	Calculated SSTLs (mg/kg)			
	Standard Worker			
	Cancer			Non-cancer
	1E-04	1E-05	1E-06	
PCB	74.4	7.4	0.74	11
	On-Site Worker			
	Cancer			Non-cancer
	1E-04	1E-05	1E-06	
PCB	609	61	6.1	87
	Construction Worker			
	Cancer			Non-cancer
	1E-04	1E-05	1E-06	
PCB	1,468	147	15	8.4

4.7.1 Evaluation of SSTL

When evaluating the range of cleanup goals presented in Table 4-4, a single value for each COPC was selected to be used as the final SSTLs against which data would be compared to support site closure. The final selection was based on a comparison of the SSTL for an appropriate target cancer risk factor and the non-cancer SSTL. The lower, more conservative value of the two was selected as the final SSTL for use to support site closure.

Standard Worker

Use of the Standard Worker scenario would permit continued unrestricted future industrial use of the site without the need for institutional controls. Given the remote location and limited potential population exposure, selection of the Standard Worker scenario at an increased cancer target risk factor of $1x10^{-4}$ would be an appropriate selection.

On-Site Worker

Use of the On-Site Worker scenario would permit the site to be used in its current and future capacity as an abandoned site. The potential exposed population is minimal to non-existent; therefore, the selection of the On-Site Worker scenario at a target cancer risk of $1x10^{-4}$ would be an appropriate selection. However, use of the On-site Worker scenario would require the implementation of institutional controls to ensure that site activities were limited to those factors used in the development of the SSTL for that scenario.

Construction Worker

Although the Construction Worker scenario is not a scenario that reflects an ongoing use/activity, its use as the final SSTL would support/supplement both the Standard Worker and On-Site Worker scenarios and eliminate the need for institutional controls.

4.7.2 Selection of SSTL

For the purposes of determining whether past remedial activities have successfully eliminated the COPCs at SWMU B24 to acceptable levels and to support closure, the site dataset was compared to the non-cancer Construction Worker SSTL. The non-cancer SSTL for the Construction Worker scenario was selected because this value is the most conservative non-cancer SSTL for all three scenarios. The non-cancer SSTL value also falls within the acceptable increased cancer risk range for both the Standard and On-Site Worker scenario. Therefore the final soil cleanup goal for the PCBs at SWMU B24, which is protective of human health and the environment, is 8.4 mg/kg, which is greater than any of the concentrations detected in the soils remaining on site.

5.0 CORRECTIVE ACTIONS

5.1 Interim Removal Action

An interim removal action was performed between August 18 and October 10, 2008 at SWMU B24. The objective of the removal action, as outlined in the Final Interim Removal Plan, SWMU B24, July 2008, was to remove all soils containing COPCs above the EPA Region IX PRGS for industrial soil. The removal action included two separate excavations of the pit bottom and soil piles. During the first excavation activity, the three soil piles adjacent to the B24 pit and the pit bottom were excavated. The three soil piles were excavated to a depth of approximately one foot below surrounding grade, and one foot of soil was removed from the pit floor. A total of 189 tons (approximately 125 cubic yards) was removed and disposed of as non-hazardous waste at U.S. Ecology in Beatty, Nevada during the first removal action. Analytical results from confirmation samples collected from the pit floor and from the former location of the soil piles indicated that concentrations of COPCs remained above the EPA Region IX PRGs and therefore a second excavation activity was necessary.

The second excavation was conducted on October 6, 2008. An additional foot of soil was excavated from below the location of the previously impacted soil piles, and an additional foot of soil was excavated from approximately one third of the pit bottom. The impacted soil, totaling 55 tons (approximately 35 cubic yards) disposed of as non-hazardous waste at U.S. Ecology in Beatty, Nevada.

5.2 Confirmation Sampling

Confirmation samples collected at the conclusion of the first and second excavation indicated that TPH and Aroclor-1260 are the only COPCs that remain above the PRG at the site. Upon receiving the confirmation soil sampling results from the second excavation, an agreement was reached between HWAD and the NDEP to use SSTLs as the new cleanup goal. Therefore, no further excavation is required and SWMU B24 is recommended for closure. Confirmation sampling locations and results for the first and second excavation are illustrated in Figure 4-2 and Figure 4-3, respectively, and presented in Table 5-1.

Table 5-1. Confirmation Sampling Results

Sample ID	B24-091508-S-PF01	B24-091508-S-PF02	B24-091508-S-PF03	B24-091508-S-PF04	B24-091508-S-PF05	NDEP Action Levels/PRGs (mg/kg)
Date	9/15/2008	9/15/2008	9/15/2008	9/15/2008	9/15/2008	
TPH-D	**1300 J**	22	**740 J**	**170**	**150**	**100***
TPH-G	0.82 J	0.41 J	0.58 J	0.37 J	0.42	**100***
Lead	390	110	350	130	260	**800**
PCBs	**1.84**	0.57	**0.95**	0.27	0.44	**0.74**
Sample ID	**B24-091508-S-PF06**	**B24-091508-S-SP01**	**B24-091508-S-SP02**	**B24-091508-S-SP03**	**B24-100708-S-PF07**	**NDEP Action Levels/PRGs (mg/kg)**
Date	9/15/2008	9/15/2008	9/15/2008	9/15/2008	10/7/2008	
TPH-D	13	**400**	82	26	75	**100***
TPH-G	0.35 J	0.45 J	0.52 J	0.4 J	0.63 J	**100***
Lead	98	65	34	99 J	16	**800**
PCBs	0.22	**5.6**	**0.86**	0.7 J	0.173J	**0.74**
Sample ID	**B24-100708-S-PF08**	**B24-100708-S-PF09**	**B24-100708-S-PF10**	**B24-100708-S-SP04**	**B24-100708-S-SF05**	**NDEP Action Levels/PRGs (mg/kg)**
Date	10/7/2008	10/7/2008	10/7/2008	10/7/2008	10/7/2008	
TPH-D	**290**	**720 J**	**780 J**	5.6	15	**100***
TPH-G	0.68 J	1.2	1.2	0.6 J	0.57 J	**100***
Lead	70	34	45	41	8.2	**800**
PCBs	**2.8**	**2.8**	**1.7**	**0.86**	0.11	**0.74**

*The NDEP has established an action level of 100 mg/kg for petroleum hydrocarbons

Bold, underlined, and shaded results exceed the Region IX PRG
J – Estimated

6.0 CONCLUSIONS

The pit at SWMU B24 was backfilled on March 23, 2009 to an elevation approximately 12 inches higher than surrounding grade, as requested by the NDEP. Site restoration photo documentation is provided in Appendix C. Since residual contamination at the SWMU is less than the SSTL, SWMUB24 is recommended for closure, with a restriction that the site only be used for industrial purposes. This restricted use should be added to the master plan for HWAD and included in any future Land Use Control Implementation Plan.

In accordance with NAC 445A.227, the following factors were evaluated to determine whether further corrective actions are required.

a. The depth of any groundwater: 100 feet bgs

b. The distance to irrigation wells or wells for drinking water: Water supply well #7 is located approximately 0.6 miles downgradient of SWMU B24. Well #7 is not a potable water source due to naturally high levels of fluoride and nitrate that exceed drinking water standards.

c. The type of soil that is contaminated: Fine to medium sand, silty sands.

d. The annual precipitation: 4.6 inches (evapotranspiration potential is 45 inches per year).

e. The type of waste or substance that was released: The source of contamination was determined to be worn out battery electrolyte waste fluid, battery acid spills, and wash down water from the Battery Shop.

f. The extent of the contamination: No COPCs remain on site above their respective SSTL. COPCs remaining above PRGs after the interim removal actions in August and October 2008 are limited to TPH-D (diesel range), PCB Aroclor-1260, and PCB Anoclor-1254. TPH-D and PCB remain present at SWMU B24 in concentrations above the PRGs but below the SSTLs created for SWMU B24. The PRG for PCB was exceeded in three surface samples (0-0.5 feet) in the eastern half of the pit bottom and one surface sample (0-0.5 feet) from beneath the location of former middle soil pile immediately south of the pit. PCB concentrations of these four samples range from 0.86 mg/kg (B24-100708-S-SP04) to 2.8 mg/kg (B24-100708-S-PF09). TPH-D remains present in soils at SWMU B24 above the TPH-D PRG of 100 mg/kg at concentrations ranging from 290 mg/kg (B24-100708-S-PF08) to 780 J mg/kg (B24-100708-S-PF10) following the interim removal actions. Three samples, all from the pit floor (0-0.5 feet), exceeded the TPH-D PRG. Confirmation sampling has verified that all other COPCs at SWMU B24 are below EPA Region IX PRGs.

g. The present and future use for the land: Industrial (present and future). Significant changes in land use (e.g., residential use) in the future may require a reassessment of the results.

h. The preferred routes of migration: Contamination pathways identified are ingestion of soil, dermal contact with soil, and inhalation of soil dust or soil gas.

i. The location of structures or impediments: Building 102-53, a tire storage shed, lies approximately 50 feet north of the impoundment. Building 102-52, a battery shop, lies

approximately 125 feet north of the impoundment. A set of railroad tracks lie immediately south of the SWMU B24 impoundment.

j. Potential fire, vapor, or explosion: None.

k. Other factors: The SWMU B24 acid pit has been backfilled to approximately 12 inches above surrounding grade to allow for surface water runoff.

7.0 REFERENCES

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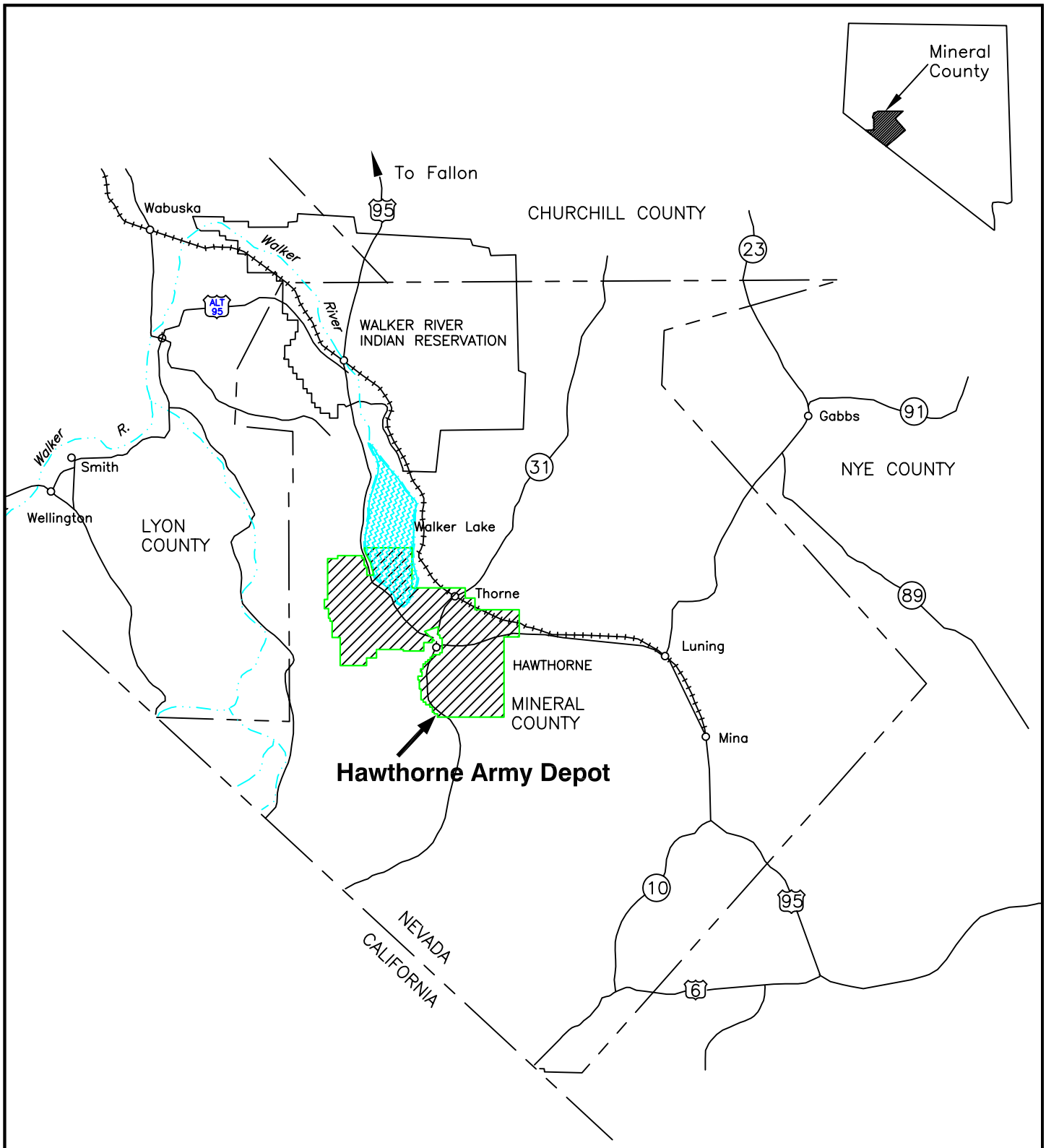
USEPA, 1994. RCRA Corrective Action Plan. Prepared by the Office of Waste Programs Enforcement, and Office of Solid Waste (OSWER Directive 9902.3-2A). May.

FIGURES



Adapted from Boyle Engineering, 1986; Reservation area based on USACE 1987

Legend

Hawthorne Army Depot

N

0 5 10 15

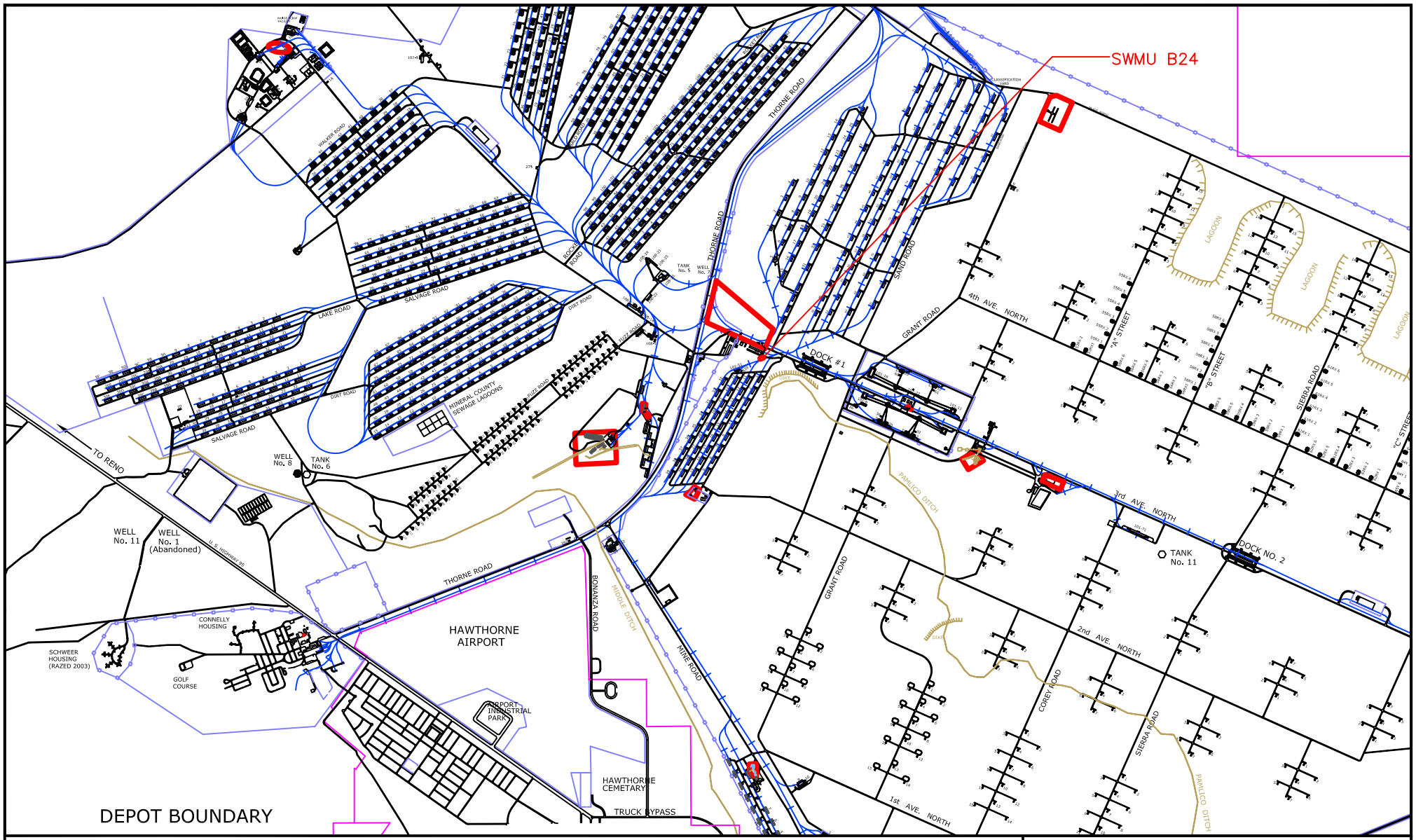
Scale in Miles

Hawthorne Army Depot Location Map

PLEXUS scientific

Figure 2-1

Hawthorne Army Depot
Hawthorne, Nevada



Legend

- Installation Boundary
- Railroad
- Road
- Fenceline
- SWMU Boundary

0 2,000 4,000
Scale in feet

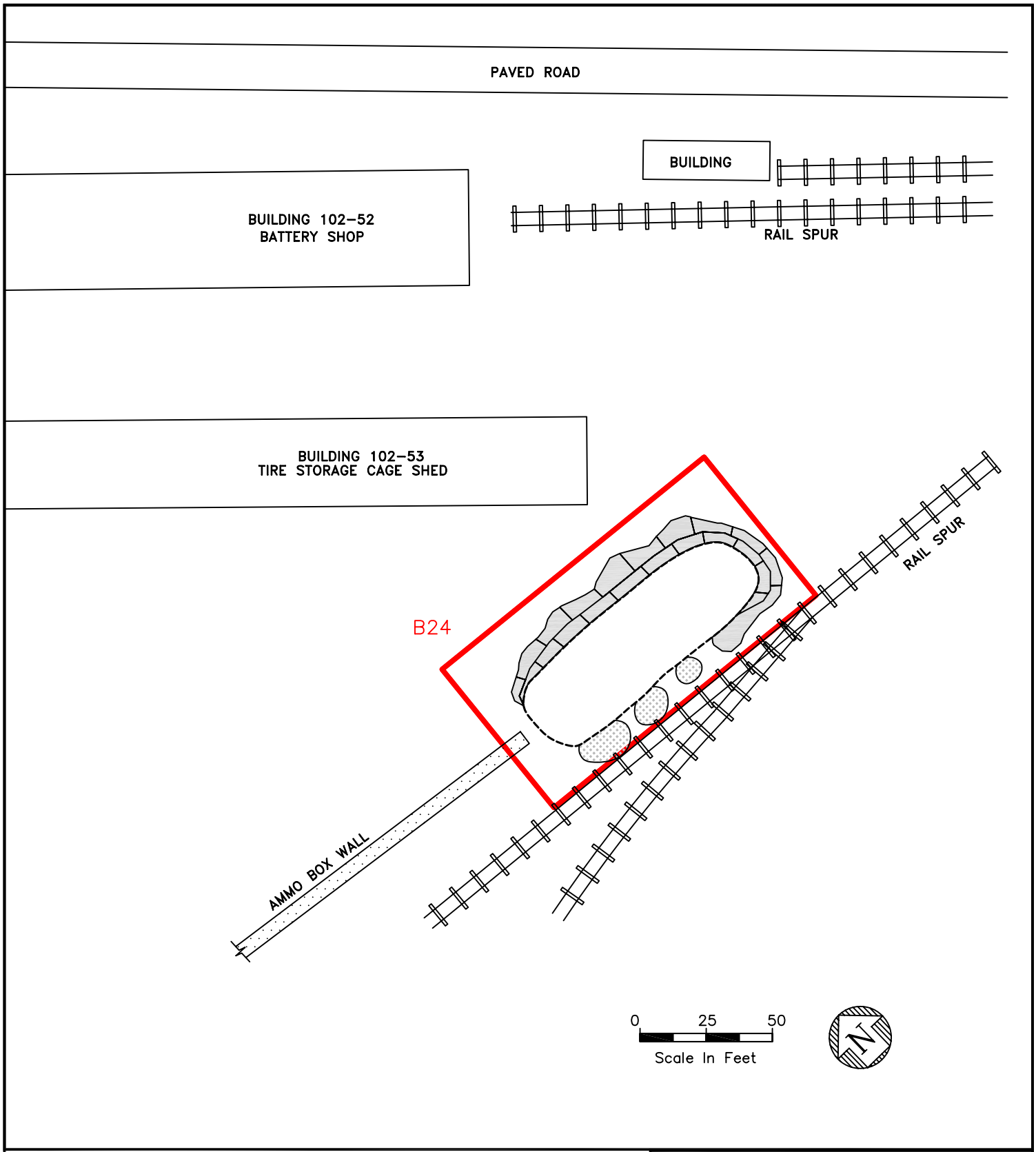
N

SWMU Location Map

PLEXUS scientific

Figure 2-2

Hawthorne Army Depot
Hawthorne, Nevada



Legend

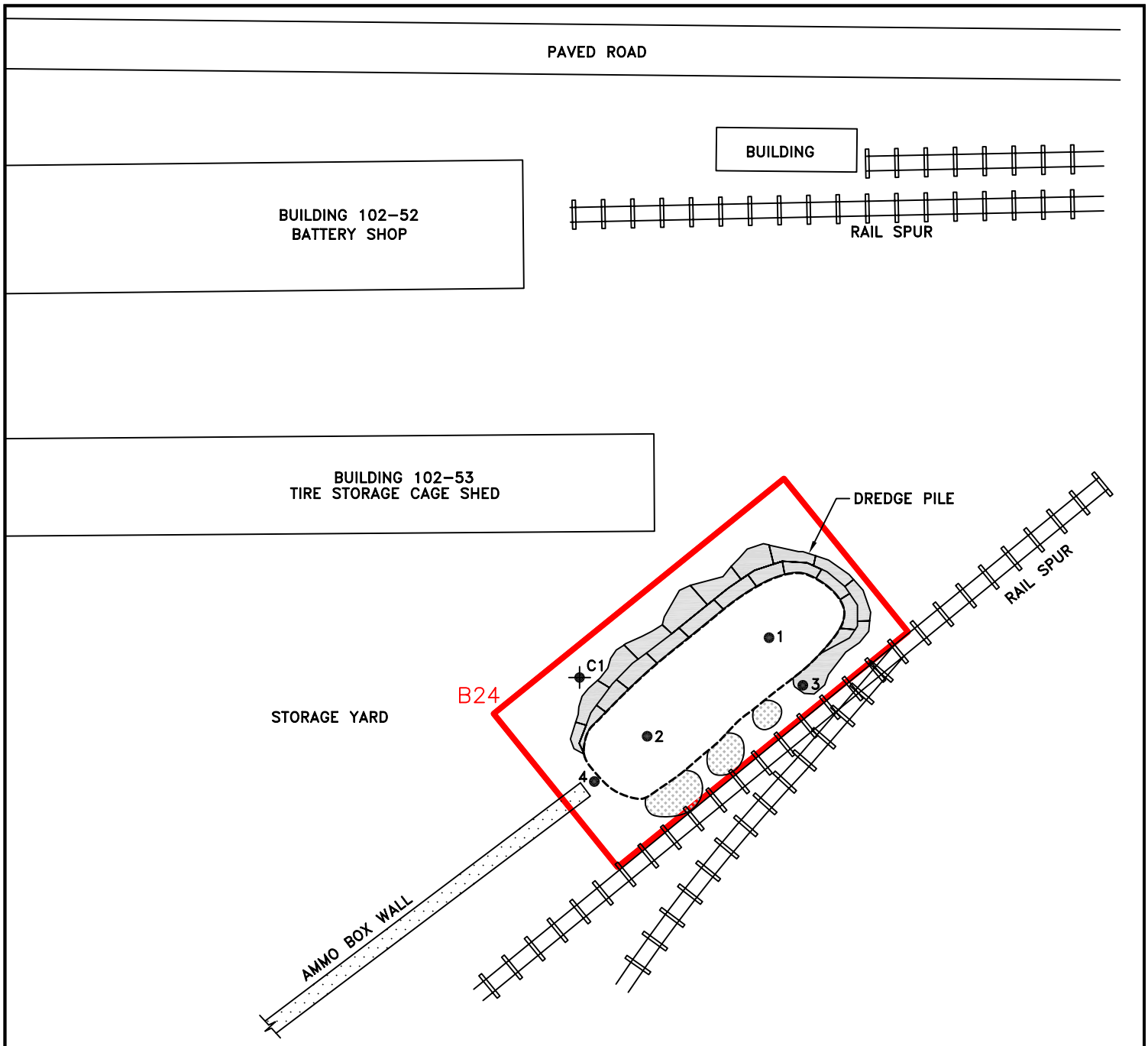
- Railroad
- Pit Rim
- Soil Piles
- Dredge Pile
- Approximate SWMU Boundary

SWMU B24
Acid Pit

PLEXUS scientific

Figure 2-3

Hawthorne Army Depot
Hawthorne, Nevada



SAMPLE SUMMARY	
Location	Sample
1	B24-HA1-1-000
	B24-HA1-1-005
2	B24-HA1-2-000
	B24-HA1-2-005
3	B24-SS1-1-000
4	B24-SS1-2-000
C1	B24-CPS1-1-011
	B24-CPS1-1-020

Legend

- Railroad
- Pit Rim
- Soil Piles
- Dredge Pile
- Approximate SWMU Boundary

2 — RFA SURFACE SOIL/HAND AUGER SAMPLING LOCATION AND NUMBER

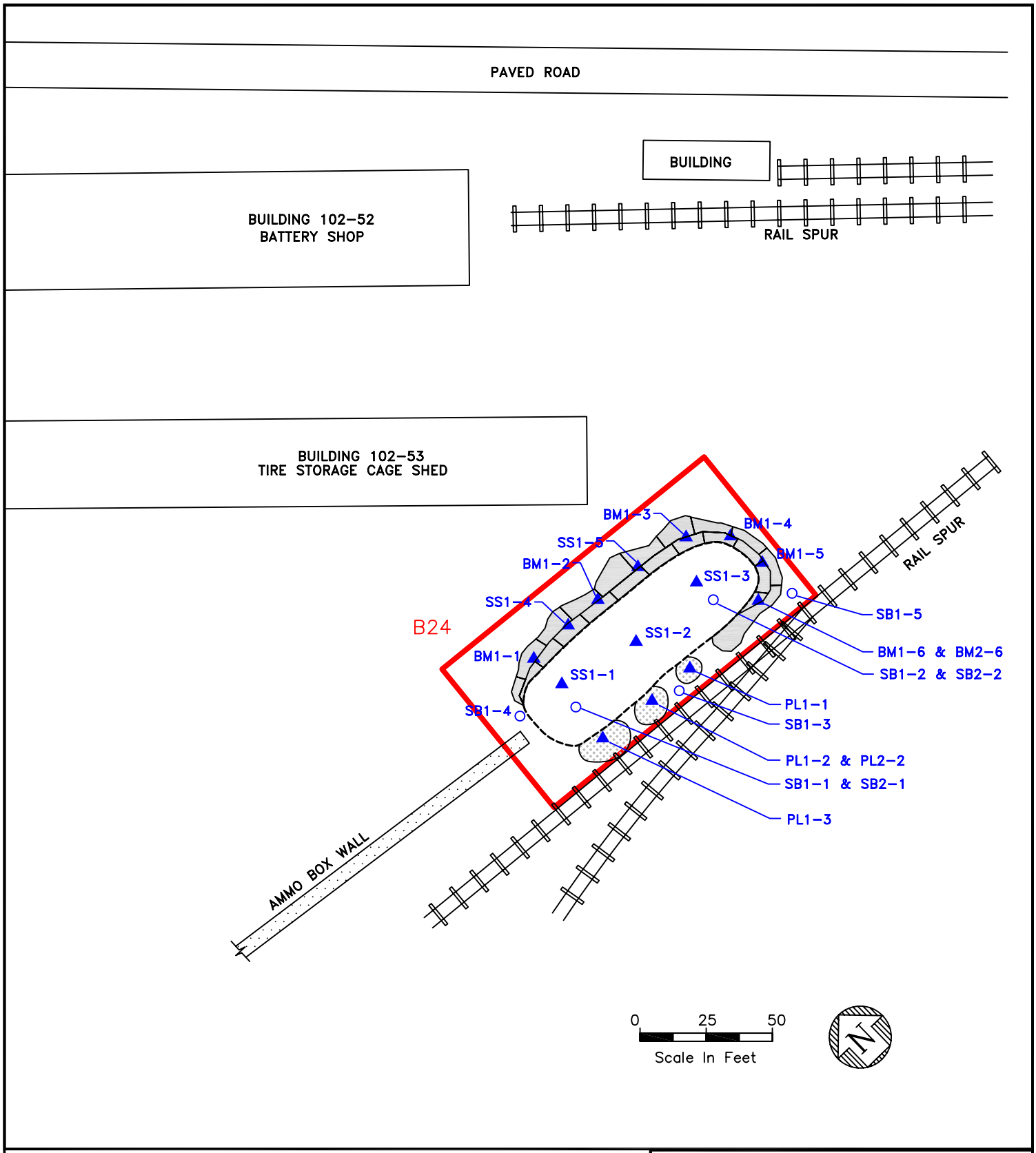
C1 — RFA CONE PENETROMETER TEST SAMPLING LOCATION AND NUMBER

RFA Sample Location
SWMU B24

PLEXUS scientific

Figure 3-1

Hawthorne Army Depot
Hawthorne, Nevada



Legend

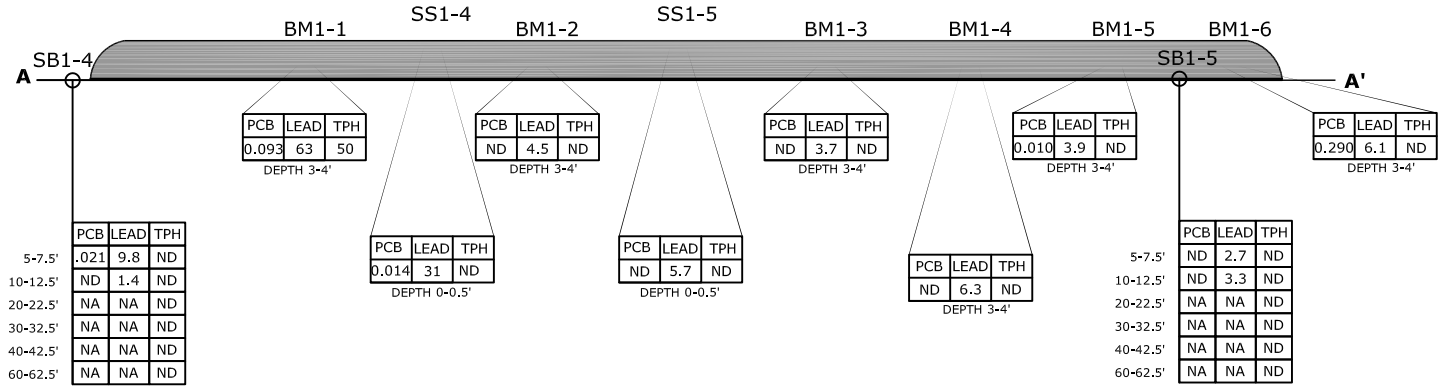
- Railroad
- Pit Rim
- Soil Piles
- Dredge Pile
- Approximate SWMU Boundary
- SB1-1 RFI SOIL BORING LOCATION
- SS1-1 RFI SURFACE SOIL SAMPLE LOCATION

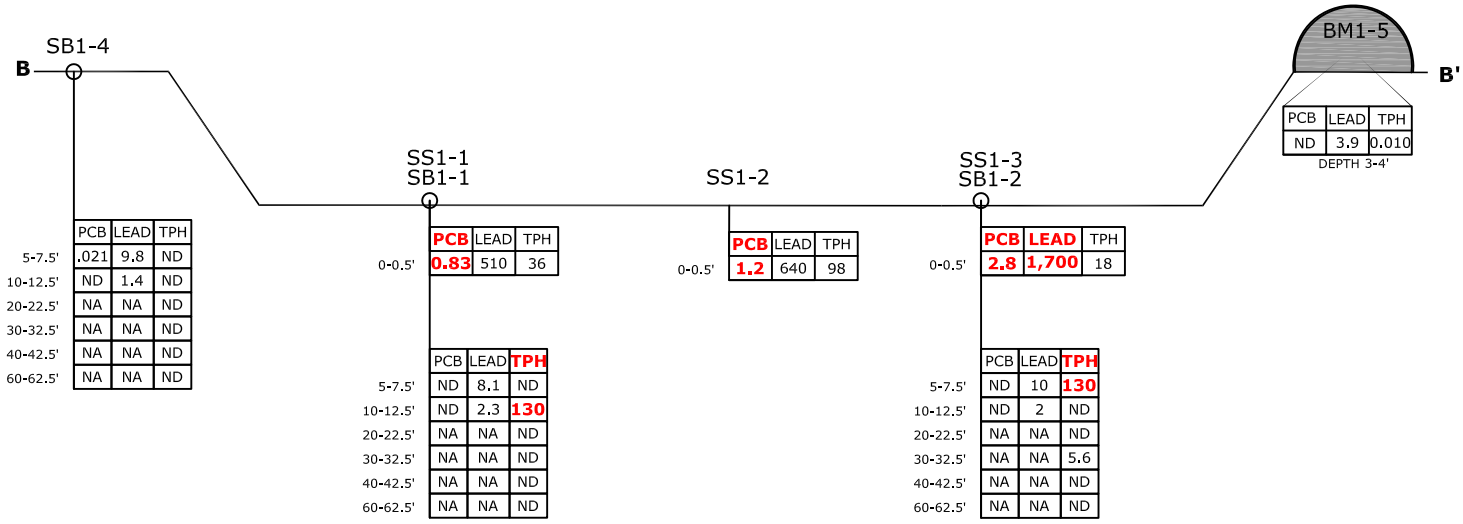
RFI Sample Location
SWMU B24

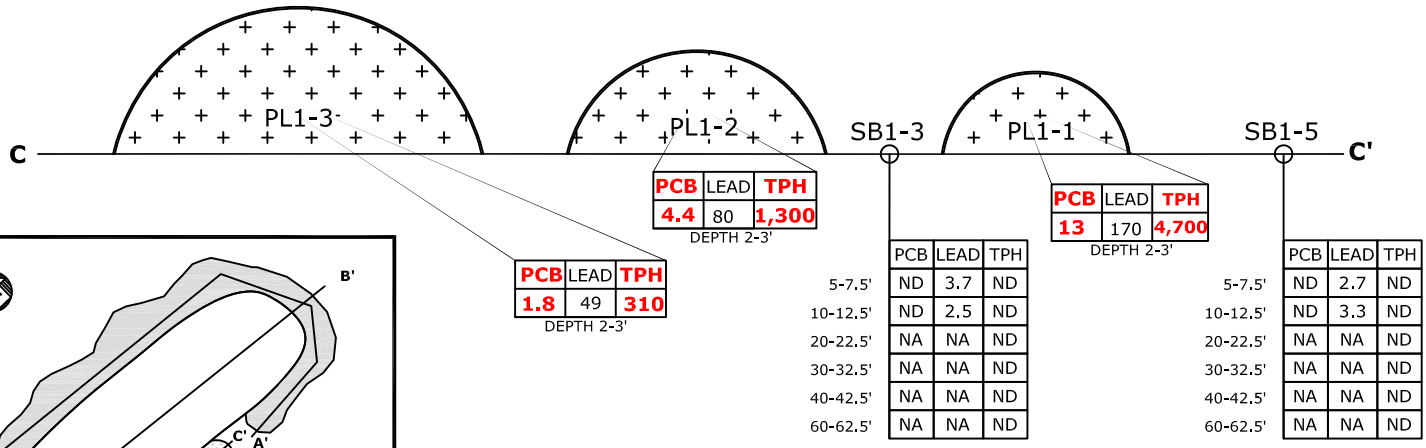
PLEXUS scientific

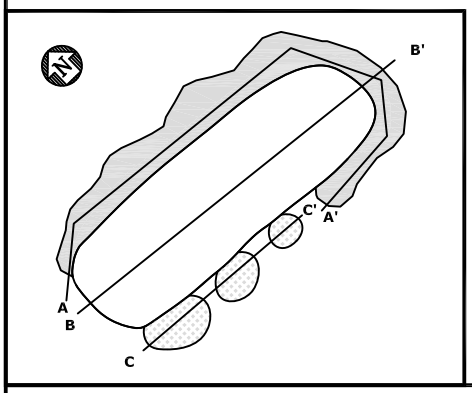
Figure 3-2

Hawthorne Army Depot
Hawthorne, Nevada









not to scale

Legend

Soil Berm

Soil Piles

SS = Surface Soil
SB = Soil Boring
BM = Berm
PL = Pile

Note: Concentrations are in mg/kg
Bold/Red = Exceeds PRG

RFA/RFI Action Levels:		2004 EPA Region 9 PRG:	
TPH	100	TPH	100(1)
LEAD	100	LEAD	800
PCB	0.09	PCB	0.74

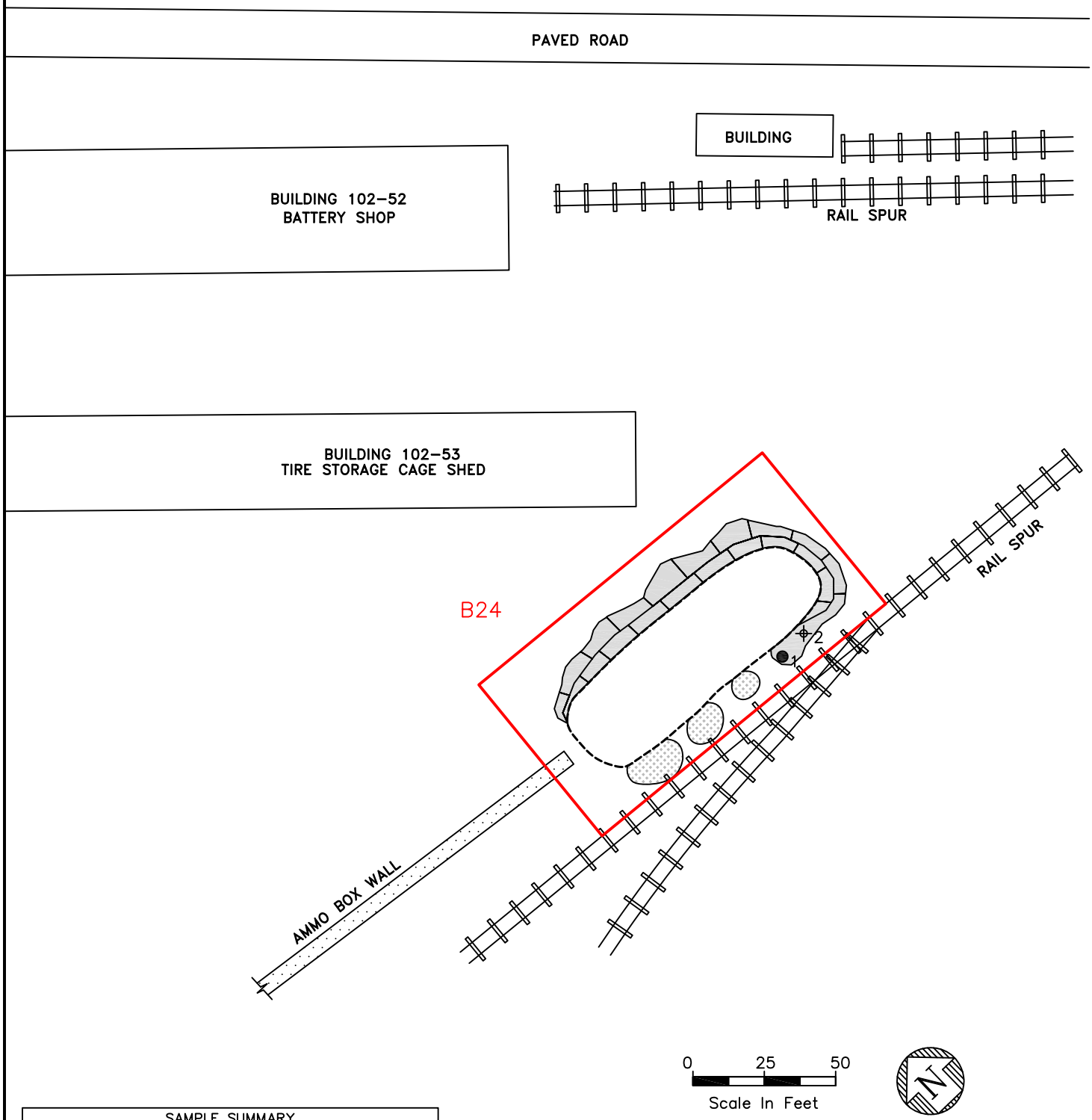
(1) TPH Action level is a NDEP derived value

Cross Section Map
SWMU B24 Acid Pit

PLEXUS scientific

Figure 3-3

Hawthorne Army Depot
Hawthorne, Nevada



SAMPLE SUMMARY		
Location	Sample Depth	Sample ID
1	0–1 feet	B24–011408–S–001
2	0–1 feet	B24–011408–S–002

Legend

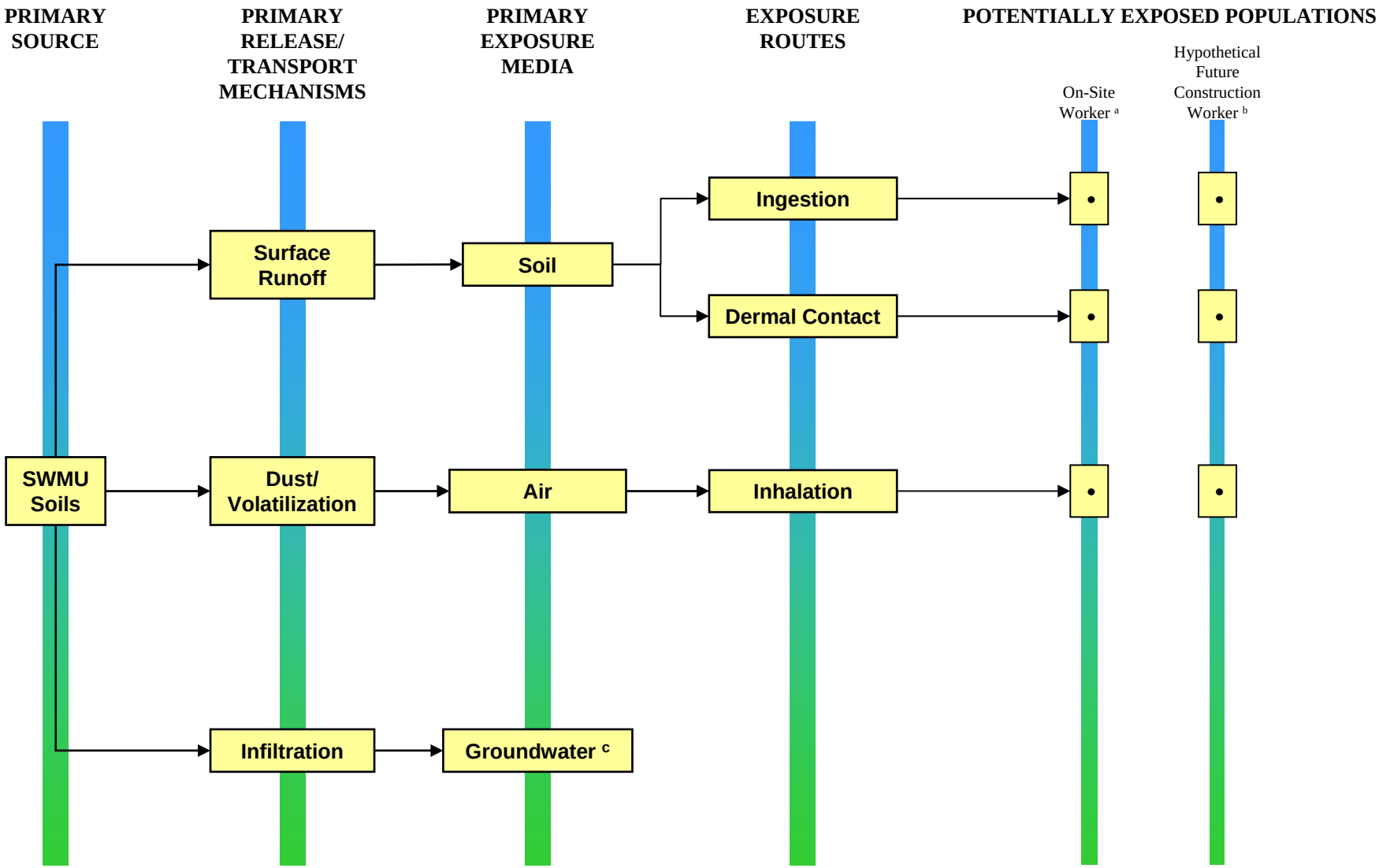
- Railroad
- Pit Rim
- Soil Piles
- Dredge Pile
- Approximate SWMU Boundary
- Initial Sample Location
- Follow–up Sample Location

Additional Characterization Sampling Locations SWMU B24

PLEXUS scientific

Figure 3-4

Hawthorne Army Depot
Hawthorne, Nevada



LEGEND:

• = Complete exposure pathway recommended for evaluation

[a] Based on current and future exposure. On-site workers are exposed to surface soils (0 to 2 ft bgs).

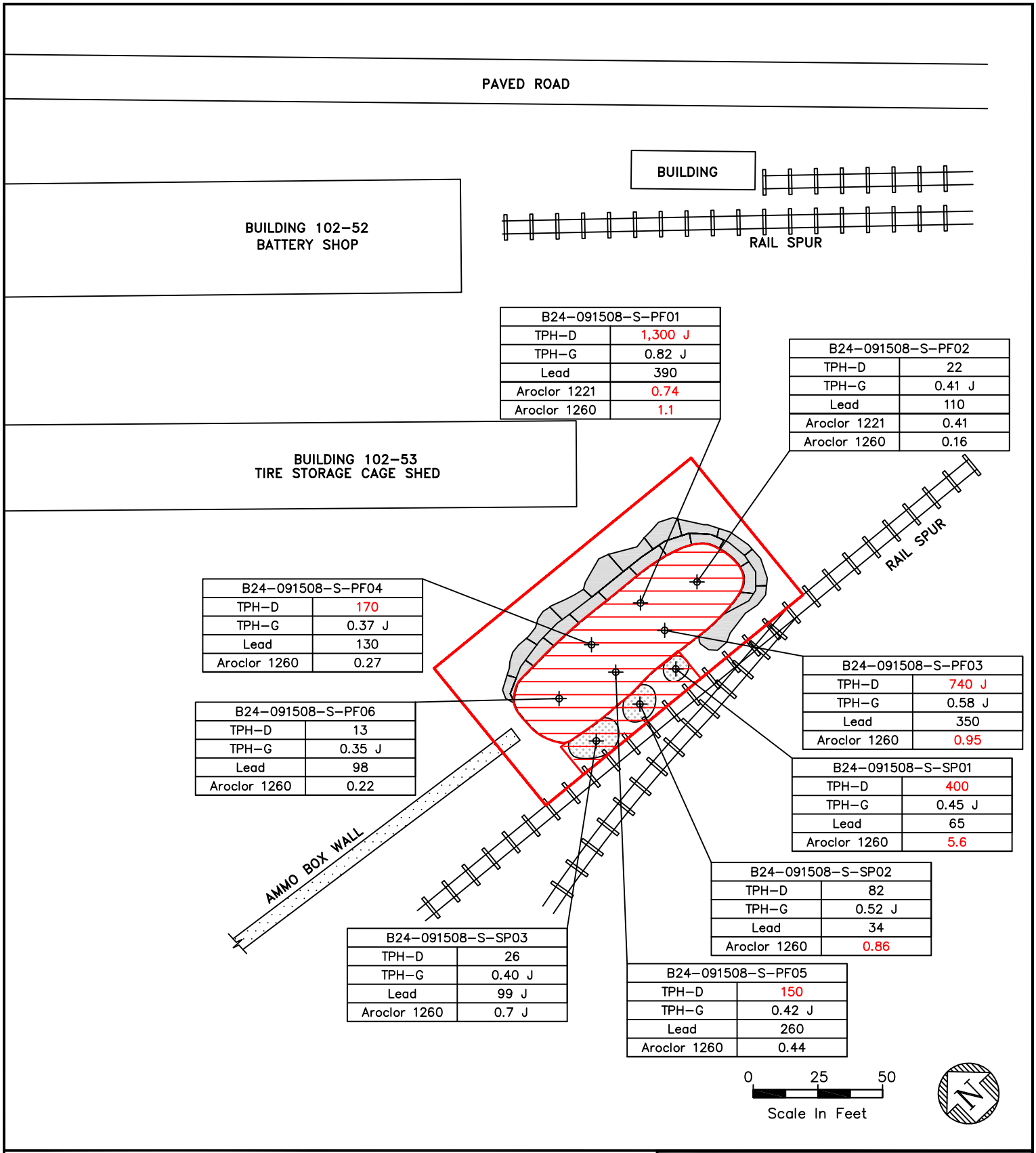
[b] Hypothetical future construction workers are exposed to aggregate soil (0 to 10 ft bgs).

[c] There is no use of the groundwater at the current time.

FIGURE 4-1

CONCEPTUAL SITE MODEL

Hawthorne Army Depot



B24-091508-S-PF01	
TPH-D	1,300 J
TPH-G	0.82 J
Lead	390
Aroclor 1221	0.74
Aroclor 1260	1.1

B24-091508-S-PF02	
TPH-D	22
TPH-G	0.41 J
Lead	110
Aroclor 1221	0.41
Aroclor 1260	0.16

B24-091508-S-PF04	
TPH-D	170
TPH-G	0.37 J
Lead	130
Aroclor 1260	0.27

B24-091508-S-PF03	
TPH-D	740 J
TPH-G	0.58 J
Lead	350
Aroclor 1260	0.95

B24-091508-S-PF06	
TPH-D	13
TPH-G	0.35 J
Lead	98
Aroclor 1260	0.22

B24-091508-S-SP01	
TPH-D	400
TPH-G	0.45 J
Lead	65
Aroclor 1260	5.6

B24-091508-S-SP02	
TPH-D	82
TPH-G	0.52 J
Lead	34
Aroclor 1260	0.86

B24-091508-S-SP03	
TPH-D	26
TPH-G	0.40 J
Lead	99 J
Aroclor 1260	0.7 J

B24-091508-S-PF05	
TPH-D	150
TPH-G	0.42 J
Lead	260
Aroclor 1260	0.44

Legend

- Railroad
- Pit Rim
- Former Soil Piles
- Dredge Pile
- Approximate SWMU Boundary
- Excavation Area
- Sample Location

BOLD = PRG exceedences

Results in mg/kg

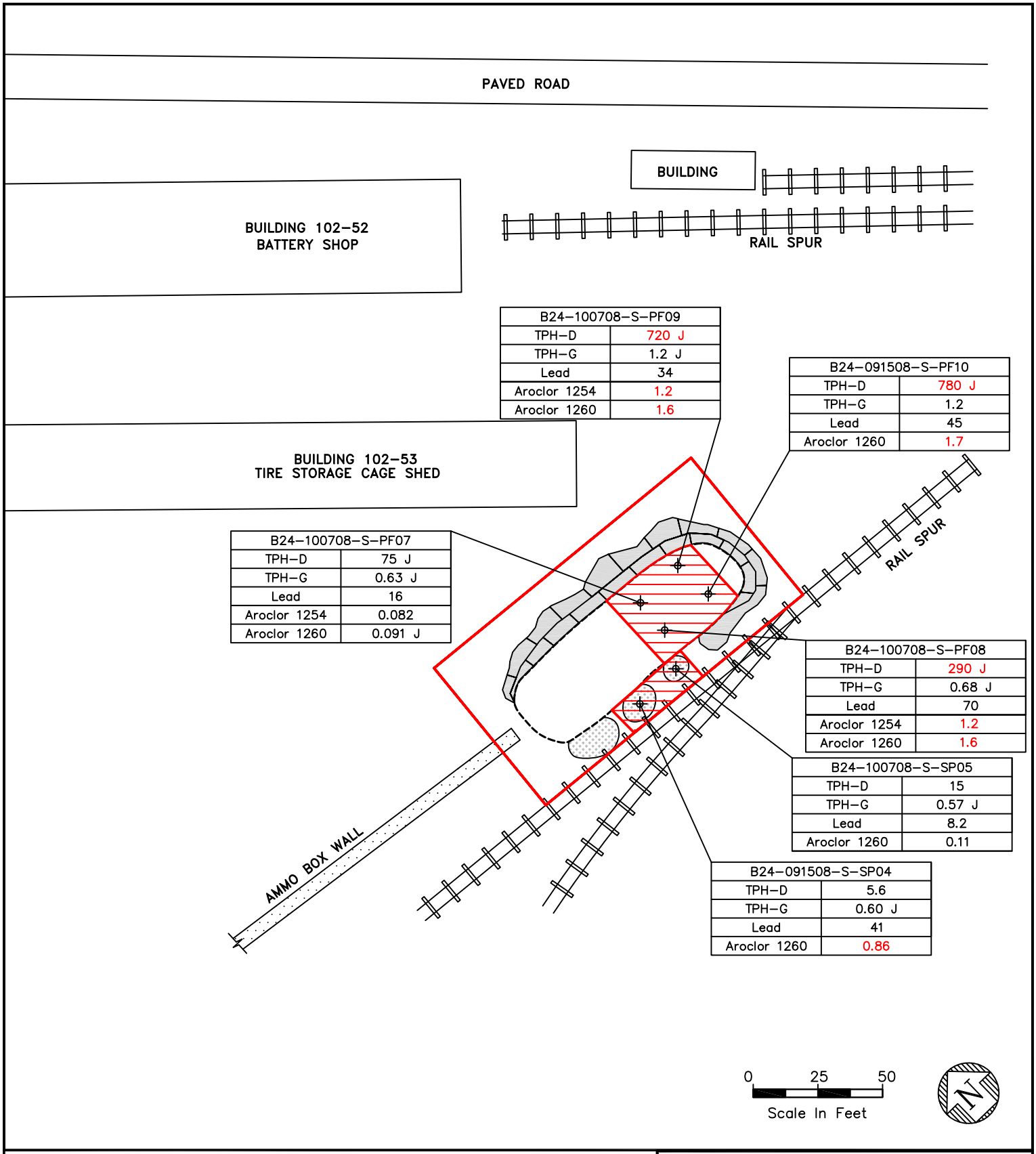
J = estimated concentration

Sample Locations and Results from First Removal Action

PLEXUS scientific

Figure 4-2

Hawthorne Army Depot
Hawthorne, Nevada



B24-100708-S-PF09	
TPH-D	720 J
TPH-G	1.2 J
Lead	34
Aroclor 1254	1.2
Aroclor 1260	1.6

B24-091508-S-PF10	
TPH-D	780 J
TPH-G	1.2
Lead	45
Aroclor 1260	1.7

B24-100708-S-PF07	
TPH-D	75 J
TPH-G	0.63 J
Lead	16
Aroclor 1254	0.082
Aroclor 1260	0.091 J

B24-100708-S-PF08	
TPH-D	290 J
TPH-G	0.68 J
Lead	70
Aroclor 1254	1.2
Aroclor 1260	1.6

B24-100708-S-SP05	
TPH-D	15
TPH-G	0.57 J
Lead	8.2
Aroclor 1260	0.11

B24-091508-S-SP04	
TPH-D	5.6
TPH-G	0.60 J
Lead	41
Aroclor 1260	0.86

Legend

- Railroad
- Pit Rim
- Former Soil Piles
- Dredge Pile
- Approximate SWMU Boundary
- Excavation Area
- Sample Location

BOLD = PRG exceedences

Results in mg/kg

J = estimated concentration

Sample Locations and Results from Second Removal Action

PLEXUS scientific

Figure 4-3

Hawthorne Army Depot
Hawthorne, Nevada

APPENDIX A
EXCERPT FROM FINAL RCRA FACILITY INVESTIGATION

UNITED STATES ARMY ENVIRONMENTAL HYGIENE AGENCY

ABERDEEN PROVING GROUND, MD 21010-5422

FINAL REPORT
GROUND-WATER CONTAMINATION SURVEY NO. 38-26-0850-88
EVALUATION OF SOLID WASTE MANAGEMENT UNITS
HAWTHORNE ARMY AMMUNITION PLANT
HAWTHORNE, NEVADA
12-19 MAY 1987
AND
1-5 AUGUST 1988

Distribution limited to U.S. Government agencies only; protection of privileged information evaluating another command; Sep 88. Requests for this document must be referred to Commander, Hawthorne Army Ammunition Plant, Hawthorne, NV 89416-5000.

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Final Rpt, Ground-Water Contamination Surv No. 38-26-0850-88, HWAAP, Hawthorne, NV, 12-19 May 87 and 1-5 Aug 88

MAP LOCATION/SITE NUMBER: HWAAP-B24.

a. SWMU Name: 102-52 Acid Impoundment.

b. Unit Characteristics.

(1) Type of unit: Unlined surface impoundment.

(2) Design Features: This is an open pit next to Building 102-52. The pit measures 30 by 100 feet and 5 feet deep.

(3) Operating Practices: The installation used the pit for worn out battery electrolyte waste fluid, battery acid spills and wash down water from the Battery Shop, Building 102-52. Acid and large quantities of water flowed from this building into this pit.

(4) Period of Operation: Circa 1950 to 1980.

(5) General Physical Conditions: Effluent flows from two pipes into the pit. The pit is stained red. Fluid does not stay in the pit. Rather, it percolates through the pit floor to the subsurface. The activity is a mess.

(6) Closure Method: None.

(7) Permit: None.

c. Waste Characteristics.

(1) Type of Wastes Placed in the Site: Battery acid and electrolyte.

(2) Migration and Dispersal Characteristics of the Waste: The aquifer is approximately 100 feet below the surface and flows northwest. The seepage velocity of the ground water is roughly 1 ft/day. The waste effluent is seeping into the subsurface material. Migration to the ground water is likely if the activity continues. Wells are not in place around the facility to confirm the depth to the ground-water table or water quality.

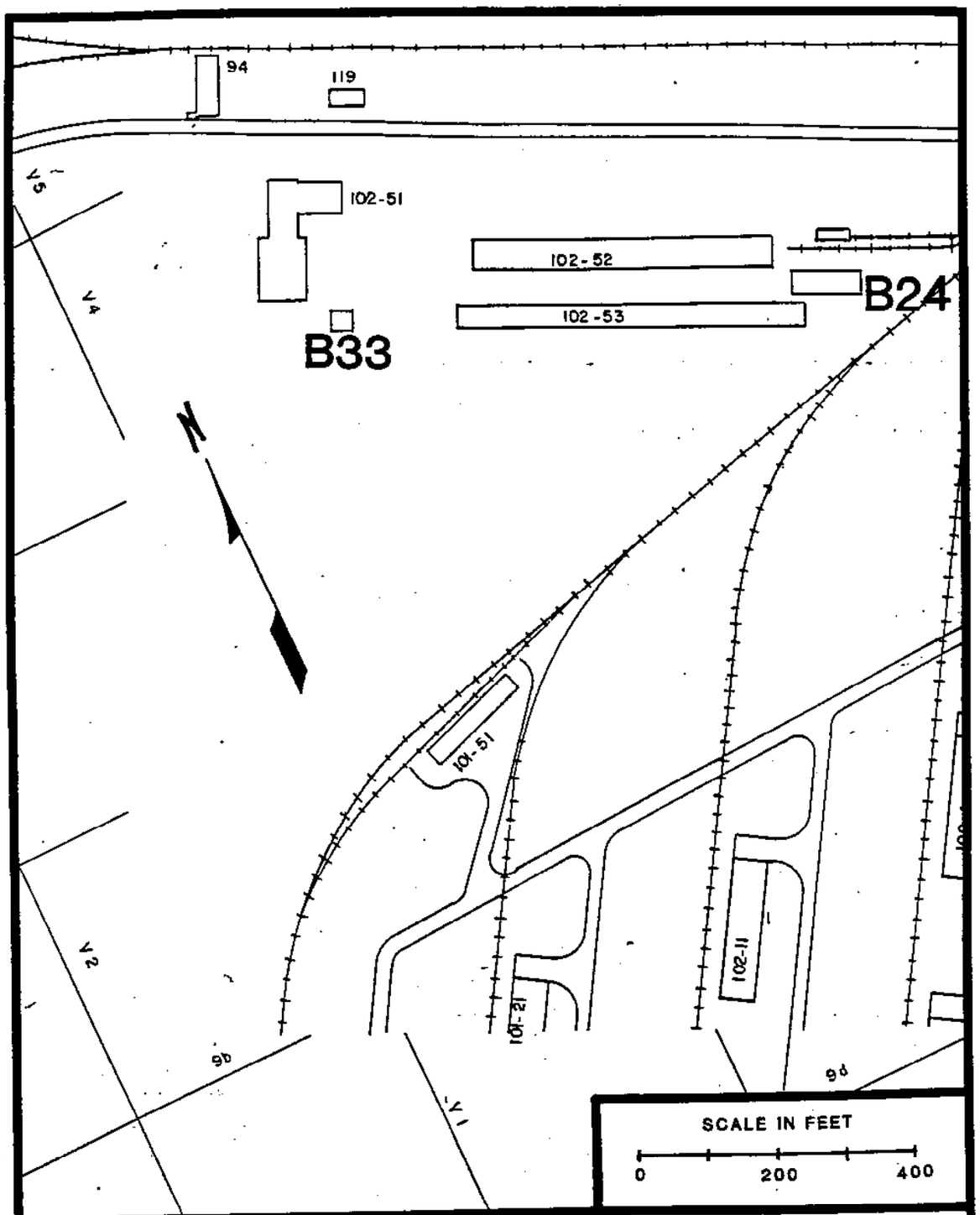
(3) Toxicological Characteristics: Possible EP toxic heavy metals (lead and cadmium).

(4) Physical and Chemical Characteristics: Unknown without samples of the waste, soil and ground water.

d. Migration Pathways: Ground Water.

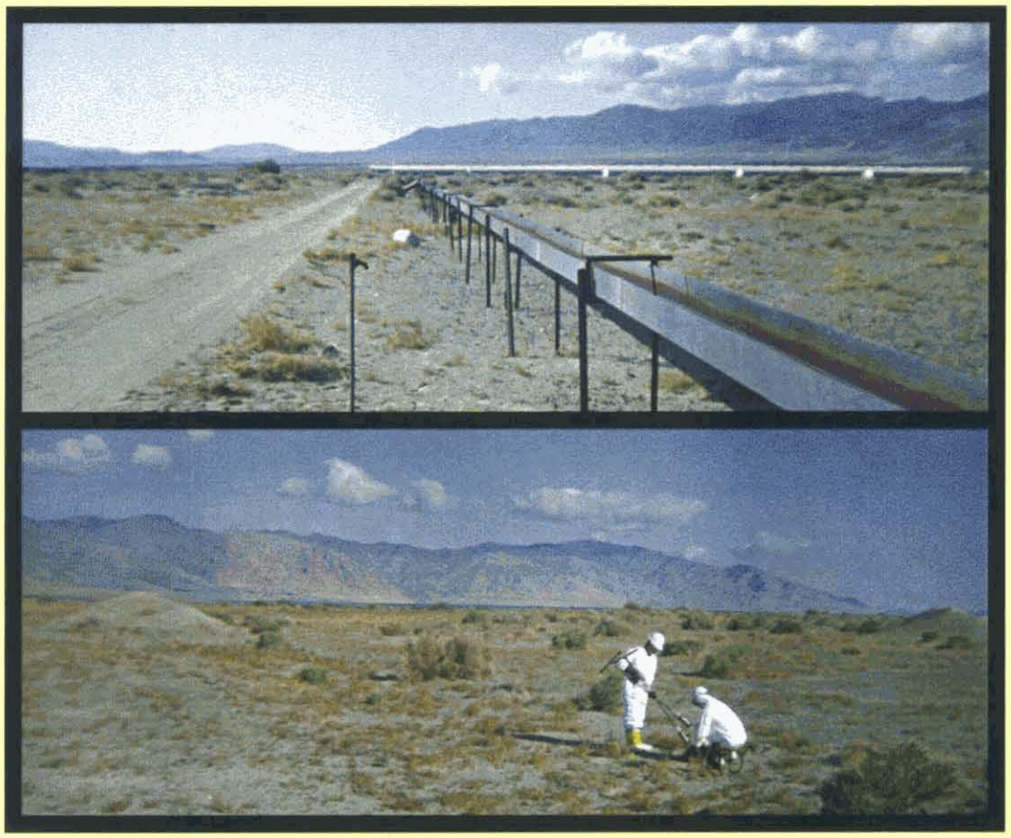
e. Evidence of Release: Stained soil.

f. Exposure Potential: Site poses a threat to the ground water. Humans do not consume the water.



HWAAP - B24: 102-52 ACID IMPOUNDMENT.

HAWTHRONE AD \ HAAD0001



FINAL

RCRA Facility Investigation Report of Group A Solid Waste Management Units A-04, B-16, B-21, B-24, B-26, and H-01

Hawthorne Army Depot
Hawthorne, Nevada

May 1997

ecology and environment, inc.
International Specialists in the Environment

U.S. Army Corps of Engineers
Sacramento District

Contract DACA05-91-D-0016
Delivery Orders 12 and 13

Environmental Engineering Branch
DERP Section

3.4 SWMU B-24: 102-52 Acid Impoundment

3.4.1 Site Description

SWMU B-24 is an inactive unlined surface impoundment located southeast of Building 102-52 (Figure 3-3). The impoundment measures 30 by 100 by 5 feet deep, but it has been eroded and partially filled with windblown sand. Effluent reportedly flowed into the impoundment from two pipes on the northeast side. These effluent pipes were not located during E & E's 1994 RFA investigation of the SWMU. USAEHA noted that liquid does not pond within the impoundment, but it percolates into the subsurface.

3.4.2 Site Background

The impoundment reportedly was in operation from circa 1950 to 1980 and received large amounts of battery electrolyte waste fluid, battery acid, and wash down water from the Battery Shop, Building 102-52. Visible evidence of red stained soils in the bottom of the impoundment was noted by the USAEHA survey team (USAEHA 1987, 1988). During the 1992 site visit, stained soils were also noted in the perimeter of the impoundment. SWMU B-24 has never been permitted and has not gone through a formal RCRA closure.

3.4.2.1 Previous Investigations

The 1994 RFA investigation at SWMU B-24 included collection and analysis of surface and subsurface soil and groundwater samples. Table 3-11 summarizes the samples collected, and Figure 3-3 illustrates the sample locations. All soil samples were analyzed for semivolatile organics, pesticides, PCBs, TPH, nitrate, picric acid, metals, explosives, and pH. Subsurface soil samples were also analyzed for VOCs.

The subsurface investigation of SWMU B-24 was performed adjacent to the impoundment and on its downgradient side closest to the reported location of the effluent discharge pipes. Two subsurface soil samples were collected from one CPT sampling location at this SWMU. The subsurface soil samples were collected from the top 18 inches of two fine-grained horizons at 11 and 22 feet bgs. Two surface soil samples from the bottom of the impoundment and two hand auger samples from 5 feet beneath the bottom of the impoundment were collected at SWMU B-24. These surface and near-surface samples were collected from the lowest elevation in the impoundment where liquids would tend to accumulate. To characterize the potential for contaminated surface soils outside of the

impoundment, two surface soil samples were collected from areas adjacent to the SWMU as shown on Figure 3-3.

3.4.2.2 Chemicals of Concern

Table 3-12 presents a summary of the compounds detected during the RFA.

Five metals (arsenic, barium, cadmium, chromium, and lead) were detected in all of the surface soil samples collected from within and on the perimeter of the impoundment. With the exception of cadmium, these same metals were also found at low levels in the subsurface soil samples. Of these metals, only lead concentrations exceeded the soil remediation criteria (100 mg/kg) in all of the surface soil samples analyzed.

RDX was detected in one surface soil sample from within the impoundment that exceeded the soil remediation criteria. All other detected nitroaromatics were present at concentrations below these criteria. Nitroaromatics were not detected in subsurface soil samples.

Organic compounds detected in the impoundment included TPH as gasoline and diesel, phenanthrene, pyrene, di-n-butyl-phthalate, and bis (2-ethylhexyl) phthalate. TPH as diesel exceeded the soil remediation criteria in all of the surface and near-surface soil samples.

PCB-1260 was detected in three samples collected at the SWMU. The concentrations detected in two of the samples exceed the soil remediation criteria of 0.09 mg/kg. Both samples were collected on the surface.

3.4.3 RCRA Facility Investigation Activities

Based on results of the RFA, it was recommended that additional surface and subsurface soil sampling be conducted to determine the extent of soil contamination. The following sections describes the RFI investigative approach and analytical results.

3.4.3.1 Field Screening

Fourteen surface and near-surface soil samples and one replicate near-surface soil sample were screened for TNT and RDX. Subsurface soils collected from depths of 5-, 10-, 20-, 30-, 40-, and 60-feet were also screened for TNT ad RDX. A total of 30 subsurface soil samples along with three replicate samples were also screened for TNT and RDX.

Field screening for TNT and RDX was performed according to the procedures presented in Section 2.3.1, and the results are listed in Table 3-13 and summarized in Appendix D.

3.4.3.2 Sampling Activities

Table 3-11 summarizes the samples collected during the RFI and Figure 3-3 illustrates the sample locations.

Five surface soil samples were collected from 0- to 6-inch depths. Three samples were collected from the bottom of the pit and two samples were collected from the bermed area along the northern edge of the pit.

Nine near-surface soil samples and two duplicate samples were collected. Three samples were collected from soil piles, one from each of the three soil piles on the southern side of the impound, and six samples were collected from the soil berm along the northern side of the impoundment. These samples were collected at a minimum depth of 6 inches below the soil surface and at the horizontal and vertical centers of the piles and the berm.

Thirty subsurface soil samples and two duplicate samples were collected from five soil borings, each drilled to a total depth of 60 feet below ground surface. Two borings were drilled through the bottom of the impoundment and three borings were drilled outside of the impoundment along the southern edge. Continuous soil cores were collected from each boring for lithologic logging and analytical sampling. Analytical samples were collected from 5-, 10-, 20-, 30-, 40-, 50-, and 60-foot depths in each boring.

Although the text in Section 5.1 of the amended FIP indicated that eight near surface soil samples were to be collected from the berm, six were actually collected, as listed in Table 5-1 of the amended FIP and in the delivery order Scope of Work.

3.4.4 RCRA Facility Investigation Results

3.4.4.1 Field Observations

There were no unusual observations made during the soil borings and collection of subsurface soil samples or the collection of the surface and the berm near surface soil samples. However, the near surface soil samples from the three soil piles contained wood scraps/pieces, roots and organic matter. Lithologic logs for each soil boring are presented in Appendix A.

3.4.4.2 Results of Analytical Work

Table 3-14 summarizes the analytical results for the RFI and Figure 3-3 illustrates the sample locations.

Surface Soil Samples

Five surface soil samples were collected from the bottom of the impoundment. TPH-diesel was detected in three of the samples at concentrations ranging from 18 to 98 mg/kg which is less than the soil remediation criteria of 100 mg/kg. In addition, one sample contained TPH-gasoline at 33 mg/kg.

Lead was detected in all five surface soil samples at concentrations ranging from 5.7 to 1,700 mg/kg. The lead concentration in three of the samples exceeded the soil remediation criteria of 100 mg/kg. These three soil samples were collected from the bottom of the impoundment.

The only nitroaromatic detected in the surface soil samples was HMX, which was detected in one sample at 7.5 mg/kg which is less than the soil remediation criteria of 4,000 mg/kg. This sample was collected from the west end of the impoundment bottom.

Polychlorinated bi-phenols (PCB-1260) was detected in four of the surface soil samples at concentrations ranging from 0.014 to 2.8 mg/kg. Three of the samples were collected from the bottom of the impoundment.

Bis(2-ethylhexyl)phthalate and di-n-butyl-phthalate was detected in all five of the surface soil samples at concentrations ranging from 0.034 to 96 mg/kg and 0.4 to 32 mg/kg, respectively. Four of detected bis(2-ethylhexyl)phthalate concentrations exceeded the soil remediation concentrations of 50 mg/kg. No other SVOCs were detected in any of the surface soil samples.

Berm Soil Samples

Six soil samples were collected from the soil berm bordering the impoundment on the north and east side. The berm soil samples were collected with a hand auger from the center of the berm pile.

TPH-diesel was detected in one sample (BM1-1-00), collected from the west end of the berm on the north side of the impoundment, at 50 mg/kg which is less than the soil remediation criteria of 100 mg/kg. TPH-gasoline was not detected in any of the berm samples.

Lead was detected in all of the berm soil samples at concentrations ranging from 3.7 to 63 mg/kg all of which are less than the soil remediation criteria of 100 mg/kg.

PCB-1260 was detected at 0.093 mg/kg in sample BM1-1-000 and at 0.29 mg/kg in sample BM1-6-000, collected from the west end and southeast corner of the berm on the north side of the impoundment. This detected concentration slightly exceeds the soil remediation criteria of 0.09 mg/kg.

Benzo(a)pyrene and chrysene were the only two SVOCs detected in the berm soil samples. These compounds were detected at 0.057 mg/kg and 0.041 mg/kg, respectively from sample BM1-1-000 collected from the west end of the berm on the north side of the impoundment. These concentrations do not exceed the soil remediation criteria. No other SVOCs were detected in any of the berm soil samples.

Soil Pile Samples

Four soil samples including one duplicate were collected from piles of soil along the southern edge of the impoundment. These samples were collected with a hand auger from the center of the soil pile.

TPH-diesel was detected in all of the soil pile samples at concentrations ranging from 310 to 4,700 mg/kg which exceed the soil remediation criteria of 100 mg/kg. TPH-gasoline was detected in one soil pile samples (PL1-1-000) at 6.7 mg/kg, which does not exceed the soil remediation criteria..

Lead was detected in all of the soil pile samples at concentrations ranging from 49 to 170 mg/kg. The eastern most soil pile sample (PL1-1-000) contained 170 mg/kg lead which exceeds the soil remediation criteria. All other detected lead concentration were less than the soil remediation criteria.

PCB-1260 was detected in all of the soil pile samples at concentrations ranging from 1.8 to 13 mg/kg with the highest concentration detected in the eastern most sample (PL1-1-000). All of these detected concentrations exceed the soil remediation criteria.

Chrysene and pyrene were detected in two of the soil pile samples at concentrations less than the soil remediation criteria.

Subsurface Soil Samples

As described in Section 3.4.3.2, five soil borings were drilled; two through the bottom of the impoundment and three outside of the impoundment from which subsurface soil samples were collected.

TPH-diesel was detected in two of the subsurface soil samples, collected from boring SB1-2 at five feet and 30 feet bgs. TPH-diesel was detected at 130 mg/kg in the five foot sample and at 5.6 mg/kg in the 30 foot sample. Only the five foot sample concentration exceeded the soil remediation criteria of 100 mg/kg. TPH-gasoline was not detected in any of the subsurface soil samples.

Lead was analyzed for and detected in eight of the subsurface soil samples. The lead concentrations ranged from 1.4 to 10 mg/kg which is below the soil remediation criteria of 100 mg/kg and is within the natural background range.

PCB-1260 was analyzed for in eight of the subsurface soil samples and was detected in only one sample, collected from boring SB-4 at five feet bgs, at 0.021 mg/kg which is below the soil remediation criteria.

No nitroaromatic compounds were detected in any of the subsurface soil samples.

Bis(2-ethylhexyl)phthalate was detected in four subsurface soil samples at concentrations ranging from 0.037 to 0.130 mg/kg. Di-n-butyl-phthalate was detected in two subsurface soil samples at concentrations ranging from 0.550 to 0.580 mg/kg.

3.4.5 Analysis of Results

3.4.5.1 Comparison of Current and Previous Investigations

Analytical results of the RFI sampling are comparable to and further support the findings of the RFA sampling. Analysis of surface soil samples collected from the bottom of the impoundment during both the RFA and RFI detected lead at concentrations exceeding the soil remediation criteria. It should be noted that surface soil samples collected during the RFA were collected from 0.5 to 1.0 feet bgs while samples collected during the RFI were collected from 0 to 0.5 feet bgs. Subsurface soil samples collected from the beneath the impoundment, at depths of five feet and deeper, during both investigations did not detect lead at concentrations exceeding the soil remediation criteria.

Both investigations also detected TPH-diesel in the surface soils collected from the impoundment bottom at concentrations exceeding the soil remediation criteria. In addition,

both investigations identified TPH-diesel at concentrations exceeding the soil remediation criteria to depths of five feet beneath the bottom of the impoundment.

PCB-1260 was detected at concentrations exceeding the soil remediation criteria in some of the surface soil samples collected from the bottom of the impoundment.

During the RFA, bis(2-ethylhexyl)phthalate was detected in the surface soil samples; however, at concentrations less than the soil remediation criteria. During the RFI, bis(2-ethylhexyl)phthalate was detected at concentrations exceeding the soil remediation criteria in surface soils collected from the impoundment bottom.

Several nitroaromatic compounds were detected in the surface and near surface soil samples collected from the impoundment bottom during the RFA including RDX which was detected at concentrations exceeding the soil remediation criteria. However, no nitroaromatic compounds were detected at concentrations exceeding the soil remediation criteria during the RFI.

Berm and soil pile samples were not collected during the RFA. However, the RFI analytical results detected PCB-1260 in the berms and soil piles at concentrations exceeding the soil remediation criteria. In addition, TPH-diesel and lead were detected in the soil piles along the southern edge of the impoundment at concentrations exceeding the soil remediation criteria.

3.4.5.2 Nature and Extent of Contamination

Based on the analytical results of the RFA and RFI, it appears that the top five feet of soils in the impoundment bottom and the soil piles along the southern edge of the impoundment contain lead, TPH-diesel, and PCB-1260 at concentrations exceeding the soil remediation criteria. Based on the RFI analytical results, it appears that the soil piles along the southern edge of the impoundment are materials which have been dredged from the impoundment bottom.

Analysis of subsurface soils collected from borings drilled through the impoundment bottom and adjacent to the impoundment did not detect any contaminants at concentrations exceeding the soil remediation criteria. This suggests that the vertical migration of contaminants has been restricted primarily to the upper five feet of soils and that minimal lateral migration has occurred.

It is estimated that approximately 800 cubic yards of soil underlying and adjacent to the impoundment are contaminated with lead, TPH, and PCBs at concentrations exceeding the

soil remediation criteria. This volume estimate was calculated using the following assumptions; contaminated soil exists in a five-foot zone about the southern perimeter of the impoundment and soil contamination extends to a maximum depth of five feet bgs beneath the impoundment bottom.

3.4.5.3 Human Health Risk Evaluation

[The final human health risk evaluation provided by Tetra Tech, Inc. will be inserted upon completion.]

3.4.6 Conclusions and Recommendations

Acidic soil pH values and high lead concentrations found within the impoundment and in the dredged soils on its perimeter support historical indications that battery related wastes were released to the impoundment. In addition, the presence of volatile and semivolatile organics, PCBs, and nitroaromatics, combined with observed soil staining indicate that other releases were made as well. Lead, TPH-diesel, RDX, and PCB-1260 were detected at levels in excess of soil remediation criteria. However, most of the contaminant concentrations decreased with depth, and deeper soil contamination was not detected in either CPT or soil boring soil samples. Based on this subsurface sampling, it appears that vertical and lateral migration of contaminants has been limited to the upper five feet of soils and within five feet of the impoundment perimeter.

A human health evaluation was conducted at SWMU B-24 to evaluate the potential carcinogenic risks and noncarcinogenic hazards associated with exposure to contaminants in surface soils at the site. The COPCs evaluated in this risk evaluation were metals, SVOCs, PCBs, TPH-gasoline and diesel, and nitroaromatic explosive compounds.

The draft human health risk evaluation determined an estimated cancer risk of 1.2E-04, above the U.S. EPA target cancer risk range (Tetra Tech 1997f). A hazard index of 0.17 was determined for the site, which is below the hazard index threshold value of 1.0. Risk evaluation findings, therefore, suggest that the identified site contaminants in surface soils at SWMU B-24 do pose a carcinogenic human health risk for on-site receptors (Tetra Tech 1997f). Although lead does not have an associated cancer risk or noncancer hazard quotient, on-site concentrations exceed the U.S. EPA Region IX PRG of 1,000 mg/kg (Tetra Tech 1997f), as well as the previously mentioned soil remediation criteria of 100 mg/kg.

Because several different types of contaminants at this SWMU exceed remediation criteria, an engineering cost analysis should be conducted to evaluate appropriate corrective measures.

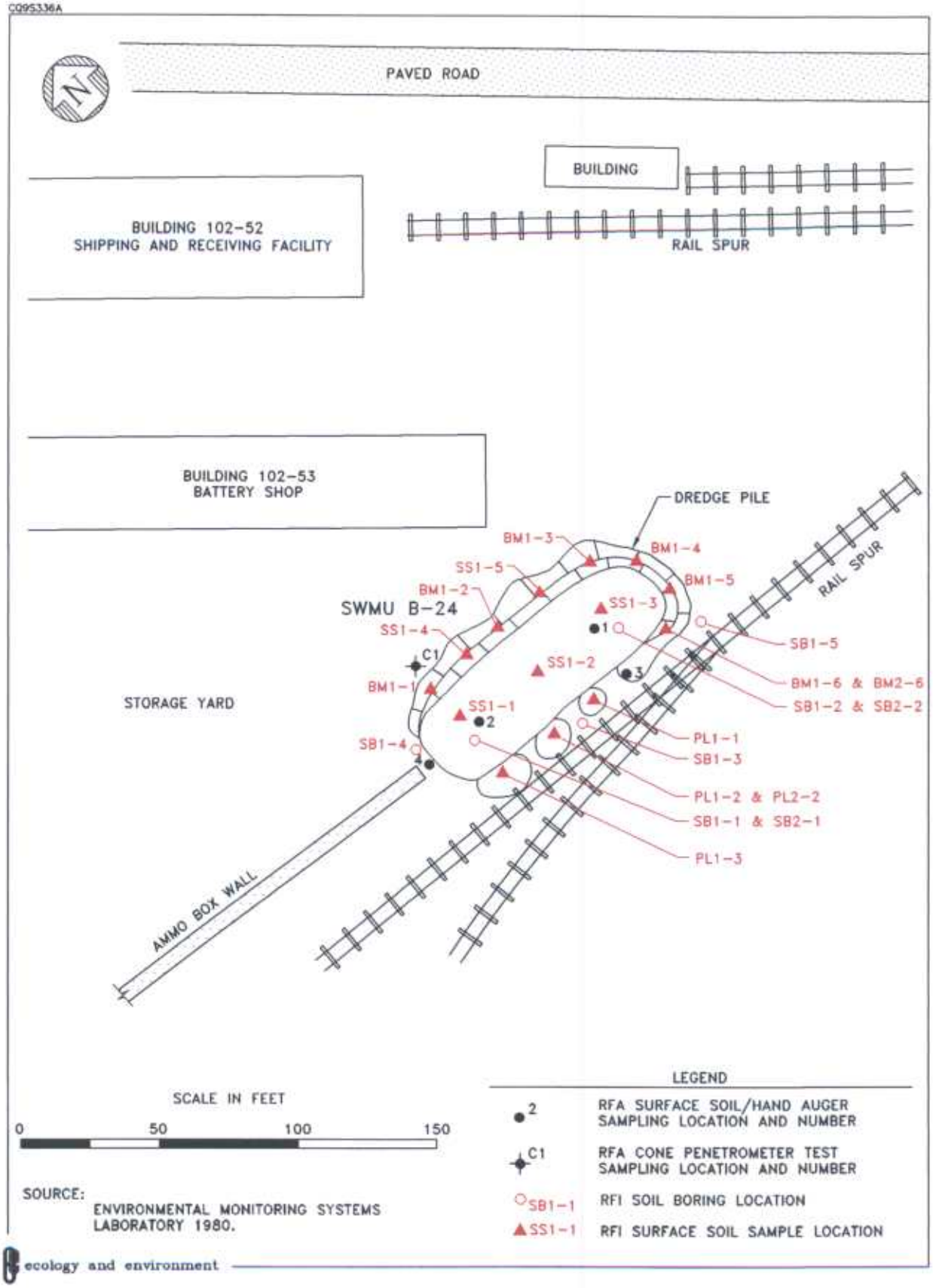


Figure 3-3 SAMPLE LOCATIONS AT SWMU B-24
ACID IMPOUNDMENT
HAWTHORNE ARMY DEPOT

Plotted: 05/07/07

Table 3-11

SWMU B-24
102-52 ACID PIT
SOIL SAMPLE SUMMARY
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

EPA Method Number	Analytical Parameter	RFA Samples (August 1994)			RFI Samples (September 1996)								
								Subsurface Samples Per Depth Interval (5 Boring Locations)					
		Surface Soil	Hand Auger	CUT Samples	Soil Piles	Soil Berms	Surface Soil	5 feet	10 feet	20 feet	30 feet	40 feet	60 feet
8080	Pesticides/ PCBs	4	2	2	3	6	5	5	5	---	---	---	---
8240	VOC	---	2	2	---	---	---	---	---	5	5	5	5
8270	SVOC	4	2	2	3	6	5	5	5	5	5	5	5
8015M	TPH-G/D	4	2	2	3	6	5	5	5	5	5	5	5
6000/7000	Metals	4	2	2	---	---	---	---	---	---	---	---	---
7421	Lead	---	---	---	3	6	5	5	5	---	---	---	---
8330	Explosives	4	2	2	3	6	5	5	5	5	5	5	5
8330M	Picric Acid	4	2	2	3	6	5	---	---	---	---	---	---
353.2	Nitrate	4	2	2	---	---	---	---	---	---	---	---	---
Field Screening	TNT/RDX	4	2	2	3	6	5	5	5	5	5	5	5

Notes: Sample numbers do not include QA/QC samples.

Metals analysis included silver, arsenic, barium, cadmium, lead, selenium, and mercury.

Key:

--- = Sample not collected.

07:CQ9903_K1083-05/06/97-D1

Table 3-12

SWMU B-24
RFA ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA
Concentrations In mg/kg (p.m.)

Sample No./ Parameter	B-24 HA1-1-000	B-24 HA1-1-005	B-24 HA1-2-000	B-24 HA1-2-005	B-24 SS1-1-000	B-24 CPS1-1-011	B-24 CPS1-1-020
Sample Depth (feet)	0.5 - 1.0	5.0 - 5.5	0.5 - 1.0	5.0 - 5.5	0.0 - 0.5	11.0 - 11.5	20.5 - 21.5
Nitrate-nitrogen (9200)	ND	ND	ND	ND	ND	ND	ND
Metals							
Silver (Method 1010)	2.5	ND	ND	ND	4.5	ND	ND
Arsenic (Method 7060)	15 J	3.8 J	12 J	7.3 J	10 J	5.6	3.2
Barium (Method 6010)	190	130	160	140	220	110	110
Cadmium (Method 6010)	7.5	6.2	11	5.8	12	ND	ND
Chromium (total) (Method 6010)	47	13	29	11	94	7.2	4.6
Lead (Method 7421)	620	16	280	73	560	5.4	2.7
Selenium (Method 7740)	ND	ND	ND	ND	1.2	ND	ND
Mercury (Method 7471)	ND	ND	ND	ND	0.13	ND	ND
Nitroaromatics (Method 8330)							
RDX	150	ND	55	ND	ND	ND	ND
1,3,5-TNB	ND	ND	ND	ND	0.28 JN	ND R	ND R
2,4,6-TNT	0.39 J	0.40 JN	ND	0.26 JN	0.45 JN	ND	ND
2-Amino-DNT	ND	ND	ND	ND	0.33 JN	ND	ND

07:CQ9903_K1083-05/07/97-D1

Key at end of table.

Table 3-12

SWMU B-24
RFA ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA
Concentrations In mg/kg (p.m.)

Sample No./ Parameter	B-24 HA1-1-000	B-24 HA1-1-005	B-24 HA1-2-000	B-24 HA1-2-005	B-24 SS1-1-000	B-24 CPS1-1-011	B-24 CPS1-1-020
Nitroaromatics (Method 8330) (Cont.)							
2,6-DNT	0.34 J	ND	ND	ND	0.31 JN	ND	ND
Picric Acid	ND UJ	ND UJ	ND UJ	ND UJ	ND UJ	ND	ND
Total Petroleum Hydrocarbons (Method 8015M)							
TPH as diesel	34,000	1,300 J	6,700	2,600 J	14,000	ND	ND
TPH as gasoline	80 J	8.0 J	ND	ND	16	ND	ND
Pesticides/PCBs (Method 8080)							
PCB-1260	ND	0.034	1.6	ND	36	ND	ND UJ
Semivolatile Organics (Method 8290)							
Phenanthrene	0.76 J	ND	ND	ND	ND	ND	ND
Di-n-butyl-phthalate	20 J	2.22	1.6 J	1.1	0.46 J	ND	ND
Pyrene	1.2 J	ND	ND	0.099 J	ND	ND	ND
Bis-(2-ethylhexyl) phthalate	40	2.0 J	5.5	4.0	3.6 J	ND	ND

NOTE: Sediment sample B-24 SS1-2-000 was not submitted for laboratory analysis because of high explosives screening values for RDX.

Key:

J = Estimated value.
JN = Estimated value, analyte not confirmed by alternate procedure.
ND = Not detected.
R = Analyte was not verified, resampling and reanalysis needed to confirm.
Shaded area = Values exceed remediation criteria in Table 1-2.

Table 3-13

SWMU B-24
TNT AND RDX
FIELD SCREENING DATA
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA
September 1996

SWMU #	Sample Location	Sample Depth (ft. BGS)	Screening Results	
			RDX Concentration Range (ppm)	TNT Concentration Range (ppm)
B-24	SB1-1	5	<0.5	<0.5
B-24	SB1-1	10	<0.5	<0.5
B-24	SB1-1	20	<0.5	<0.5
B-24	SB1-1	30	<0.5	<0.5
B-24	SB1-1	40	<0.5	<0.5
B-24	SB1-1	60	<0.5	<0.5
B-24	SB1-2	5	<0.5	<0.5
B-24	SB1-2	10	<0.5	<0.5
B-24	SB1-2	20	<0.5	<0.5
B-24	SB1-2	30	2.5 to 4.5	<0.5
B-24	SB1-2	40	0.5 to 1.5	<0.5
B-24	SB1-2	60	<0.5	<0.5
B-24	SB1-3	5	<0.5	<0.5
B-24	SB1-3	10	<0.5	<0.5
B-24	SB1-3	20	<0.5	<0.5
B-24	SB1-3	30	<0.5	1.5 to 3.0
B-24	SB1-3	40	<0.5	<0.5
B-24	SB1-3	60	<0.5	<0.5
B-24	SB1-4	5	1.5 to 2.5	<0.5
B-24	SB1-4	10	<0.5	<0.5
B-24	SB1-4	20	<0.5	<0.5
B-24	SB1-4	30	<0.5	<0.5
B-24	SB1-4	40	1.5 to 2.5	<0.5
B-24	SB1-4	60	1.5 to 2.5	<0.5
B-24	SB1-5	5	<0.5	<0.5
B-24	SB1-5	10	<0.5	<0.5

Table 3-13

SWMU B-24
TNT AND RDX
FIELD SCREENING DATA
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA
September 1996

SWMU #	Sample Location	Sample Depth (ft. BGS)	Screening Results	
			RDX Concentration Range (ppm)	TNT Concentration Range (ppm)
B-24	SB1-5	20	1.5 to 2.5	<0.5
B-24	SB1-5	30	<0.5	<0.5
B-24	SB1-5	40	<0.5	<0.5
B-24	SB1-5	60	<0.5	<0.5
B-24	PL1-1	3.0	<0.5	<0.5
B-24	PL1-2	3.0	<0.5	0.5 to 1.5
B-24	PL1-3	3.0	<0.5	<0.5
B-24	BM1-1	3.0	<0.5	<0.5
B-24	BM1-2	3.0	<0.5	<0.5
B-24	BM1-3	3.0	<0.5	<0.5
B-24	BM1-4	3.0	<0.5	<0.5
B-24	BM1-5	3.0	<0.5	<0.5
B-24	BM1-6	3.0	<0.5	<0.5
B-24	SS1-1	.5	<0.5	<0.5
B-24	SS1-2	.5	<0.5	<0.5
B-24	SS1-3	.5	1.5 to 2.5	<0.5
B-24	SS1-4	.5	<0.5	<0.5
B-24	SS1-5	.5	<0.5	<0.5

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Surface Soil					Berm Soil	
Sample Number	**2-B24-SS1-1-000**	**2-B24-SS1-2-000**	**2-B24-SS1-3-000**	**2-B24-SS1-4-000**	**2-B24-SS1-5-000**	**2-B24-BM1-1-000**	**Soil Remediation Criteria**
Depth (feet)	**0 to 0.5**	**0 to 0.5**	**0 to 0.5**	**0 to 0.5**	**0 to 0.5**	**3.0 to 4.0**	
Total Petroleum Hydrocarbons (mg/kg)							
TPH as Diesel (Method 8015m)	36 J	98 J	18 J	ND (5.0 U)	ND (5.0 U)	50	100
TPH as Gasoline (Method 8015m)	ND (5.6 U)	ND (5.6 U)	33	ND (5.0 U)	ND (5.0 U)	ND (5.1 U)	100
Metals (mg/kg)							
Lead (Method 7421)	510	640	1,700	31	5.7	63	100
Nitroaromatics (Method 8030) (mg/kg)							
HMX	7.5	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (10.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)							
PCB 1260	0.83	1.2	2.8	0.014 J	ND (0.020 U)	0.093	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)							
Benzo(a)Pyrene	ND (7.4 U)	ND (18 U)	ND (22 U)	ND (0.330 U)	ND (0.33 U)	0.057 J	0.096
Bis(2-ethylhexyl)phthalate	54	96	67	.094 J	0.034 J	ND (0.340 UJ)	50
Chrysene	ND (7.4 U)	ND (18 U)	ND (22 U)	ND (0.330 U)	ND (0.330 U)	.041 J	95.9
Di-N-Butyl-Phthalate	11	22	32	0.40	0.540	ND (0.340 UJ)	8,000
Indeno(1,2,3-cd)Pyrene	ND (7.4 U)	ND (18 U)	ND (22U)	ND (0.330 U)	ND (0.330 U)	ND (0.340 UJ)	—
Pyrene	ND (7.4 U)	ND (18 U)	ND (22U)	ND (0.340 U)	ND (0.330 U)	ND (0.340 UJ)	2,400
Volatile Organics (Method 8240) (mg/kg)							
Carbon Disulfide	NA	NA	NA	NA	NA	NA	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Berm Soil					
Sample Number	**2-B24-BM1-2-000**	**2-B24-BM1-3-000**	**2-B24-BM1-4-000**	**2-B24-BM1-5-000**	**2-B24-BM1-6-000**	**Soil Remediation Criteria**
Depth (feet)	**3.0 to 4.0**	**3.0 to 4.0**	**3.0 to 4.0**	**3.0 to 4.0**	**3.0 to 4.0**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	ND (5.0 U)	ND (5.0 U)	100
TPH as Gasoline (Method 8015m)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	ND (5.0 U)	100
Metals (mg/kg)						
Lead (S.O. 7421)	4.5	3.7	6.3	3.9	6.1	100
Nitroaromatics (Method 8030) (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8030) (mg/kg)						
PCB 1260	ND (0.020 U)	ND (0.020 U)	ND (0.020 U)	0.010 J	0.29	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	50
Chrysene	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	95.9
Di-N-Butyl-Phthalate	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	—
Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.33 U)	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	NA	NA	NA	NA	NA	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Berm Soil	Soil Pile				
Sample Number	**2-B24-BM2-6-000**	**2-B24-PL1-1-000**	**2-B24-PL1-2-000**	**2-B24-PL2-2-000**	**2-B24-PL1-3-000**	**Soil Remediation Criteria**
Depth (feet)	**3.0 to 4.0**	**2.0 to 3.0**	**2.0 to 3.0**	**2.0 to 3.0**	**2.0 to 3.0**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.0 U)	4,700	1,300	1,500	310	100
TPH as Gasoline (Method 8015m)	ND (5.0 U)	6.7	ND (5.3 U)	ND (5.2 U)	ND (5.1 U)	100
Metals (mg/kg)						
Lead (Method 7421)	4.0	170	80	63	49	100
Nitroaromatics (Method 8030) (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)						
PCB 1260	0.22	13	4.4	4.1	1.3	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.33 U)	ND (1.7 U)	ND (0.35 U)	ND (0.34 UJ)	ND (0.34 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.33 U)	ND (3.7 U)	ND (0.68 U)	ND (0.69 UJ)	ND (0.34 U)	50
Chrysene	ND (0.33 U)	ND (1.7 U)	ND (0.35 U)	0.070 J	0.044 J	95.9
Di-N-Butyl-Phthalate	0.048 J	ND (1.7 U)	ND (0.35 U)	ND (0.34 UJ)	ND (0.34 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.33 U)	ND (1.7 U)	ND (0.35 U)	ND (0.34 UJ)	0.040 J	—
Pyrene	ND (0.33 U)	ND (1.7 U)	ND (0.35 U)	0.074 J	0.061 J	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	NA	NA	NA	NA	NA	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 1						Soil Remediation Criteria
Sample Number	**2-B24-SB1-1-005**	**2-B24-SB1-1-010**	**2-B24-SB1-1-020**	**2-B24-SB1-1-030**	**2-B24-SB2-1-030**	**2-B24-SB1-1-040**	
Depth (feet)	**5.0 to 7.5**	**10.0 to 12.5**	**20.0 to 22.5**	**30.0 to 32.5**	**30.0 to 32.5**	**40.0 to 42.5**	
Total Petroleum Hydrocarbons (mg/kg)							
TPH as Diesel (Method 8015m)	ND (6.2 UJ)	130 J	ND (5.5 U)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	100
TPH as Gasoline (Method 8015m)	ND (6.2 U)	ND (5.1 U)	ND (5.5 U)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	100
Metals (mg/kg)							
Lead (Method 7421)	8.1	2.3	NA	NA	NA	NA	100
Nitroaromatics (Method 8030) (mg/kg)							
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)							
PCB 1260	ND (0.025 U)	ND (0.020 U)	NA	NA	NA	NA	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)							
Benzo(a)Pyrene	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	50
Chrysene	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	95.9
Di-N-Butyl-Phthalate	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	–
Pyrene	ND (0.41 U)	ND (0.34 U)	ND (0.36 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	2,400
Volatile Organics (Method 8240) (mg/kg)							
Carbon Disulfide	NA	NA	0.0047 J	ND (0.0051 U)	ND (0.0051 UJ)	ND (0.0051 U)	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 1	Soil Boring 2					
Sample Number	**2-B24-SB1-1-060**	**2-B24-SB1-2-005**	**2-B24-SB1-2-010**	**2-B24-SB1-2-020**	**2-B24-SB2-2-020**	**2-B24-SB1-2-030**	**Soil Remediation Criteria**
Depth (feet)	**60.0 to 62.5**	**5.0 to 7.5**	**10.0 to 12.5**	**20.0 to 22.5**	**20.0 to 22.5**	**30.0 to 32.5**	
Total Petroleum Hydrocarbons (mg/kg)							
TPH as Diesel (Method 8015m)	ND (7.2 U)	130	ND (5.2 U)	ND (5.2 U)	ND (5.2 U)	5.6	100
TPH as Gasoline (Method 8015m)	ND (7.2 U)	ND (6.2 U)	ND (5.2 U)	ND (5.2 U)	ND (5.2 U)	ND (5.3 U)	100
Metals (mg/kg)							
Lead (Method 7421)	NA	10	2.0	NA	NA	NA	100
Nitroaromatics (Method 8030) (mg/kg)							
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)							
PCB 1260	NA	ND (0.025 U)	ND (0.021 U)	NA	NA	NA	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)							
Benzo(a)Pyrene	ND (0.48 U)	ND (0.41 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND 350 UJ)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.48 U)	0.130 J	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.35 UJ)	50
Chrysene	ND (0.48 U)	ND (0.41 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.35 UJ)	95.9
Di-N-Butyl-Phthalate	ND (0.48 U)	ND (0.41 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.35 UJ)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.48 U)	ND (0.41 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.35 UJ)	—
Pyrene	ND (0.48 U)	ND (0.41 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.35 UJ)	2,400
Volatile Organics (Method 8240) (mg/kg)							
Carbon Disulfide	ND (0.0072 U)	NA	NA	ND (0.0052 U)	ND (0.0052 U)	ND (0.0052 U)	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 2		Soil Boring 3			Soil Remediation Criteria
Sample Number	**2-B24-SB1-2-040**	**2-B24-SB1-2-060**	**2-B24-SB1-3-005**	**2-B24-SB1-3-010**	**2-B24-SB1-3-020**	
Depth (feet)	**40.0 to 42.5**	**60.0 to 62.5**	**5.0 to 7.5**	**10.0 to 12.5**	**20.0 to 22.5**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.6 U)	ND (5.2 U)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	100
TPH as Gasoline (Method 8015m)	ND (5.6 U)	ND (5.2 U)	ND (5.1 U)	ND (5.1 U)	ND (5.1 U)	100
Metals (mg/kg)						
Lead (Method 7421)	NA	NA	3.7	2.5	NA	100
Nitroaromatics (Method 8030) (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (mg/kg)						
PCB 1260	NA	NA	ND (0.020 U)	ND (0.020 U)	NA	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	50
Chrysene	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	95.9
Di-N-Butyl-Phthalate	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	–
Pyrene	ND (0.37 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	0.0065	ND (0.0052 U)	NA	NA	ND (0.0051 U)	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 3			Soil Boring 4		
Sample Number	**2-B24-SB1-3-030**	**2-B24-SB1-3-040**	**2-B24-SB1-3-060**	**2-B24-SB1-4-005**	**2-B24-SB1-4-010**	**Soil Remediation Criteria**
Depth (feet)	**30.0 to 32.5**	**40.0 to 42.5**	**60.0 to 62.5**	**5.0 to 7.5**	**10.0 to 12.5**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.4 U)	ND (5.1 U)	ND (5.5 U)	ND (5.3 U)	ND (5.1 U)	100
TPH as Gasoline (Method 8015m)	ND (5.4 U)	ND (5.1 U)	ND (5.5 U)	ND (5.3 U)	ND (5.1 U)	100
Metals (mg/kg)						
Lead (Method 7421)	NA	NA	NA	9.8	1.4	100
Nitroaromatics (Method 8030) (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)						
PCB 1260	NA	NA	NA	0.021	ND (0.020 U)	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.36 U)	ND (0.34 U)	ND (0.36 U)	ND (0.35 U)	ND (0.34 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.36 U)	ND (0.34 U)	ND (0.36 U)	0.037 J	0.044 J	50
Chrysene	ND (0.36 U)	ND (0.34 U)	ND (0.36 U)	ND (0.35 U)	ND (0.34 U)	95.9
Di-N-Butyl-Phthalate	ND (0.36 U)	0.550	ND (0.36 U)	0.580	ND (0.34 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.36 U)	ND (0.34 U)	ND (0.36 U)	ND (0.35 U)	ND (0.34 U)	—
Pyrene	ND (0.36 U)	ND (0.34 U)	ND (0.36 U)	ND (0.35 U)	ND (0.34 U)	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	ND (0.0054 U)	ND (0.0051 U)	ND (0.0055 U)	NA	NA	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 4				Soil Boring 5	
Sample Number	**2-B24-SB1-4-020**	**2-B24-SB1-4-030**	**2-B24-SB1-4-040**	**2-B24-SB1-4-060**	**2-B24-SB1-5-005**	**Soil Remediation Criteria**
Depth (feet)	**20 to 22.5**	**30 to 32.5**	**40 to 42.5**	**60 to 62.5**	**5 to 7.5**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.2 U)	ND (5.7 U)	ND (5.2 U)	ND (5.2 U)	ND (5.1 U)	100
TPH as Gasoline (Method 8015m)	ND (5.2 U)	ND (5.7 U)	ND (5.2 U)	ND (5.2 U)	ND (5.1 U)	100
Metals (mg/kg)						
Lead (Method 7421)	NA	NA	NA	NA	2.7	100
Nitroaromatics (Method 8030 (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)						
PCB 1260	NA	NA	NA	NA	ND (0.020 U)	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	0.096
Bis(2-ethylhexyl)phthalate	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	50
Chrysene	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	95.9
Di-N-Butyl-Phthalate	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	—
Pyrene	ND (0.34 U)	ND (0.38 U)	ND (0.34 U)	ND (0.34 U)	ND (0.34 U)	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	ND (0.0052 U)	ND (0.0057 U)	ND (0.0052 U)	ND (0.0052 U)	NA	8,000

Key at end of table.

Table 3-14

SWMU B-24
102-52 ACID PIT
RFI ANALYTICAL RESULTS
HAWTHORNE ARMY DEPOT
HAWTHORNE, NEVADA

	Soil Boring 5					Soil Remediation Criteria
Sample Number	**2-B24-SB1-5-010**	**2-B24-SB1-5-020**	**2-B24-SB1-5-030**	**2-B24-SB1-5-040**	**2-B24-SB1-5-060**	
Depth (feet)	**10 to 12.5**	**20 to 22.5**	**30 to 32.5**	**40 to 42.5**	**60 to 62.5**	
Total Petroleum Hydrocarbons (mg/kg)						
TPH as Diesel (Method 8015m)	ND (5.2 U)	ND (5.2 U)	ND (5.4 U)	ND (5.1 U)	ND (5.3 U)	100
TPH as Gasoline (Method 8015m)	ND (5.2 U)	ND (5.2 U)	ND (5.4 U)	ND (5.1 U)	ND (5.3 U)	100
Metals (mg/kg)						
Lead (Method 7421)	3.3	NA	NA	NA	NA	100
Nitroaromatics (Method 8030) (mg/kg)						
HMX	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	ND (1.0 U)	4,000
Pesticides/PCBs (Method 8080) (mg/kg)						
PCB 1260	ND (0.021 U)	NA	NA	NA	NA	0.09
Semi-Volatile Organics (Method 8270) (mg/kg)						
Benzo(a)Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	0.096
Bis(2-ethylhexyl)phthalate	0.042 J	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	50
Chrysene	ND (0.34 U)	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	95.9
Di-N-Butyl-Phthalate	ND (0.34 U)	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	8,000
Indeno(1,2,3-cd)Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	—
Pyrene	ND (0.34 U)	ND (0.34 U)	ND (0.35 U)	ND (0.34 U)	ND (0.35 U)	2,400
Volatile Organics (Method 8240) (mg/kg)						
Carbon Disulfide	NA	ND (0.0052 U)	ND (0.0054 U)	ND (0.0051 U)	ND (0.0053 U)	8,000

Key at end of table.

Table 3-14 (Continued)

Notes: Picric acid was analyzed for but not detected at SWMU B-24.
Lead was the only metal analyzed for at SWMU B-24 during the RFI.

Key:

ND	=	The material was analyzed for, but was not detected. The associated numerical value in parentheses is a method quantitation limit adjusted for sample weight/sample volume, extraction volume, percent solids, and sample dilution.
U	=	Not detected.
NA	=	Not analyzed.
J	=	Estimated value.
TPH	=	Total petroleum hydrocarbons.
mg/kg	=	Milligrams per kilogram.
HMX	=	Cyclotetramethylenetetranitramin.
Shaded area	=	Value exceeds soil remediation criteria.

APPENDIX B

American Petroleum Institute (API) Bulletin No. 9

Non-Aqueous Phase Liquid (NAPL) Mobility Limits in Soil, American Petroleum Institute (API), June 2000

American Petroleum Institute

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SOIL & GROUNDWATER RESEARCH BULLETIN

A summary of research results from the American Petroleum Institute & GRI.

June 2000 No. 9

NON-AQUEOUS PHASE LIQUID (NAPL) MOBILITY LIMITS IN SOIL

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ABSTRACT

Conservative screening concentrations for non-aqueous phase liquids (NAPL) that could be considered immobile in unsaturated zone soils are presented. Total concentrations measured at a crude oil or petroleum product release site (using total petroleum hydrocarbon [TPH] or a similar analysis method) can be compared to the screening concentrations to determine the potential for NAPL to migrate in soil. The screening values are based on an analysis of published data for a range of soil texture classifications and a range of NAPL density from 0.7 to 1.5 g/cm3.

The paper includes summary tables and histograms of residual NAPL void fraction, Sr, as a function of soil type. These provide a basis for selecting conservative values used in calculating screening concentrations for immobile NAPL. For example, in medium to coarse sands, with Sr = 0.06 cm3-oil/cm3-void, one would expect that NAPL would be immobile in 90% of samples with equivalent NAPL concentration levels for this soil type.

Measured concentrations of immobile NAPL reported in the literature vary considerably with soil type, chemical composition, and the measurement method. The proposed screening levels are conservative (lower range) estimates within the range of measured residual NAPL concentration values. Higher values could be applicable in many cases, both in unsaturated and saturated soil conditions.

This paper addresses immobile bulk NAPL in soils at concentrations up to the threshold of mobility. This document does not address the movement and flow of NAPL, the dissolution of NAPL chemical into soil pore water solution, nor NAPL volatilization into soil pore air. Transport by these mechanisms may be estimated using other published and accepted methods.

INTRODUCTION

Organic chemicals released to soil may migrate as vapors in soil gas, as dissolved constituents in soil pore water, or as a bulk phase liquid which is immiscible in water. Assessment of potential migration pathways for chemical releases into the environment are discussed in several related documents (USEPA 1996, 1991; ASTM E1739, PS104-98). These migration pathways are important in a general risk-based site assessment. This paper is confined to discussion of the mobility of non-aqueous phase liquids, either as pure chemicals or as chemical mixtures.

Many organic chemicals, including hydrocarbons, are nearly immiscible in water. Release of a non-aqueous phase liquid (NAPL) to near-surface unsaturated soil can result in downward gravity-driven migration of the NAPL towards the water table. At the water table, light nonaqueous phase liquids (LNAPL), including petroleum, which are less dense than water, will mound and spread horizontally. LNAPL may also move with the groundwater gradient. Dense nonaqueous phase liquids (DNAPL) will migrate downward, mound, and spread horizontally, until a path of least resistance further downward into the saturated region is found. This could be when the accumulation is great enough to exceed the capillary entry pressure into the saturated zone, or when the DNAPL mound reaches a region of high vertical permeability, or when it reaches a fracture.

The volume of mobile NAPL depletes as immobile residual chemical is left behind through the soil column in which the NAPL is descending. NAPL migration may be limited by this depletion, or by physical barriers, such as low permeability layers. Our intent in this paper is to determine conservative NAPL concentrations in unsaturated soil, below which the NAPL will be immobile. By "conservative" we mean under-predicting the concentration at which mobility would actually occur.

PRESENCE OF A NAPL IN SOIL

For a pure chemical, NAPL will not be present at concentrations below the soil saturation limit (USEPA, 1996; ASTM E1739, PS104-98), defined as:

$$C_{sat,soil,i} = S_i \cdot \left(\frac{\theta_w + K_{oc,i} \cdot f_{oc} \cdot \rho_s + H_i \cdot \theta_a}{\rho_s} \right) \qquad [1]$$

with

$C_{sat,soil,i}$	soil saturation limit for chemical i (mg/kg)
S_i	pure chemical aqueous solubility limit for chemical i (mg/L)
θ_w	soil water content (cm^3-water/cm^3-soil)

$K_{oc,i}$ organic carbon/water partition coefficient for chemical i (L-water/kg-oc)

f_{oc} mass fraction of organic carbon in soil (g-oc/g-soil)

ρ_s dry soil bulk density (g/cm³)

H_i Henry's law coefficient for chemical i (cm³-water/cm³-air)

θ_a soil air content (cm³-air/cm³-soil)

For a pure chemical, $C_{sat,soil}$ is a value above which the chemical is present in soil pore water at its aqueous solubility limit, and is present in soil pore air at its saturated vapor concentration. Equilibrium partitioning of the chemical between soil (sorbed), pore water, and pore vapors at concentrations below $C_{sat,soil,i}$ is presumed.

For mixtures of miscible chemicals that are fractionally soluble in water, including petroleum, the concentration at which NAPL will be present is a function of the mixture composition. The soil saturation limit for the mixture, using methods presented in Johnson *et al.*, (1990), Mott (1995), and Mariner (1997), is:

$$\sum_{i=1}^{N} \left(\frac{C_{sat,soil,T} \cdot \chi_i \cdot \rho_s}{S_i \cdot (\theta_w + K_{oc,i} \cdot f_{oc} \cdot \rho_s + H_i \cdot \theta_a)} \right) = 1 \qquad [2]$$

with

$C_{sat,soil,T}$ soil saturation limit for the NAPL mixture, total concentration (mg/kg)

χ_i mass fraction of each chemical i in the NAPL mixture (kg/kg)

N the number of individual chemicals in the mixture

Note that Eq. [2] simplifies to Eq. [1] for a single chemical. The component concentration of a chemical i at the soil saturation limit in a mixture is ($C_{sat,soil,T} \cdot \chi_i$). The soil saturation limit calculated for a pure chemical, in every case, will be greater than the chemical component concentration ($C_{sat,soil,T} \cdot \chi_i$) calculated for a mixture, that is:

$$C_{sat\text{-}soil,i} \geq C_{sat,soil,T} \cdot \chi_i$$

Eq. [1] overstates $C_{sat\text{-}soil,i}$ for components in a mixture because it does not consider effective vapor pressure and solubility limits (Rault's law) for the mixture components (USEPA, 1996). The soil saturation limits for mixtures (and pure chemicals) tabulated in this paper were calculated with computer codes included with DeVaull *et. al.*, (1999). This method is consistent with the references cited above.

Residual NAPL Concentration

Our intent in this paper is to define a soil concentration, $C_{res,soil}$, below which the NAPL, if present, will not migrate due to convection or gravity. This refers to a pure chemical concentration or a total chemical mixture concentration, as applicable. This residual NAPL concentration in soil is specified as:

$$C_{res,soil} = \left(\frac{\theta_o \cdot \rho_o}{\rho_s} \right) \cdot 10^6 \ \frac{mg}{kg} \qquad [3]$$

with

$$\theta_o = S_r \cdot \theta_T$$

and

$C_{res,soil}$ residual NAPL concentration in soil (mg-res/kg-soil)

θ_o residual non-aqueous phase volume fraction (cm³-res/cm³-soil)

ρ_o density of chemical residual non-aqueous phase liquid (g-res/cm³-res)

ρ_s dry soil bulk density (g-soil/cm³-soil)

θ_T soil porosity (cm³-void/cm³-soil)

S_r fraction of residual non-aqueous phase filled void (cm³-res/cm³-void)

Residual non-aqueous phase volume fraction (θ_o, or retention capacity) is similarly defined by Cohen and Mercer (1990) and Zytner *et. al.*, (1993), but in dimensional units of (cm³-res/L-soil). The value of $C_{res,soil}$ is generally much larger than the soil saturation limit, $C_{sat,soil}$. Eq. [3] includes only the residual NAPL volume. Additional chemical mass within the soil matrix is contained in soil pore water and soil pore air, and is sorbed onto soil. These volumes may be included in a slightly more complicated equation consistent with the assumptions in Eqs. [1] and [2]; these terms may generally be neglected. This leaves the residual NAPL concentration in soil, $C_{res,soil}$, directly related to the residual NAPL volume fraction in soil, θ_o, or the residual NAPL fraction in the voids, S_r.

Below the residual NAPL concentration in soil, $C_{res,soil}$, capillary retention forces are greater than the gravitational forces which tend to mobilize the NAPL. These capillary forces (in this context, including surface tension effects, van der Waals, and Coulombic forces), particularly at low residual non-aqueous phase levels, may exceed the gravitational force by several orders of magnitude. The residual NAPL concentration in soil, $C_{res,soil}$, may depend on NAPL properties including liquid density, surface tension, and viscosity. It also may depend on soil properties including porosity, organic carbon fraction, moisture content, relative permeability, moisture wetting history, and soil heterogeneity.

For concentrations greater than the threshold $C_{res,soil}$ level, capillary retention forces are less than the gravitational forces, and the NAPL is mobile. Movement of NAPL in soil is beyond the scope of this paper. It is covered in a number of references, however, including Charbeneau (1999), Huntley and Beckett (1999), USEPA (1991), Cohen and Mercer (1990), and Pfannkuch (1983).

This paper describes the determination of screening values for NAPL immobility in soil. Screening values are expressed as the residual NAPL concentration in soil, $C_{res\text{-}soil}$, the non-aqueous phase volume fraction in soil, θ_o, and the residual non-aqueous phase fraction in the soil voids. Our study included a review of existing measured data on residual NAPL concentration in soil, published empirical models, and methods of field measurement.

The calculated value, $C_{sat,soil}$, as previously defined in Eqs. [1] and [2] predicts the presence or absence of a residual NAPL. Since a NAPL must be present to be mobile, it also represents a conceivable screening concentration for NAPL mobility. However, observed residual NAPL concentrations based either on laboratory measurement or physical removal of NAPL from impacted sites are typically several *orders of magnitude* higher

Table 1. Residual NAPL Concentration in Soil Compared to Soil Saturation Limit.

Name	Ref	S_r residual NAPL in the void fraction (cm^3/cm^3)	$C_{res,soil}$ residual NAPL concentration in soil (mg/kg)	$C_{sat,soil}$ soil saturation limit (mg/kg)	ρ_o liquid chemical density (g/cm^3)	MW molecular weight (g/g-mol)	S aqueous solubility (mg/L)	P_{vap} vapor pressure (mm Hg)
trichloroethylene (TCE)	a	0.2	70,000	1,045	1.46	131	1,100	75
benzene	b	0.24	53,000	444	0.88	78	1,750	95
o-xylene	c	0.01	2,000	143	0.88	106	178	6.6
gasoline	d,e	0.02 to 0.6	3,400 to 80,000	106	0.78	99	164	102
diesel	d,f	0.04 to 0.2	7,700 to 34,000	18	0.94	207	3.9	0.79
fuel oil	d,f	0.08 to 0.2	17,000 to 50,000	18	0.94	207	3.9	0.79
mineral oil	g	0.1 to 0.5	20,000 to 150,000	3	0.81	244	0.36	0.035

Notes: Unsaturated zone fine to medium sand. Nominal values $\theta_w = 0.12\ cm^3/cm^3$, $f_{oc} = 0.005$ g/g in $C_{sat,soil}$ calculation.
a = Lin et al. (1982); b = Lenham and Parker (1987); c = Boley and Overcamp (1998); d = Fussell et al. (1981); e = Hoag and Marley (1986); f = API (1980); g = Pfannkuch (1984).

than $C_{sat,soil}$. The value $C_{sat,soil}$ specifies the presence or absence of a residual phase; it does not address mobility. In this effort, we have used available data to define values for $C_{res,soil}$ which can be conservatively used to screen sites for NAPL mobility. A comparison of calculated $C_{sat,soil}$ values with measured values of $C_{res,soil}$ is shown in Table 1 for selected chemicals and hydrocarbon mixtures.

The trend of $C_{sat,soil}$ in Table 1 decreases with decreasing chemical (or mixture) solubility and vapor pressure. The measured values of residual NAPL concentration in soil and residual NAPL fraction in voids do not show a similar decreasing trend. Therefore, using a calculated $C_{sat,soil}$ value as a screening level for the mobility of a residual phase becomes increasingly and significantly more conservative for less soluble, less volatile chemicals and chemical mixtures.

Screening levels for NAPL mobility consistent with the definition of residual NAPL concentration n soil, $C_{res,soil}$, have already been implemented in a number of programs. The State of Ohio [OAC 3745-300-08 Generic Numerical Standards] has promulgated rules, including values of residual NAPL concentration in soil, for several combinations of specified soil types and petroleum composition ranges. The State of Washington [WAC 173-340-747 Part VII Cleanup Standards] has proposed values based on a similar methodology. CONCAWE (1979, 1981) provides residual NAPL concentration in soil values for a range of petroleum products and soil types.

Existing Models and Methods

Monographs are available which detail the movement of NAPL in soils (Charbeneau, 1999; Huntley and Beckett, 1999; USEPA, 1991; Cohen and Mercer, 1993; and Pfannkuch, 1983). Several investigators have specifically developed empirical models for predicting immobile NAPL, as a residual NAPL concentration in soil, $C_{res,soil}$, for a limited number of NAPL types in various soil matrices. Summaries of two published approaches follow.

Hoag and Marley (1986) proposed an empirical method to estimate residual NAPL saturation values for gasoline in dry sand and in sand matrices containing moisture at field capacity. Their equations, which relate measured gasoline retention at residual saturation with soil particle surface area, are:

$$C_{res,soil} = \left(1.154 \cdot 10^{-2} \cdot d_p + 0.652 \cdot 10^{-3}\right) \cdot \frac{6}{2.65 \cdot d_p \cdot \rho_w} \cdot 10^6 \frac{mg}{kg} \quad [4a]$$

zero soil moisture

$$C_{res,soil} = \left(1.136 \cdot 10^{-2} \cdot d_p + 0.131 \cdot 10^{-3}\right) \cdot \frac{6}{2.65 \cdot d_p \cdot \rho_w} \cdot 10^6 \frac{mg}{kg} \quad [4b]$$

field capacity soil moisture

with

$C_{res,soil}$ residual NAPL concentration in soil (mg-res/kg-soil)

d_p average sand particle diameter (cm)

ρ_w density of water (g/cm^3) = 1

Eqs. [4a] and [4b] refer, respectively, to residual NAPL concentration in dry soil and soil initially at field moisture capacity. An assumption in these equations is that the soil particles and soil surface area can be defined by an average soil particle diameter (Sauter mean diameter). These authors found that changes in soil surface area adequately predicted changes in residual NAPL saturation. Smaller soil particles have greater available surface area in a given volume or weight of soil, and the associated narrower pores will result in greater capillary forces. Residual NAPL concentration in soil therefore decreases with increasing particle size. At field capacity moisture content, measured $C_{res,soil}$ was reduced. At field capacity moisture, many of the smaller pore spaces are saturated with water. This reduces the overall pore volume available for trapping NAPL.

Eqs. [4a] and [4b] were developed using Connecticut sands sieved into three classifications; fine (d_p = 0.0225 cm), medium (d_p = 0.0890 cm) and coarse (d_p = 0.2189 cm). A fourth set of experiments was conducted using mixed sands with the mixture being made from equal portions of each of the above three classifications. Effectively, Eqs. [4a] and [4b] have been developed for data in the range of:

$$0.02\ cm < d_p < 0.22cm$$

Zytner *et. al.,* (1993) correlated measured soil retention capacity with soil porosity, soil bulk density, and NAPL density. Their experiments included several NAPL types in a variety of natural soils. The soils were air dried (less than 1.5% moisture), saturated with NAPL, and then allowed to drain. Their empirical equation, for dry soils is:

$$C_{res,soil} = \left(1.05 \cdot \theta_T \cdot \frac{\rho_o}{\rho_s} - 0.15\right) \cdot 10^6 \frac{mg}{kg} \quad [5]$$

th

:s,soil residual NAPL concentration in soil (mg-res/kg-soil)
soil porosity (cm³-void/cm³-soil)
density of chemical residual NAPL (g-res/cm³-res)
dry soil bulk density (g-soil/cm³-soil)

ıis study was limited to air dried soils and did not specifically clude sand. It does, however, show a dependence of $C_{res,soil}$ on il porosity, θ_T, and chemical density, ρ_o.

wide range of natural soils was used in the development of ɿ. [5], including sandy loam (θ_T = 0.45), clay (θ_T = 0.466), ganic top soil (θ_T = 0.555), two different peat mosses (θ_T ~ 8), as well as mixtures of these soils. Three NAPL types were cluded in their work to assess the influence of NAPL density ı retention capacity: tetrachloroethene (ρ_o = 1.622 g/cm³), ichloroethene (ρ_o = 1.456 g/cm³), and gasoline (ρ_o = 0.75 g/cm³). res,soil values obtained in their study ranged from 414,000 to ,894,000 mg/kg for PCE, 329,000 to 5,219,000 mg/kg for CE, and 94,000 to 2,738,000 mg/kg for gasoline. Effectively, q. [5] has been developed for data in the range of:

$$0.23 < \left(\theta_T \cdot \frac{\rho_o}{\rho_s}\right) < 6.7 \qquad [6]$$

'he broad range of values for $C_{res,soil}$ can be attributed to the ınge in soil densities, from 0.2 g/cm³ (peat moss) to 1.5 g/cm³ ;andy loam).

ıltho ugh the $C_{res,soil}$ measurements used in developing Eqs. [4] nd [5] were conducted by different researchers using different oils, a comparison of dry fine sand data (Hoag and Marley, 986; θ_T = 0.4, and ρ_s = 1.6 g/cm³) with dry sandy loam data Zytner *et. al.*, 1993; θ_T = 0.45, ρ_s = 1.5 g/ cm³) show very good greement of $C_{res,soil}$ of 104,000 and 115,000 mg/kg, respectively, or gasoline.

Measured Data and Comparison with Models

Cohen and Mercer (1990) compiled measured residual NAPL ;aturation data from several investigators, including residual NAPL fraction in the voids, S_r, or residual NAPL volume fraction, θ_o, for a number of organic liquids and soil types. These values represent the residual amount of hydrocarbon remaining n soil pore volume after the soil was saturated with hydrocarbon ınd then allowed to drain. Values from Cohen and Mercer, with ıdditional tabulated data from other references, are included in Table 2 (see pages 5 and 6). This table also includes ıdditional values derived from the experimental data, including the residual NAPL concentration in soil, $C_{res,soil}$.

The values in Table 2 vary considerably between experiments, soil types, and chemicals. While this may be due to differences in laboratory test methods, it may also indicate the reasonable range in measured residual NAPL concentration in soils encountered between different soil types, chemical types, and measurement observations.

Calculated values for the soil saturation limit, $C_{sat,soil}$, for the indicated chemicals or chemical mixtures, are included in Table 2. These values are plotted in Figure 1. In all cases, $C_{res,soil}$ is greater than $C_{sat,soil}$. As a measure of immobile NAPL, $C_{sat,soil}$

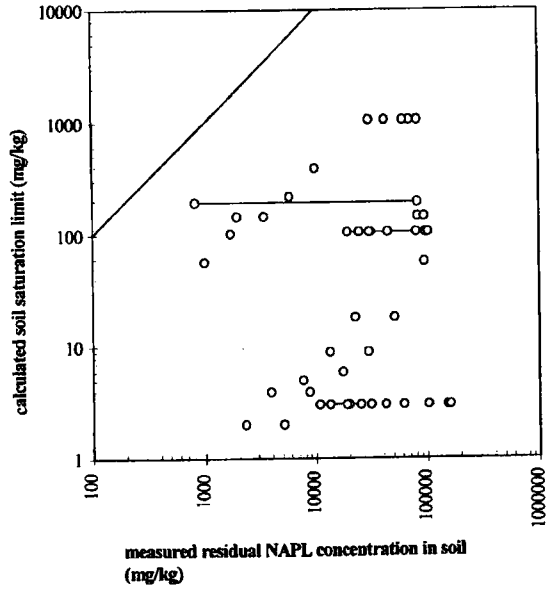

Figure 1. Comparison of data for residual NAPL concentration in soil, $C_{res,soil}$, to the calculated soil saturation limit, $C_{sat,soil}$. All plotted values are from Table 2. The solid diagonal line marks a direct correspondence between residual NAPL concentration in soil and soil saturation limit. For ranges of residual NAPL concentration in soil data in the same test series (Table 2), the upper and lower values are joined by a horizontal line. In all cases the calculated soil saturation limit is much less than the measured residual NAPL concentration in soil.

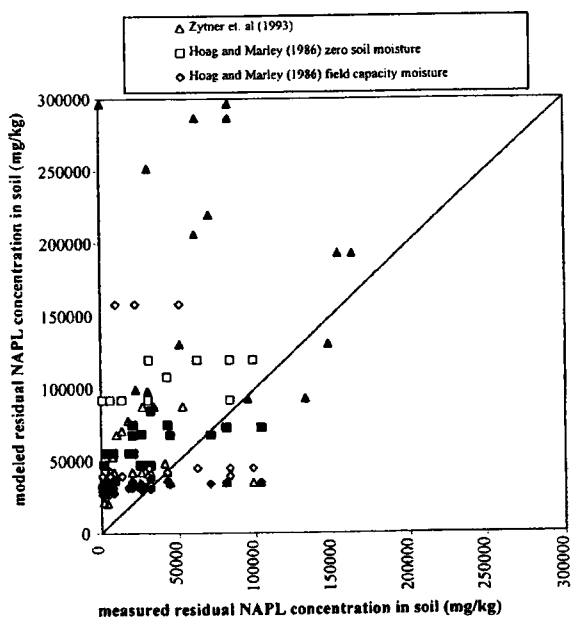

Figure 2. Comparison of data for residual NAPL concentration in soil, $C_{res,soil}$, from Table 2 to the models of Eq. [4a] Hoag and Marley (1986), zero soil moisture; Eq. [4b] Hoag and Marley (1986), field capacity soil moisture; and Eq. [5] Zytner et al., (1993). Filled points indicate the data value is within the intended range of model applicability. For ranges of residual NAPL concentration in soil data (Table 2), both the upper and lower values are shown as points. The solid diagonal line marks a direct correspondence between measured and modeled residual NAPL concentration in soil. The plot indicates that the empirical models generally predict higher residual NAPL concentration in soil than the measured values given in Table 2.

Table 2. Summary values of residual NAPL concentration in soil, $C_{res,soil}$, residual NAPL volume fraction, θ_o, and residual NAPL fraction in the voids, S_r. Calculated values for soil saturation limit, $C_{sat,soil}$, are also shown. Parameters for the calculations are shown in the second part of the table.

	NAPL	Soil Type	Ref	Measured S_r (cm^3/cm^3)	Measured $1000 \cdot \theta_o$ (cm^3/cm^3)	Measured $C_{res,soil}$ (mg/kg)	$C_{sat,soil}$ (mg/kg)
1.	Gasoline	coarse gravel	1	*0.01*	2.5	1,000	57
2.	Gasoline	coarse sand and gravel	1	*0.01*	4	1,697	102
3.	Gasoline	medium to coarse	1	*0.02*	7.5	3,387	143
4.	Gasoline	fine to medium sand	1	*0.03*	12.5	5,833	215
5.	Gasoline	silt to fine sand	1	*0.05*	20	10,000	387
6.	Middle distillates	coarse gravel	1	*0.02*	5	2,286	2
7.	Middle distillates	coarse sand and gravel	1	*0.02*	8	3,879	4
8.	Middle distillates	medium to coarse	1	*0.04*	15	7,742	5
9.	Middle distillates	fine to medium sand	1	*0.06*	25	13,333	9
10.	Middle distillates	silt to fine sand	1	*0.1*	40	22,857	18
11.	Fuel oils	coarse gravel	1	*0.04*	10	5,143	2
12.	Fuel oils	coarse sand and gravel	1	*0.05*	16	8,727	4
13.	Fuel oils	medium to coarse	1	*0.08*	30	17,419	6
14.	Fuel oils	fine to medium sand	1	*0.1*	50	30,000	9
15.	Fuel oils	silt to fine sand	1	*0.2*	80	51,429	18
16.	Light oil & gasoline	soil	2	0.18	*72*	40,800	9 (a)
17.	Diesel & light fuel oil	Soil	2	0.15	*60*	34,000	NE (b)
18.	Lube & heavy fuel oil	Soil	2	0.2	*80*	53,067	NE
19.	Gasoline	coarse sand	3	0.15 to 0.19	*61 to 77*	24,954 to 31,609	106
20.	Gasoline	medium sand	3	0.12 to 0.27	*48 to 109*	19,767 to 44,476	106
21.	Gasoline	fine sand	3	0.19 to 0.6	*76 to 240*	31,065 to 98,100	106
22.	Gasoline	Graded fine-coarse	3	0.46 to 0.59	*184 to 236*	80,500 to 103,250	106
23.	Mineral oil	Ottawa sand	4	0.11	*39*	20,116	3
24.	Mineral oil	Ottawa sand	4	0.14	*49*	25,602	3
25.	Mineral oil	Ottawa sand	4	0.172	*60*	31,454	3
26.	Mineral oil	Ottawa sand	4	0.235	*82*	42,975	3
27.	Mineral oil	glacial till [NA]	4	0.15 to 0.28	*30 to 56*	13,500 to 25,200	3
28.	Mineral oil	glacial till	4	0.12 to 0.21	*24 to 42*	10,800 to 18,900	3
29.	Mineral oil	alluvium [NA]	4	0.19	*95*	61,071	3
30.	Mineral oil	Alluvium	4	0.19	*95*	61,071	3
31.	Mineral oil	loess [NA]	4	0.49 to 0.52	*240*	154,000 to 163,800	3
32.	Paraffin oil	coarse sand	5	0.12	48	27,000	
33.	Paraffin oil	fine sediments	5	0.52	229	147,086	
34.	Paraffin oil	Ottawa sand	5	0.11 to 0.23	39	20,382 to 42,618	
35.	Trichloroethene	medium sand	6	0.2	*78*	70,448	1045
36.	Trichloroethene	fine sand	6	0.15 to 0.2	*65 to 86*	62,344 to 83,125	1067
37.	Trichloroethene	loamy sand	7	0.08	*33*	30,713	1057
38.	Tetrachloroethene	Fine/med. beach sand	8	0.002 to 0.20	1 to 82	830 to 83,025	195
39.	O-Xylene	Coarse sand	9	0.01	3	1,936	143
40.	Gasoline	Sandy loam	10	0.42 to 0.59	189 to 266	94,500 to 132,750	
41.	Tertrachloroethene	Sandy loam	10	0.85	383	413,000	
42.	Trichloroethene	Sandy loam	10	0.75 to 0.92	338 to 412	328,000 to 401,208	

Notes: 1 = Fussell et al. (1981); 2 = API (1980); 3 = Hoag and Marley (1986); 4 = Pfannkuch (1984); 5 = Converly (1979); 6 = Lin et al. (1982); 7 = Cary et al. (1989); 8 = Poulsen and Kueper (1992); 9 = Boley and Overcamp, (1998); 10 = Zytner et al. (1993).
(a) - Assumed 50:50 mixture diesel and gasoline to estimate $C_{sat,soil}$. (b) - NE = Not estimated, composition data not available.
Between reported S_r or θ_o, the italicized values represent the calculated term. These values were converted to concentrations in soil using available values for NAPL density, soil bulk density and porosity, as shown in the table.

Table 2. (continued) Values for soil properties used in the calculations.

	Hydrocarbon NAPL	Soil Type	θ_T Soil Porosity (cm^3/cm^3)	θ_w Pore Water (cm^3/cm^3)	f_{oc} Fraction of Organic Carbon (f_{oc})	ρ_s Soil Bulk Density (g/cm^3)	ρ_o Liquid Density (g/cm^3)	d_p Soil Particle Size (mm)
1.	Gasoline	coarse gravel	0.28	0.02	0.001	1.75	0.7	2 to 4
2.	Gasoline	coarse sand and gravel	0.35	0.03	0.002	1.65	0.7	0.5 to 4
3.	Gasoline	medium to coarse sand	0.39	0.04	0.003	1.55	0.7	1 to 0.25
4.	Gasoline	fine to medium sand	0.41	0.043	0.005	1.5	0.7	0.5 to 0.1
5.	Gasoline	silt to fine sand	0.44	0.045	0.01	1.4	0.7	0.25 to 0.002
6.	Middle distillates	coarse gravel	0.28	0.02	0.001	1.75	0.8	2 to 4
7.	Middle distillates	coarse sand and gravel	0.35	0.03	0.002	1.65	0.8	0.5 to 4
8.	Middle distillates	medium to coarse sand	0.39	0.04	0.003	1.55	0.8	1 to 0.25
9.	Middle distillates	fine to medium sand	0.41	0.043	0.005	1.5	0.8	0.5 to 0.1
10.	Middle distillates	silt to fine sand	0.44	0.045	0.01	1.4	0.8	0.25 to 0.002
11.	Fuel oils	coarse gravel	0.28	0.02	0.001	1.75	0.9	2 to 4
12.	Fuel oils	coarse sand and gravel	0.35	0.03	0.002	1.65	0.9	0.5 to 4
13.	Fuel oils	medium to coarse sand	0.39	0.04	0.003	1.55	0.9	1 to 0.25
14.	Fuel oils	fine to medium sand	0.41	0.043	0.005	1.5	0.9	0.5 to 0.1
15.	Fuel oils	silt to fine sand	0.44	0.045	0.01	1.4	0.9	0.25 to 0.002
16.	Light oil and gasoline	soil	0.4	0.04	0.005	1.5	0.75	
17.	Diesel and light fuel oil	Soil	0.4			1.5	0.9	
18.	Lube and heavy fuel oil	Soil	0.4			1.5	0.9	
19.	Gasoline	Coarse sand	0.4	0.04	0.002	1.6	0.7	1 to 0.5
20.	Gasoline	Medium sand	0.4	0.04	0.002	1.6	0.7	0.5 to 0.25
21.	Gasoline	fine sand	0.4	0.04	0.002	1.6	0.7	0.25 to 0.1
22.	Gasoline	well graded fine-coarse sand	0.4	0.04	0.002	1.6	0.7	1 to 0.1
23.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.5
24.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.35
25.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.25
26.	Mineral oil	Ottawa sand [NA]	0.35	No water	0.002	1.7	0.9	0.18
27.	Mineral oil	glacial till [NA]	0.2	No water	0.002	2	0.9	
28.	Mineral oil	glacial till	0.2	0.02	0.002	2	0.9	
29.	Mineral oil	alluvium [NA]	0.5	No water	0.002	1.4	0.9	
30.	Mineral oil	Alluvium	0.5	0.03	0.001	1.4	0.9	
31.	Mineral oil	loess [NA]	0.49	No water	0.002	1.4	0.9	
32.	Paraffin oil	coarse sand	0.4			1.6	0.9	1 to 0.5
33.	Paraffin oil	fine sediments	0.44			1.4	0.9	0.05 to 0.002
34.	Paraffin oil	Ottawa sand	0.35			1.7	0.9	0.5 to 0.18
35.	Trichloroethene	medium sand	0.39	0.04	0.003	1.6	1.46	0.5 to 0.25
36.	Trichloroethene	fine sand	0.43	0.04	0.005	1.5	1.46	0.25 to 0.1
37.	Trichloroethene	loamy sand	0.41	0.06	0.005	1.4	1.46	
38.	Tertrachloroethene	fine to medium beach sand	0.41	0.04	0.005	1.6	1.62	0.5 to 0.1
39.	O-Xylene	Coarse sand	0.33	0.04	0.003	1.6	0.88	1 to 0.5
40.	Gasoline	Sandy loam	0.45			1.5	0.75	
41.	Tertrachloroethene	Sandy loam	0.45			1.5	1.62	
42.	Trichloroethene	Sandy loam	0.45			1.5	1.46	

Notes: Porosity data and particle size information (ranges) estimated from USEPA (1991); pore water data adapted from Carsel and Parrish, (1988); f_{oc} data adapted from Wiedemeier et al., (1999).

underpredicts measured values of $C_{res,soil}$ by a factor ranging from 5 to over 50,000. As was noted in Table 1, the difference between $C_{sat,soil}$ and $C_{res,soil}$ increases with decreasing NAPL volatility and decreasing aqueous solubility.

A comparison of the data in Table 2 for residual NAPL concentration in soil, $C_{res,soil}$ to the models of Eq. [4a], [4b], and [5] is shown in Figure 2. Within the applicable range of values in the original references, both models predict values of $C_{res,soil}$ which are, on average, biased high relative to the comparable values listed in Table 2. In all cases, excepting point 38 (tetrachloroethene) in Table 2, for Eq. [4a], the model to data ratio ranges from 0.7 to 69; for Eq. [4b], the ratio ranges from 0.3 to 27; for Eq. [5], the model to data ratio ranges from 0.3 to 11. Point 38 has an exceptionally broad range of measured $C_{res,soil}$ values in the same soil.

Both the models of Zytner *et. al.*, (1993) and Hoag and Marley (1986) are correlations based on measured data. The indicated bias between the models and data of Table 2 could be due to differences in data measurements methods, or may indicate the reasonable range in variability for this type of measurement.

Screening Values for Residual NAPL Concentration

Based on the model to data comparisons of the last section, it is possible to specify conservative screening values for NAPL mobility based on a range of qualifying information. In many cases the screening levels will be very conservative estimates of mobility. In such cases, site-specific measurements may be used to refine the estimate, if necessary. Such measurements, for example, could include observation (or lack thereof) of floating and migrating hydrocarbon in shallow groundwater wells surrounding a known NAPL source area.

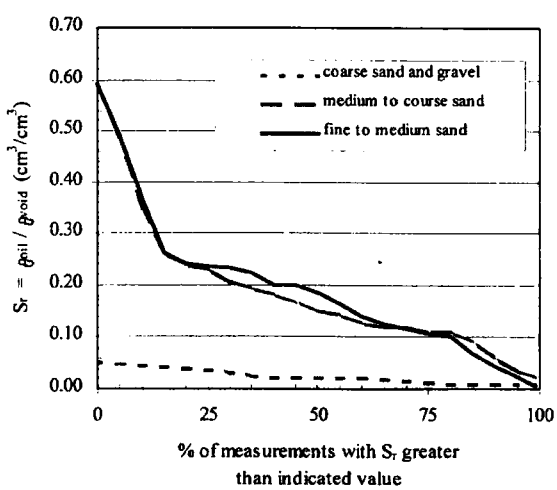

Figure 3. Cumulative distribution for measured residual NAPL void fraction, S_r, as a function of soil type. These cumulative histograms are based on the data in Table 2. Values for the "medium to course sand" and the "fine to medium sand" are very similar over the distribution. The "coarse sand and gravel" shows much lower values and narrower distribution of S_r over the range of different experiments. Tolerance limits for these distributions are given in Table 3.

Table 3. Screening values for residual phase void fraction as a function of soil type. The tabulated values are based on distributions of data from Table 2 for each soil type. The 95% statistical tolerance limit indicates that 5% of individual measurements showed lower values for S_r; the 50% tolerance limit is the median value for the soil type. The 90% tolerance limit is sufficiently conservative for most screening applications. The distribution of values is plotted in Figure 3.

Soil type	Indicated statistical tolerance limit		
	95%	90%	50%
	residual NAPL fraction in the voids, S_r, (cm³-res/cm³-void)		
coarse sand and gravel	0.01	0.01	0.02
medium to course sand	0.04	0.06	0.15
fine to medium sand	0.02	0.05	0.19

Table 4. Residual Saturation Screening Values. Values are tabulated for medium to coarse sand and represent lower limits from Table 2. If a tolerance limit is needed, or for chemicals not listed (but with densities in the range of 0.7 to 1.5 g/cm³, including petroleum products and crude oil), we suggest the use of the S_r parameters in Table 3 as screening values.

	Name	S_r residual NAPL fraction in the voids (cm³/cm³)	$C_{res,soil}$ residual NAPL concentration in soil (mg/kg)
(3.)	Gasoline	0.02	3,000
(8.)	Middle distillates	0.04	8,000
(13.)	Fuel oils	0.08	17,000
(39.)	O-xylene	0.01	2,000
(35.)	Trichloroethylene (TCE)	0.2	70,000

Note: Data row from Table 2 is indicated.

Several histograms of measured residual NAPL void fraction, S_r, as a function of soil type, are shown in Figure 3. These histograms are based on the relevant data in Table 2 and provide a basis for estimating conservative values of S_r within a specified statistical tolerance limit. Numerical values are given in Table 3. For example, with a medium to coarse sand, in specifying a screening level of S_r = 0.06, we would expect 90% of individual samples with equivalent NAPL concentrations below this level to be immobile in this soil type.

We expect that the tolerance limits in Table 3 and Figure 3 are biased conservatively, given that the Table 2 data showed lower residual NAPL concentration in soils than the empirical correlations of Eqs. [4] or [5]. The data in Table 2 is for NAPLs with densities ranging from about 0.7 to 1.5 g/cm³. The screening values for residual NAPL fraction in the voids, S_r, in Table 3, should be valid and reasonably conservative for this range in NAPL density.

Consolidated minimum values for S_r are shown in Table 4 for the various NAPL types in Table 2 listed as "medium sands". Again, these should be reasonably conservative screening values for NAPL mobility, for the indicated pure chemicals and hydrocarbon mixtures. No tolerance limits are specified for the Table 4 values, given the sparse data available when the screening values are qualified by both soil type and NAPL composition. If a tolerance limit is needed, or for chemicals not listed in Table 4 (with densities in the range of 0.7 to 1.5 g/cm³ including petroleum and crude oil), we suggest the use of the S_r parameters in Table 3 as screening values. A tolerance limit of 90% is reasonable in most cases.

These screening values are intended to be worst-case estimates for mobility. Higher values may be applicable on a site-specific basis. For example, with an adequate distance in unsaturated

soil between the lower depth of a mobile NAPL and groundwater, it may also be reasonable to account for potential NAPL redistribution in the unsaturated soil layer. This redistribution would decrease the concentrations of mobile NAPL to concentrations in soil equivalent. to S_r. After this redistribution, an acceptable distance between the deepest expected NAPL penetration and the historical top boundary of the water table capillary fringe must still remain.

These screening values, as already discussed, are intended for use in estimating conservative limits of NAPL mobility. The data of Table 2 may be used for other purposes, such as relating a known released volume of NAPL to an equivalent soil volume at the residual concentration level. While it is not the purpose of this paper to detail this type of calculation, the variability of an estimated residual concentration level, as illustrated in Figure 3, clearly needed to be considered.

Summary and Conclusions

Screening values describing residual saturation of NAPLs in unconsolidated vadose zone soils have been tabulated. These values are proposed for use in estimating concentrations of immobile NAPL in soil. The values, in Tables 3 and 4, are based on measured, published values for residual NAPL concentrations in soil, $C_{res,soil}$, in the unsaturated soil zone.

Another value, the soil saturation limit, $C_{sat,soil}$, has already found use as a screening level for NAPL mobility. $C_{sat,soil}$ is a calculated value estimating the presence of a residual NAPL. Data in this paper shows $C_{sat,soil}$, is a factor up to 50,000 times less than the residual NAPL concentration in soil, $C_{res,soil}$. For screening immobile NAPL concentrations the soil saturation limit is exceptionally conservative. We would instead recommend use of the values in Tables 3 and 4.

A complete site assessment, in addition, would also include evaluation of other potential transport mechanisms, including soluble dissolution into mobile soil pore water, and volatilization into soil pore air. These transport mechanisms, as noted previously, are discussed elsewhere.

Use of residual NAPL concentration in soil values for screening immobile NAPL presumes homogenous soils and soil properties. Consolidated soil matrices, macropores, and fractures will greatly affect the flow and movement of NAPL and must be recognized when these screening values are applied. Further, we note that the values have been developed using a limited data set, from multiple authors, and no attempt has been made to judge bias or error in the individual measurement techniques.

Acknowledgement

Support for preparing this document from American Petroleum and GRI (formerly the Gas Research Instutite) under GRI Contract No. 5097-210-3874 is gratefully acknowledged.

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APPENDIX C
Photo Documentation

B24 Pit Excavation

B24 Pit Backfill

B24 Pit Backfill
WARNING
HAZARDOUS
WASTE AREA
NO DUMPING
UNAUTHORIZED
PERSONNEL
KEEP OUT