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Kennedy/Jenks Consultants

Remedial Investigation/Feasibility Study
South Tacoma Field Superfund Site
Tacoma, WA

Remedial Investigation Report
Volume 1 of 6

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Draft Report

SOUTH TACOMA FIELD REMEDIAL
INVESTIGATION REPORT

SOUTH TACOMA FIELD REMEDIAL INVESTIGATION REPORT
(VOLUME 1 OF 6)

SOUTH TACOMA FIELD
SUPERFUND SITE
REMEDIAL INVESTIGATION AND FEASIBILITY STUDY

FINAL

Prepared for

SOUTH TACOMA FIELD SITE GROUP

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ACRONYMS FOR THE SOUTH TACOMA FIELD REMEDIAL INVESTIGATION REPORT

Acronym	Full Phrase
AA	atomic absorption
AFB	Air Force Base
AFWQC	acute freshwater quality criteria
AL	Action Level
APHA	American Public Health Association
ARAR	Applicable or Relevant and Appropriate Requirement (ARARs for plural)
ASTM	American Society for Testing Materials
ATSDR	Agency for Toxic Substances and Disease Registry (U.S. Public Health Service)
AWQC	Ambient Water Quality Criteria
BGS	below ground surface
BNA	base, neutral, acid (organic compounds)
BNR	Burlington Northern Railroad
CAA	Clean Air Act
CCC	calibration compound check
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund)
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System (EPA database of NPL sites)
CFWQC	chronic freshwater quality criteria
CLP	Contract Laboratory Program
CRDL	contract required detection limit
CRQL	contract required quantitation limit
CWA	Clean Water Act
DCE	1,2-dichloroethene
DEHP	bis(2-ethylhexyl)phthalate
DQO	data quality objective
DW	dry well
Ecology	Washington State Department of Ecology
EHI	Engineering Hydraulics Inc. (subconsultant for the geophysical survey)
EM	electromagnetic (geophysical survey)
EPA	U.S. Environmental Protection Agency
FLAA	flame atomic absorption
FR	Federal Register
FS	feasibility study
FSAP	field sampling and analysis plan

ACRONYMS FOR THE SOUTH TACOMA FIELD REMEDIAL INVESTIGATION REPORT

Acronym	Full Phrase
GC	gas chromatography
GC/ECD	gas chromatography/electron capture detection
GC/MS	gas chromatography/mass spectrometry
GFAA	graphite furnace atomic absorption
GIS	Geographic Information System
GPR	ground penetrating radar
HI	hazard index
HPLC	high pressure (or high performance) liquid chromatography
HQ	hazard quotient
ICP	inductively coupled plasma (atomic emission spectroscopy)
ICS	interference check sample
IDL	instrument detection limit
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MLW	mean low water
MPN	most probable number
MSD	matrix spike duplicate
MSL	mean sea level
MTCA	Model Toxics Control Act
MW	monitoring well
MWEP	Monofilled Waste Extraction Procedure
NA	not available (or not applicable)
NAAQS	National Ambient Air Quality Standards
NAPL	non-aqueous phase liquid
NCP	National Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OVA	organic vapor analyzer
PAH	polynuclear aromatic hydrocarbon (PAHs for plural)
PCBs	polychlorinated biphenyls
PCE	tetrachloroethene
PID	photoionization detector
PRP	potentially responsible party
PTFE	polytetrafluoroethylene
PVC	polyvinyl chloride

ACRONYMS FOR THE SOUTH TACOMA FIELD REMEDIAL INVESTIGATION REPORT

Acronym	Full Phrase
QA	quality assurance
QAPjP	quality assurance project plan
QA/QC	quality assurance/quality control
QC	quality control
RA	risk assessment
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RI/FS	remedial investigation/feasibility study
SARA	Superfund Amendments and Reauthorization Act of 1986
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SM	Standard Method
SMCL	Secondary Maximum Contaminant Level
SOG	standard operating guideline (SOGs for plural)
SOP	standard operating procedure (SOPs for plural)
SOW	statement of work
SPCC	system performance check compound
STF	South Tacoma Field
STFSG	South Tacoma Field Site Group
TCE	trichloroethene
TCL	target compound list
TCLP	Toxicity Characteristic Leaching Procedure
TDS	total dissolved solids
TIC	tentatively identified compound (TICs for plural)
TIP	Tacoma Industrial Properties Management Inc.
TOC	total organic carbon
TRC	Tracer Research Corporation (subconsultant for the soil gas survey)
TRC Environmental Consultants	subconsultant for air dispersion modeling
TSS	total suspended solids
UCL	upper confidence limit
USCS	Unified Soil Classification System
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UST	underground storage tank
VOA	volatile organic analyses (VOAs for plural)
VOC	volatile organic compound (VOCs for plural)
WAC	Washington Administrative Code

leached metals deeper in the subsurface. Leaching could move small amounts of soluble metals into the saturated zone in areas where they are present deeper in the subsurface (e.g., fill areas or Tacoma City Light dry wells). However, a number of mechanisms may still serve to retard their movement into groundwater.

- The potential dissolution and movement rates of PCBs and PAHs in soil and sediment at the site are negligible. These chemicals are expected to mostly remain sorbed and decompose slowly within the soil/sediment matrices in which they were deposited.

- Surface water runon is contributing to the elevated metals and PAH concentrations in onsite surface water and sediment. Mass loading estimations (made as part of the analysis of data gathered during the Surface Water and Sediment investigation) indicate that a significant quantity of the metals and PAHs discharged from upstream offsite sources into the onsite surface water channel are retained onsite. The average annual increases in individual metal concentrations in onsite sediment (caused by the deposition of metals in runon) were estimated based on the total volume of sediment theoretically subject to loading. These estimates assumed that no future decreases in runon metals loading would occur. Based on this evaluation, the potential long-term increases in metals concentrations in onsite sediment caused by runon loading appear to be relatively small.

- Minimal transport of metals from soil and sediment into the saturated soil zone (i.e., groundwater) is expected to occur. This conclusion is based on the relatively low leachability of metals from soils indicated by MWEP testing results as well as the abundant capacity of the unsaturated zone soils to retain metal by sorption processes. Accordingly, metal concentrations in undisturbed soil and sediment are expected to remain substantially constant.

The data obtained during the RI and presented in this document, meet the objectives of the RI and are adequate to initiate the FS. Focused investigations may be warranted based on the findings of the FS, contents of the Record of Decision (ROD), and the types of remedial actions selected for implementation at the site.

EXECUTIVE SUMMARY

This Remedial Investigation (RI) Report for the South Tacoma Field (STF) Superfund site has been prepared by Kennedy/Jenks Consultants on behalf of a group of the potentially responsible parties (PRPs) identified by the U.S. Environmental Protection Agency (EPA).

In 1981, EPA published an "interim priority list" of 115 hazardous waste sites targeted for action under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). This list included the Commencement Bay site in Tacoma. When the final list of the nation's top 418 sites was published [the National Priorities List (NPL)], the Commencement Bay site was listed as two separate sites: 1) Commencement Bay - Nearshore/Tideflats and 2) Commencement Bay - South Tacoma Channel. In 1983, the Commencement Bay - South Tacoma Channel site was divided into three Operable Units; STF, Tacoma Landfill, and Tacoma Well 12A.

On 12 October 1990, EPA and the PRPs signed an Administrative Order on Consent (Consent Order) for the STF site. The Consent Order, among other requirements, directed that an RI be conducted to determine the nature and extent of environmental contamination by hazardous substances at the STF site. The STF RI was conducted in accordance with a Final Work Plan that was prepared by ICF Technology, Inc. (ICF 1990b). Kennedy/Jenks Consultants was retained by the PRPs to conduct the RI in accordance with the Final Work Plan, Revision 1, dated September 1990 (ICF 1990b).

This report presents the findings of the RI and generally follows the suggested format for RI reports in the EPA's "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA," with minor modifications.

The STF RI was designed to provide a characterization of the nature and extent of chemicals of concern in the environment at the site that would be sufficient to permit 1) the determination of the potential risks these chemicals pose to human health and the environment, and 2) the selection of appropriate remedial action(s). The RI included the performance of 11 investigative studies of various environmental media to characterize the nature and extent of contamination onsite and address the data needs identified in the Final Work Plan (ICF 1990b) and the Final Field Sampling and Analysis Plan (FSAP) (Kennedy/Jenks/Chilton 1991a). The RI tasks or studies were:

1. Phase I Soil Investigation (surface and subsurface)
2. Phase II Soil Investigation (surface and subsurface)
3. Groundwater Investigation
4. Hydraulic (Aquifer) Characterization
5. Surface Water and Sediment Investigation
6. Blackberry Investigation
7. Wetland Delineation and Endangered Plant Species Survey
8. Air Dispersion Modeling
9. Soil Gas Survey
10. Geophysical Survey
11. Subsurface Target Confirmation Investigation.

Based on previous investigations and an evaluation of historical use, the STF site was divided into the following sampling units:

- BNR Dismantling Yard
- BNR Railyard
- Former Swamp/Lakebed
- Airport
- TIP property
- Amsted property
- Tacoma City Light property.

The RI fieldwork was conducted between February 1991 and August 1992. The following items summarize the findings and conclusions of the investigative tasks:

- In general, groundwater quality at STF does not show evidence of sitewide degradation; however, a few areas were identified where shallow groundwater quality was impacted by a possible localized source.
- Concentrations of metals in blackberries from the STF site were similar to those in blackberries collected offsite. Concentrations of metals were low or undetected and EPA concluded that the measured concentrations posed no significant human health risks.
- Approximately 6.9 acres of jurisdictional wetlands are present on the STF site; about 6.0 acres are perennial wetlands and 0.9 acres are seasonal wetlands.

- There are no known endangered or threatened animal or plant species inhabiting the STF site.

- Based on the results of air dispersion modeling, concentrations of chemicals of concern in air are below all industrial screening levels onsite and below all residential screening levels offsite.

- During the soil gas survey, concentrations of halogenated VOCs generally were not detected; only low concentrations of one VOC (carbon tetrachloride) were detected in soil gas samples collected from Pioneer Builders Supply property.

- A comprehensive geophysical survey, which included electromagnetic, magnetometer, and ground penetrating radar techniques, was conducted to identify potential locations of tanks and drums. Of the 60 potential subsurface geophysical targets (tanks and drums), only two underground storage tanks (and no drums) were found using backhoe exploration procedures.

Based on the data collected during the RI and previous investigations at the STF site, the following conclusions were made concerning the nature and extent of contamination:

- The distribution of elevated chemical concentrations in onsite surface soil is patchy (i.e., no apparent concentration gradients). This distribution appears to be related to and consistent with specific activities that occurred in individual areas of the site.

- Concentrations of several metals in onsite soil in certain areas of the site are elevated in comparison to background levels (as established based on the background sampling specified in the Final Work Plan). Onsite surface soil concentrations of copper, lead, and zinc are the most elevated in contrast to background concentrations and were mainly detected in samples from the Amsted property, BNR Dismantling Yard, and BNR Railyard. Soil samples from these areas also contained elevated concentrations of arsenic, beryllium, and cadmium, and to a lesser degree antimony, barium, chromium, cobalt, iron, manganese, mercury, and nickel. Elevated metal concentrations were also detected, but to a lesser degree, in surface soil samples from the Former Swamp/Lakebed area. However, the assemblage of elevated metals in the Former Swamp/Lakebed is markedly different from the remaining areas of the STF site. Elevated concentrations of barium, cadmium, chromium, magnesium, manganese, nickel, and vanadium were more commonly detected in samples from the Former Swamp/Lakebed.

- PAHs were also detected in surface soil throughout the site at relatively low to moderate concentrations. Elevated PAH concentrations were detected sporadically in some areas where elevated concentrations of metals occurred (i.e., the Amsted property, BNR Dismantling Yard, BNR Railyard, and Former Swamp/Lakebed).

- Organic chemicals, such as phthalates and phenols, were also detected sporadically in surface soil, but do not constitute significant contamination in terms of concentration levels or areal extent. PCBs were detected in several surface sampling locations at relatively low concentrations.

- Metals and PAH concentrations exceeding background levels were generally confined to shallow soil (i.e., less than 2 feet deep), except in areas where fill materials have been placed. Such fill areas include portions of the Amsted property, TIP, Former Swamp/Lakebed, and the south end of the BNR Railyard.

- Elevated concentrations of arsenic, cadmium, chromium (total), copper, lead, mercury, zinc, and PAHs were detected in a number of shallow sediment samples collected from the onsite surface water channel. The major source of detectable contamination in onsite surface water is surface water runon from two storm drain outfalls that drain nearby areas of the city. The detected concentrations are characteristic of urban runoff. Runoff from the site was generally of better quality than runon, and the quantity of runoff was significantly less than the estimated runon.

- Elevated concentrations of PAHs, PCBs, and several other organic chemicals were detected in subsurface soil sampled at and underlying the bottoms of some of the dry wells at the Tacoma City Light property. Elevated concentrations of most chemicals were limited to a few feet in vertical and lateral extent around the bottoms of the dry wells. In general, concentrations of detected organic compounds decreased with depth. A few dry wells (i.e., DW-19, DW-20, DW-22, and DW-26) had detectable organic chemical concentrations in some samples from the lower unsaturated zone.

- Elevated concentrations of 1,2,4-trichlorobenzene, PCBs, and a complex petroleum hydrocarbon mixture were detected in unsaturated zone soil samples from beneath and immediately surrounding the location where three underground tanks were removed at Pioneer Builders Supply. The hydrocarbon mixture included detectable concentrations of toluene, xylenes, and ethyl benzene, as well as a number of different hydrocarbons in the carbon 8 to carbon 12 range. These hydrocarbons are commonly found in gasoline.

- With few exceptions, groundwater quality beneath the STF site shows little evidence of degradation. Although RI groundwater analytical results do not indicate the presence of a sitewide plume or appreciable regional impact to groundwater, four localized areas of the site were identified where appreciable variations in shallow groundwater chemical quality occurred.

- The first area is the Pioneer Builders Supply property where the concentrations of ethyl benzene, 1,1,2-trichloroethane, and benzene were detected at concentrations above the current or proposed Federal maximum contaminant levels (MCLs). These chemicals and a number of other hydrocarbon compounds detected in groundwater at this location may be attributed to a release(s) from the former underground storage tanks that were removed from this area or other sources. Analytical results of groundwater samples from this location also indicate the presence of low concentrations of PAHs and elevated concentrations of iron and manganese.
- The second and third areas include contiguous portions of the Airport and Former Swamp/Lakebed areas, and the former railcar cleanout area in the south end of the BNR Railyard. Concentrations of some inorganic constituents (primarily iron and manganese) in these areas were detected at levels exceeding the 95 percent upper confidence limit (95% UCL) of background concentrations. The reason for elevated metal concentrations is unknown. However, naturally elevated concentrations of some metals occur locally as a result of the surrounding geologic conditions or variations in groundwater pH and redox potentials. A study performed in the vicinity of the Tacoma Landfill, which is less than 1 mile from the STF site, indicated that iron and manganese concentration in the study area were generally above available EPA drinking water standards (Lum and Turney 1985). Several individual groundwater samples collected from these areas contained metals concentrations exceeding current or proposed MCLs. These exceedances were antimony (one sample), arsenic (one sample), beryllium (two samples), and nickel (three samples).
- The fourth area includes the Amsted property where a relatively small volume of low miscibility, heavy fuel oil was encountered floating on the surface of the water table. The hydrocarbon

contamination of this area is being investigated under a separate Consent Order with EPA (Region 10).

Based on the information developed during the RI, the following conclusions can be made concerning the potential transport and fate of chemicals of concern at the site:

- The current potential for chemical transport by surface water erosion, wind erosion, or volatilization is minimal. In the subsurface, leaching of chemicals and subsequent transport by moving groundwater appear to be the only potentially significant transport mechanisms.

- The resuspension and redeposition of soil and dust as a result of human activities (e.g., vehicular traffic, bike riding) could be a transport mechanism of potential concern. Presently, the nature of human activity and the level of vegetative cover at the site does not promote significant soil or dust transport.

- Migration rates estimated for VOCs and semivolatile organic compounds in soil are considerably greater than those estimated for the higher molecular weight organics. This is consistent with the known behavior of VOCs and semivolatile organic compounds in soil/water systems and the fact that they were detected locally in groundwater during the RI. While some retardation due to sorption by organic matter in the saturated zone can be expected to influence the migration and fate of these chemicals, processes such as volatilization, dispersion, diffusion, and biodegradation are expected to be more important in reducing their concentrations in groundwater.

- The metals present in onsite shallow soil and sediment tend to be relatively immobile inasmuch as they are only slightly leachable and there are a number of physical and chemical mechanisms that tend to retard and retain

1.0 INTRODUCTION

1.0 INTRODUCTION

This report presents findings of the South Tacoma Field (STF) Remedial Investigation (RI). The STF Superfund site is located within a physiographic subprovince of the northwestern United States known as the Puget Sound Lowland (Figure G-1). More specifically, the STF site is located in the southwestern portion of the City of Tacoma, Washington, on an industrial property approximately 260 acres in size (Figure G-2). Currently, the STF site is largely vacant with some remnant structures and recently constructed industrial and commercial buildings.

On 23 November 1981, the U.S. Environmental Protection Agency (EPA) published an "interim priority list" of 115 hazardous waste sites targeted for action under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). This list included the Commencement Bay site in Tacoma. When the final list of the nation's top 418 sites was published [the National Priorities List (NPL)], the Commencement Bay site was listed as two separate sites: 1) Commencement Bay - Nearshore/Tideflats and 2) Commencement Bay - South Tacoma Channel. In 1983, the Commencement Bay - South Tacoma Channel site was divided into three Operable Units; South Tacoma Field (STF), Tacoma, Landfill, and Tacoma Well 12A.

On 12 October 1990, EPA and the potentially responsible parties (PRPs) signed an Administrative Order on Consent (Consent Order) for the STF site. The Consent Order, among other requirements, directed that a remedial investigation be conducted to determine the nature and extent of environmental contamination at the STF site.

The Consent Order cites the Final Work Plan, which establishes the level of effort required by EPA to complete a Remedial Investigation/Feasibility Study (RI/FS) at the STF site. The Final Work Plan was prepared for EPA by ICF Technology, Inc. (ICF 1990b). Kennedy/Jenks Consultants was retained by the PRPs to conduct the

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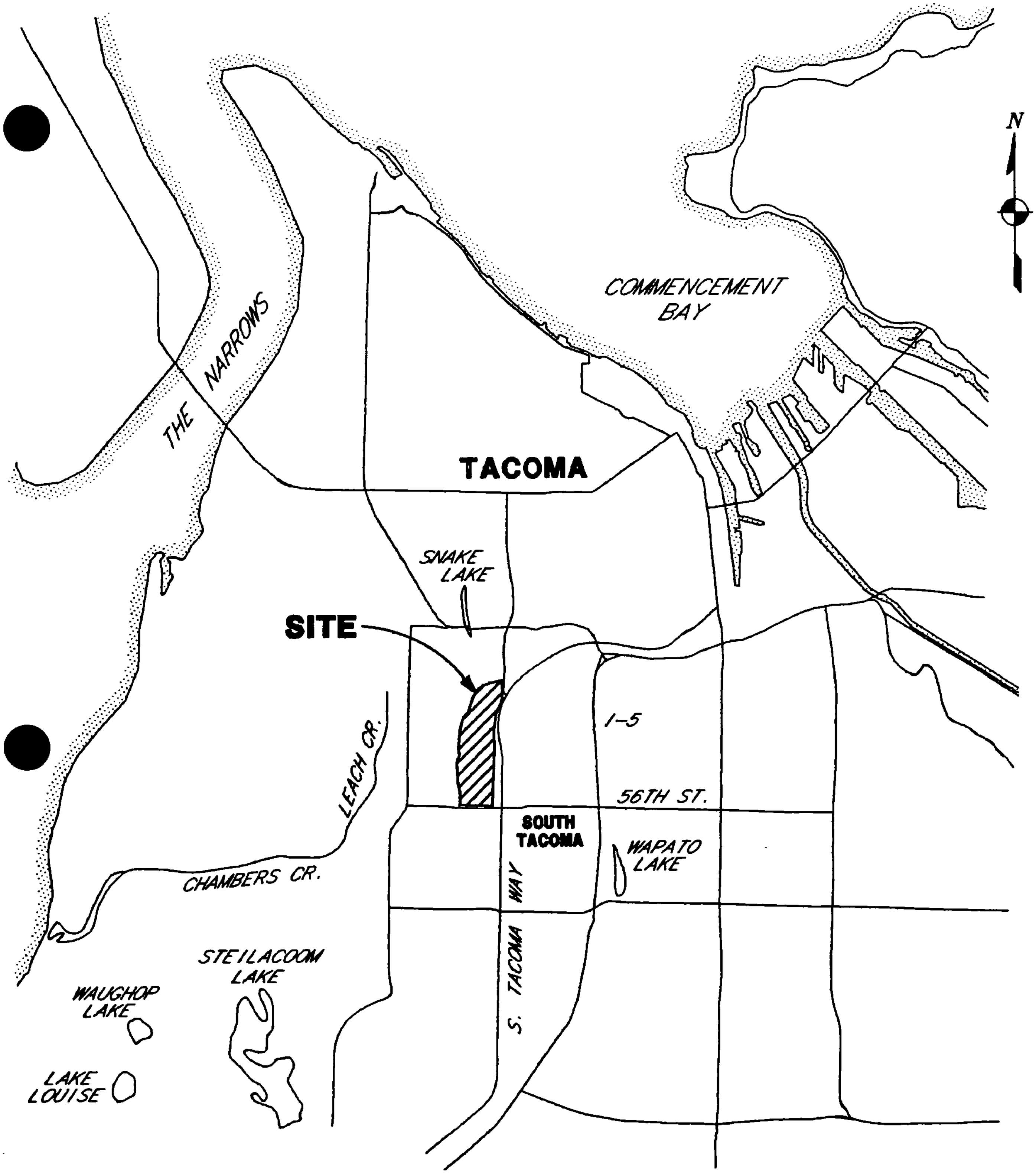
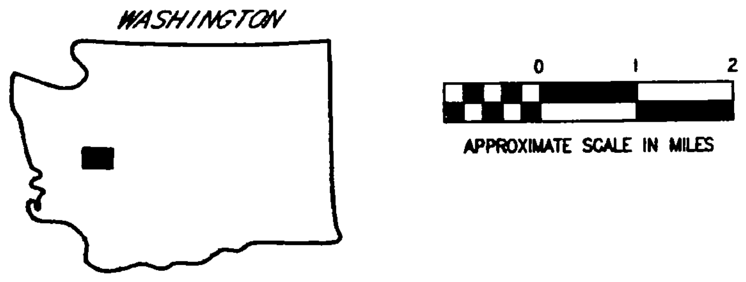
SOUTH TACOMA FIELD
TACOMA, WASHINGTON

REGIONAL MAP

916055.02/P1SK092

FIGURE G-1





Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

SITE LOCATION MAP

916055.19/P2SK191

FIGURE G-2

RI/FS in accordance with the Final Work Plan, Revision 1, dated September 1990 (ICF 1990b).

The RI is composed of discrete investigations of surface soil, subsurface soil, groundwater, surface water, sediment, and blackberries. A wetland delineation and endangered plant species survey, dispersion air modeling, soil gas survey, geophysical survey, and hydraulic characterization were also discrete components of the STF RI. Results of each of these investigations are presented separately as appendices (Volumes 2-6) to this RI Report. This RI Report (Volume 1) presents a synthesis of the findings of these investigations. In addition, a Subsurface Target Confirmation Investigation was conducted based on the results of the Geophysical Survey. Results of this subsurface target investigation will be prepared as an addendum to the RI Report and submitted in January 1993.

1.1 OBJECTIVE OF REMEDIAL INVESTIGATION

The objective of this RI was to adequately characterize the nature and extent of target compound list (TCL) chemicals at the STF site. This RI was conducted in accordance with EPA's (1988b)"Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" (OSWER Directive 9355.3-01).

1.2 SUMMARY OF RI SCOPE OF WORK

The STF RI was composed of 11 separate investigations. Table RI-1 contains a list of these investigations and summary of the scope of work for each investigation. A detailed work plan/sampling and analysis plan was prepared for each of these investigations. All plans were reviewed and approved by EPA prior to implementation.

TABLE RI-1

SUMMARY OF SCOPE OF WORK FOR STF REMEDIAL INVESTIGATION

TASK INVESTIGATION	SCOPE OF WORK
PHASE I SOIL	Prepared Sampling and Analysis Plan Calculated coordinates and staked sampling grid Collected 11 background samples Collected surface soil samples from 269 grids at the BNR Dismantling Yard Collected surface soil samples from 44 grids at Amsted property Collected surface soil samples from 155 grids at BNR Railyard Collected surface soil samples from 73 grids at Former Swamp/Lakebed Collected surface soil samples from 6 grids at Tacoma Industrial Properties Collected surface soil samples from 41 grids at the Airport Advanced 8 borings in Tacoma City Light dry wells and collected 32 subsurface soil samples Advanced 5 borings at Pioneer Builders Supply property and collected 27 subsurface soil samples Collected 40 samples (including 6 composites) for testing of geotechnical soil properties Prepared report (Appendix SS, RI Vol. 2)
PHASE II SOIL	Prepared Sampling and Analysis Plan Advanced 13 borings and collected 36 subsurface soil samples at the BNR Dismantling Yard Advanced 6 borings and collected 24 subsurface soil samples at the Amsted property Advanced 28 borings and collected 84 subsurface soil samples at the BNR Railyard Advanced 4 borings and collected 24 subsurface soil samples at the Pioneer Builders Supply property Collected 37 surface soil samples at the BNR Railyard Advanced 11 borings and collected 44 subsurface soil samples at the Former Swamp/Lakebed Collected 19 surface soil samples at the Former Swamp/Lakebed Advanced 6 borings and collected 19 subsurface soil samples at Tacoma Industrial Properties Collected 8 surface soil samples at Tacoma Industrial Properties Advanced 5 borings and collected 15 subsurface soil samples at the Airport Collected 7 surface soil samples at the Airport Collected 4 composite surface soil samples for metals leaching testing Collected 4 composite surface soil samples for PAH leaching testing Collected 23 samples for testing of geophysical soil parameters Prepared report (Appendix SB, RI Vol. 3)

TABLE RI-1

SUMMARY OF SCOPE OF WORK FOR STF REMEDIAL INVESTIGATION

TASK INVESTIGATION	SCOPE OF WORK
GROUNDWATER	Prepared Sampling and Analysis Plan Installed and developed 11 new monitoring wells Inspected all wells for integrity and purged existing groundwater wells Sampled 5 background wells during 2 quarters Sampled 5 upgradient wells during 2 quarters Sampled 26 onsite wells during 4 quarters Monitored water levels monthly in 30 wells Abandoned 1 vandalized well Prepared report (Appendix GW, RI Vol. 4)
HYDRAULIC CHARACTERIZATION	Prepared Work Plan Monitored water levels monthly in 30 wells for 12 consecutive months Conducted 2 aquifer pumping tests in shallow onsite wells Conducted slug tests at 16 onsite wells Monitored water levels in onsite wells during performance of a pump test at an adjacent offsite production well Prepared report (Appendix HC, RI Vol. 4)
SURFACE WATER AND SEDIMENT	Prepared Sampling and Analysis Plan Installed a flow monitoring meter and monitored surface water runoff flow for 1 year Characterized upgradient drainage basins Collected 10 background surface water from 5 locations during 2 seasons (i.e., dry and wet) Collected 21 monthly runon samples at 2 locations Collected 11 stormwater runon samples at 2 locations Collected 41 onsite surface water samples and 69 sediment samples from 29 locations during 3 seasonal sampling events (transitional, dry, and wet seasons) Collected 4 biweekly runoff samples Prepared report (Appendix SW, RI Vol. 5)
BLACKBERRY	Prepared Sampling and Analysis Plan Collected 6 composite samples, divided each, and analyzed washed and unwashed Prepared draft report Prepared final report (Appendix BB, RI Vol. 5)

TABLE RI-1

SUMMARY OF SCOPE OF WORK FOR STF REMEDIAL INVESTIGATION

TASK INVESTIGATION	SCOPE OF WORK
WETLAND DELINEATION AND ENDANGERED PLANT SPECIES SURVEY	Prepared Work Plan Delineated jurisdictional boundaries of perennial and seasonal wetlands Conducted survey for endangered plant species *Arenaria paludicola* Prepared report (Appendix WL, RI Vol. 6)
PRELIMINARY AIR DISPERSION MODELING	Prepared Modeling Plan Conducted QA review of local meteorological data Conducted preliminary dispersion modeling of selected chemicals Prepared report (Appendix DM, RI Vol. 6)
SOIL GAS SURVEY	Prepared Work Plan Collected 35 soil gas samples from 24 locations at Pioneer Builders Supply property Prepared report (Appendix SG, RI Vol. 6)
GEOPHYSICAL SURVEY	Prepared Work Plan Established survey grid Approximately 160 miles of electromagnetic transect lines Approximately 160 miles of magnetometer transect lines Screened and prioritized electromagnetic and magnetometer anomalies Investigated about 200 Priority 1 and Priority 2 anomalies using ground penetrating radar (GPR) Performed GPR survey inside General Plastics and Pioneer Builders Supply buildings Prepared report (Appendix GS, RI Vol. 6)
SUBSURFACE TARGET CONFIRMATION	Prepared Sampling and Analysis Plan Investigated about 60 potential subsurface targets using a backhoe Identified 2 tanks and sampled contents of one (the other was empty) Excavate and remove tanks (in progress) Prepare report as addendum to RI (tentatively scheduled for January 1993)

1.3 PRELIMINARY CHEMICALS OF CONCERN

EPA identified preliminary chemicals of concern for surface soil, groundwater, and air based on the findings of the separate investigations of those media (Kennedy/ Jenks Consultants 1992a, 1992b; TRC Environmental Consultants 1992). Preliminary chemicals of concern for these media are shown in Tables RI-2, RI-3, and RI-4, respectively. Evaluations in this report focus on these preliminary chemicals of concern because they were determined to be the only chemicals that potentially present human health or environmental risks at the STF site.

1.4 REPORT ORGANIZATION

The STF RI comprises several investigations conducted from March 1991 through August 1992. Each investigation was completed as a stand-alone investigation and required the preparation of stand-alone reports, which were submitted to EPA for review. Except for the Phase II Soil Investigation and the Hydraulic Characterization Reports, EPA's comments have been incorporated into a final report for each investigation (RI appendices) and/or otherwise addressed. The schedule for submittal of the draft reports for the Phase II Soil Investigation and Hydraulic Characterization did not allow sufficient time to receive and incorporate EPA's comments. This RI Report contains the following six volumes:

- Volume 1: Remedial Investigation Report
- Volume 2: Phase I Soil Investigation Report (Appendix SS)
- Volume 3: Phase II Soil Investigation Report (Appendix SB)
- Volume 4: Groundwater Investigation Report (Appendix GW) and Hydraulic Characterization Report (Appendix HC)

TABLE RI-2

PRELIMINARY CHEMICALS OF CONCERN FOR SURFACE SOIL AND CONCENTRATION RANGES DETECTED AT STF

Chemical of Concern[a]	Soil (mg/kg)[b]
Inorganics	
Aluminum	1,350-104,000
Antimony	2.0-491
Arsenic (total)	0.24-696
Beryllium	0.090-14.4
Cadmium	0.11-29.9
Chromium (total)	2.9-707
Copper	7.2-163,000
Lead	5.3-118,000
Manganese	22.7-21,800
Mercury	0.0036-5.3
Zinc	13.4-61,600
Organics	
Carcinogenic PAHs (total)	0.020-38
PCBs	0.17-42

(a) Reference: EPA (1992a,b,c).
(b) Concentrations from Kennedy/Jenks Consultants (1992b).

TABLE RI-3

PRELIMINARY CHEMICALS OF CONCERN FOR GROUNDWATER AND CONCENTRATION RANGES DETECTED AT STF

Chemical of Concern[a]	Groundwater (μg/L)[b]
Inorganics	
Aluminum	<16.0-5,940
Antimony	<11.0-50.7
Arsenic	<1.0-50.9
Boron	20.2-1,940
Cobalt	<3.0-218
Copper	<1.0-19.7
Cyanide	11.2-80
Manganese	<1.0-5,200
Nickel	<6.7-1,950
Selenium	<1.0-26.8
Silver	<3.0-10.6
Vanadium	<3.3-30.5
Zinc	<2.0-726
Organics	
Benzene	86-480
Chloroform	1-20
Ethylbenzene	150-1,000
2,4-Dimethylphenol	61[c]
Hexanone	16[c]
2-Methylnaphthalene	1-47
Naphthalene	2.3-190
Tetrachloroethene	3-4
Toluene	1-770
1,1,2-Trichloroethane	51[c]
Xylenes	141-2,300

(a) Reference: EPA (1992b).
(b) Concentrations from Kennedy/Jenks Consultants (1992a).
(c) Chemical only detected once.

TABLE RI-4

PRELIMINARY CHEMICALS OF CONCERN FOR AIR AND PREDICTED CONCENTRATION RANGES AT STF

Chemical of Concern[a]	Air ($\mu g/m^3$)[b]
Inorganics	
Arsenic	1×10^{-6}-2.17×10^{-5}
Beryllium	2×10^{-8}-4.42×10^{-7}
Cadmium	1×10^{-7}-1.54×10^{-6}
Chromium (VI)	5×10^{-8}-6.29×10^{-7}
Cobalt	5×10^{-7}-5.89×10^{-6}
Manganese	5×10^{-5}-1.23×10^{-3}
Mercury	2×10^{-8}-3×10^{-7}
Organics	
Carcinogenic PAHs (total)	2×10^{-7}-2.01×10^{-6}

(a) Reference: EPA (1992b).

(b) Predicted ranges based on Dispersion Model Screening Analysis Report (TRC Environmental Consultants 1992).

- Volume 5: Surface Water and Sediment Investigation Report (Appendix SW) and Blackberry Investigation Report (Appendix BB)

- Volume 6: Wetland Delineation and Endangered Plant Species Survey Report (Appendix WL), Dispersion Model Screening Analysis (Appendix DM), Soil Gas Survey Report (Appendix SG), and Geophysical Survey Report (Appendix GS).

Each report contains a detailed description of the investigative objectives, scope of work completed, and investigation methods. Analytical data were presented, and compared with applicable criteria, when available. Finally, each report presents the results and conclusions for the specific investigation.

In addition, four data appendices were compiled for the STF RI. These data appendices contain database printouts, explanatory information, and data validation reports for all laboratory data generated during the following investigations:

- Phase I Soil Investigation Data Appendix

- Phase II Soil Investigation Data Appendix

- Groundwater Investigation Data Appendix

- Surface Water and Sediment Data Appendix.

This RI Report (Volume 1) is a synthesis of the results from all the individual investigations (Volumes 2 through 6). This RI Report aims to identify cross-media impacts. Evaluations are focused on preliminary chemicals of concern as identified by EPA. The remaining sections of this RI Report are described below.

- Section 2.0 summarizes the site background, including current and historical site descriptions, and previous investigations at the STF site.

- Section 3.0 provides a description of the physical characteristics of the site including land use and demography, climate and local meteorology, surface water hydrology, soil, geology, hydrogeology, and ecology.

- Section 4.0 describes the methods used to collect, analyze, ensure quality, evaluate, and present data obtained during the RI.

- Section 5.0 presents a summary of investigative findings by media. Investigative findings were grouped into three discussions, including surface, unsaturated subsurface, and saturated subsurface.

- Section 6.0 discusses the fate and transport of the preliminary chemicals of concern.

- Section 7.0 provides a summary and conclusions.

- Section 8.0 contains references for documents cited and used in the preparation of this report.

2.0 SITE BACKGROUND

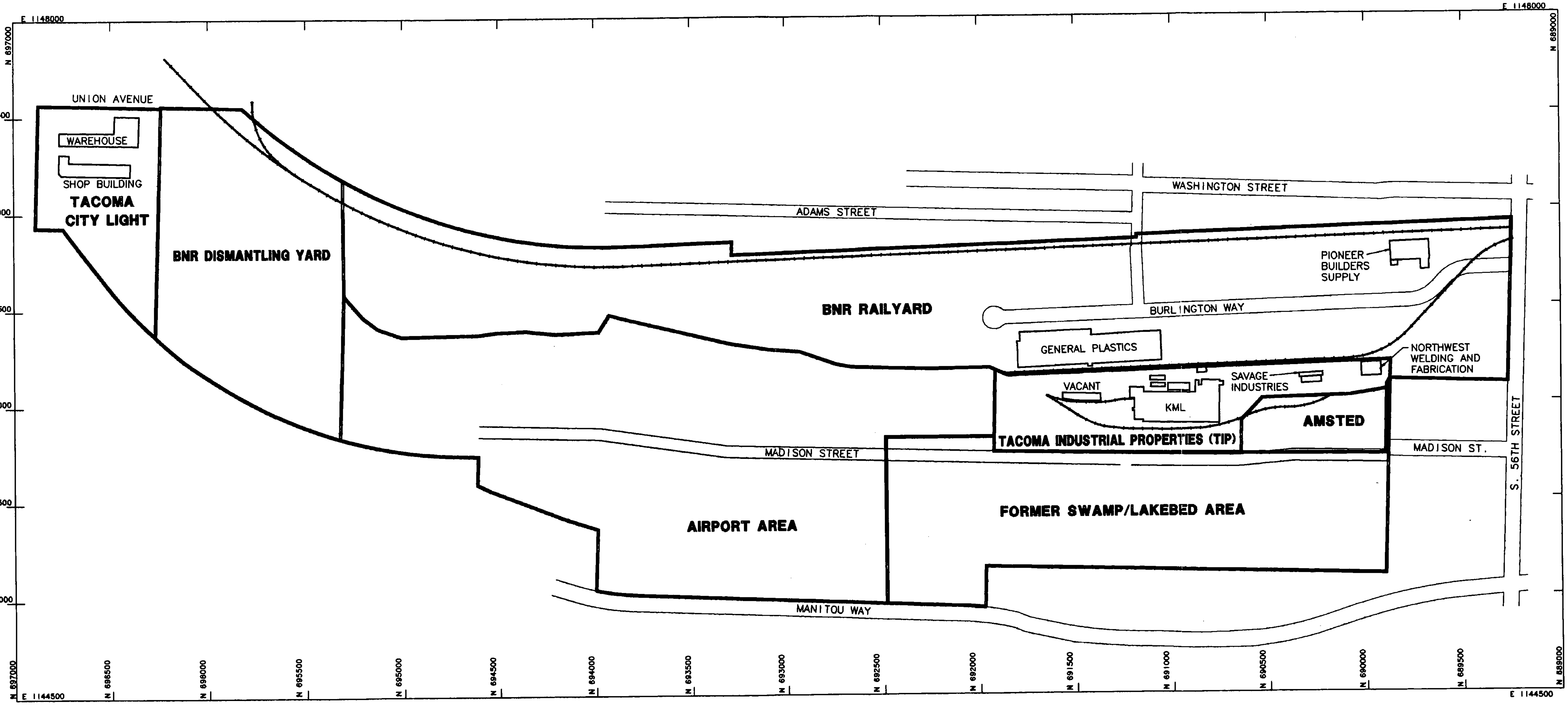
2.0 SITE BACKGROUND

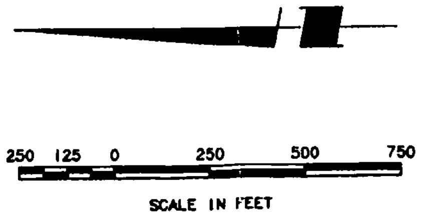
2.1 SITE DESCRIPTION

The STF site is located on the floor of a topographic lowland area referred to as the South Tacoma Channel, which is as much as 150 feet lower than the surrounding uplands. The site, once covered with industrial structures, is now mostly open fields of grass with a few industrial and commercial facilities. Surface water is sometimes present in the western portion of the site, but no creeks, streams, or rivers currently pass through the site. A review of aerial photographs from 1946 showed the presence of a lake in the southwestern portion of the STF site, but not the surface water channel. A 1969 aerial photograph showed the surface water channel along the western site boundary had been formed or constructed.

Much of the STF site is currently undeveloped and awaiting industrial development. The site is covered with field grass, blackberry bushes, shrubs, and a few trees. Concrete rubble, old foundations, and trash are apparent in some areas. A portion of the STF site is used for light industrial and commercial operations. Some businesses have operated from facilities previously used in association with the former foundries and railyard, while other manufacturers have constructed new facilities. Information in this section has been prepared using the Site Background Summary Report (ICF 1990a). A map of businesses currently operating on the STF site is shown in Figure G-3. All current site uses are industrial. The site is zoned heavy industrial and is designated in Tacoma's plan as an important part of Tacoma's future industrial expansion area.

Tacoma Public Utilities (Tacoma City Light) provides electrical service and drinking water to Tacoma residents and businesses, and has operated from the northern-most end of the STF site since 1953. Tacoma Public Utilities uses its facility for maintenance and repair of equipment, as a storage and distribution center for





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SOUTH TACOMA FIELD
TACOMA, WA

SAMPLING UNIT DESIGNATIONS AND BUSINESSES CURRENTLY OPERATING AT THE STF SITE

916055.19/P2SK192

FIGURE G-3

electrical and water supply system components, and as an administration center. The Tacoma City Light property is covered with asphalt pavement and buildings. Stormwater runoff drains to modified dry wells that have soil bottoms and interconnecting piping leading to the City of Tacoma's storm drainage system. Some of the dry wells have been plugged with bentonite to prevent surface water infiltration.

The Tacoma City Light property has used four underground tanks and three aboveground tanks that are used to store automotive fuel, waste oil, and new, used, and waste mineral oil. Three of the underground tanks, which had contained leaded and unleaded gasoline, and diesel fuel, were removed in September 1992. The other underground tank, which had contained waste oil, was removed in September 1992 (Post, R., 20 February and 4 June 1992, and 10 January 1993 personal communication). Clean closures were achieved for all four of the removed underground tanks. The three aboveground tanks, which contain mineral oil, are located in enclosed areas with complete secondary containment.

In addition to the tanks, Tacoma City Light stores electrical equipment, including approximately 3,500 new and used transformers. Some of the transformers contained or have previously contained polychlorinated biphenyls (PCBs). PCB contamination of Tacoma City Light soil was documented by Black & Veatch (1983) and by Hart-Crowser (1989).

Tacoma Industrial Properties (TIP) Management Inc. owns property in the central portion of the STF site, which is the site of a former iron foundry. TIP uses the area for a variety of industrial purposes. Three businesses operate on TIP property: KML Corporation, Savage Industries, and Northwest Welding and Fabrication. KML Corporation has operated in the former iron foundry building since 1986. KML laminates films onto particle board for the construction of cabinets and interior partitions. Savage Industries has used a former wood patterns and vaults building since the early 1970s to manufacture wood picture frames. Northwest Welding and Fabrication has operated at TIP since 1986. Northwest Welding and

Fabrication activities include repair of boats, motors, and boat trailers, as well as steel product fabrication and repair.

Other businesses have used TIP facilities; however, little information is available about their operations. These businesses reportedly included steel tubing, bending, and fabrication; lamination of plastic overlays on particle boards; portions of the brass foundry; soil stabilization materials manufacturing; warehousing; and steel fabrication.

Facilities recently constructed on STF site property include the General Plastics and Pioneer Builders Supply complexes. General Plastics built a manufacturing plant in 1981 on a portion of the former Northern Pacific Car Shops area. General Plastics manufactures high-density rigid and flexible polyurethane foams and high-density rigid polyisocyanurate foams for the aviation, construction, marine, nuclear, architectural, and sports equipment industries. General Plastics uses and/or stores several chemical products onsite, including chlorofluorocarbons, methylene chloride, and isocyanates. One underground storage tank, formerly available for spill containment purposes, was removed in the summer of 1990 and disposed (Schatz, H., 25 February 1992, personal communication).

Pioneer Builders Supply purchased land in the southeast portion of the STF site for a warehouse and office building that were constructed in 1988. Pioneer Builders Supply operates a distribution center for asphalt and cedar roofing materials. Pioneer Builders Supply used two underground tanks for approximately 5 years to store gasoline and diesel fuel. Pioneer Builders Supply excavated the tanks in December 1991 and determined that the surrounding soil was contaminated with petroleum products (Saltbush Environmental Services 1992). In addition, three underground tanks were discovered in the northeast corner of the Pioneer Builders Supply property in early 1990 and were excavated and disposed of in June 1990 (Hildenbrand, J., 12 February 1991, personal communication).

2.2 SITE HISTORY

A description of STF site history is available in the Site Background Summary Report (ICF 1990a), along with references to other documents that provide additional information on historical site use. This discussion of historical activities at the STF site is based on material contained in this Site Background Summary Report (ICF 1990a). An independent study of historical activities was not conducted to verify the findings of this report.

The STF site has been used for a variety of industrial purposes for approximately 100 years. Locations where various activities have occurred at the site are shown in Figure G-4. Areas where significant historical activities occurred are briefly discussed in the following paragraphs.

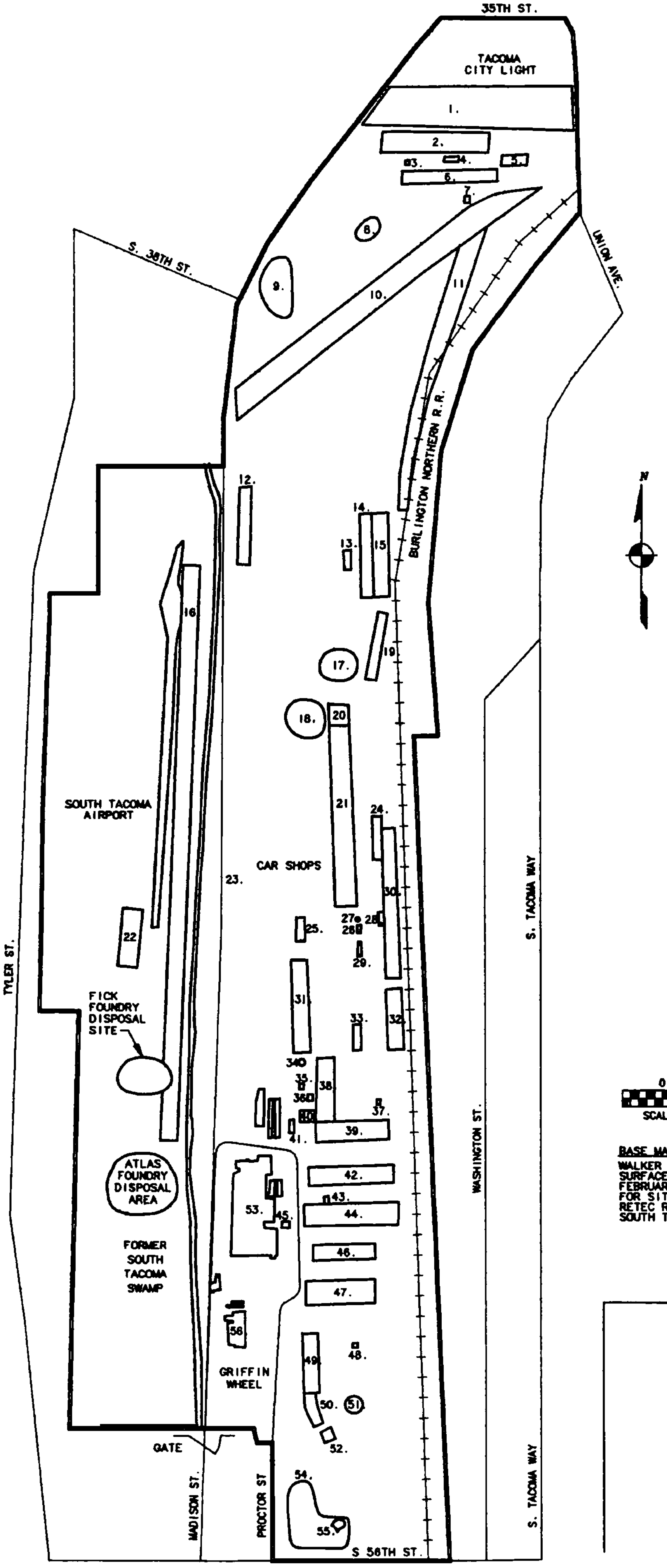
The South Tacoma Car Shops area operated as a manufacturing and repair facility from 1892 until 1974. The area was used for manufacturing, repair, and maintenance of railroad equipment.

The BNR Dismantling Yard was located in the northern portion of the Car Shops area. Cars were cleaned and dismantled in this area.

Foundry facilities operated onsite from 1890 through 1980. An iron foundry produced iron wheels until 1957. A brass foundry produced journal bearings composed primarily of lead, tin, copper, zinc, and antimony until 1980.

The South Tacoma Airport operated from 1936 to 1973. Aircraft maintenance and refueling operations were performed at this location during those years. A lake was located beyond the south end of the former runway and, in the late 1940s, was used by seaplanes.

Reportedly, a variety of filling activities has occurred during the history of the site. Foundry, construction, and domestic wastes reportedly were disposed of as fill



LEGEND

━━ STF-NPL SITE BOUNDARY

1. TCL YARD AREA
2. GANTRY CRANE AREA
3. FUEL TANK
4. SHED
5. LANTERN SHED
6. STOREHOUSE, BELTHOUSE ROLLING MILL, STORAGE BLDG
7. FUEL CELLAR
8. BURN PIT
9. TRASH DUMP
10. STORAGE YARD
11. RUBBISH TRACK CORRIDOR
12. CONCRETE CASTING PLANT
13. SANDBLAST SHED
14. BLACKSMITH SHOP
15. CONCRETE FLOOR
16. LANDING STRIP
17. TRASH BURNING AREA
18. TRASH PIT (PAINT SHOP)
19. CAR CASTINGS PLATFORM
20. PAINT SHOP
21. CAR SHOP
22. AIRPORT BLDG
23. MADISON STREET
24. OPEN SHED
25. DRY KILN
26. WASTE SOAKING VAT
27. UST (OIL)
28. PAINT SHOP
29. PAINT HOUSE
30. FREIGHT REPAIR SHED
31. FINISHED LUMBER SHED
32. WHEEL SHOP
33. GENERATOR HOUSE
34. UST (OIL)
35. PUMPS
36. DIP TANK
37. DROP PIT
38. WOODWORKING SHOP
39. COACH SHOP
40. BOILER HOUSE
41. OIL TANKS
42. PAINT SHOP
43. BRASS
44. MACHINE SHOP
45. SOLVENT SHED
46. BOILER, TIN TANK, AND COPPER SHOP
47. SOUTH MACHINE SHOP
48. TRASH BURNER
49. BLACKSMITH SHOP
50. IRON & STEEL STORAGE
51. TURNTABLE
52. COKE & COAL
53. FORMER IRON FOUNDRY
54. RAILCAR CLEANOUT AREA
55. BURIED DRUMS (REMOVED)
56. FORMER BRASS FOUNDRY SITE

0 200 400
SCALE IN FEET

BASE MAP REFERENCE
WALKER & ASSOC. 10-22-86
SURFACE DEBRIS SAMPLING PLAN
FEBRUARY 1987
FOR SITTS & HILL ENGINEERS, INC
RETEC REMEDIATION TECHNOLOGIES, INC.
SOUTH TACOMA SWAMP

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

MAJOR HISTORICAL USES OF THE STF SITE

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FIGURE G-4

material in the Former Swamp/Lakebed area (ICF 1990a). In the 1930s and 1940s, portions of the site reportedly were used as unauthorized household and commercial waste dumping areas. Actual records of fill materials and volumes could not be obtained.

Tacoma City Light operations are located at the north end of the site. Repair, maintenance, and distribution of electric and water service equipment have occurred at the Tacoma City Light site since 1953.

2.3 SUMMARY OF PREVIOUS INVESTIGATIONS AT STF

Prior to initiation of the field investigations associated with the STF RI, several investigations were conducted at individual properties within the STF site. The following reports were prepared for the STF site (previously referred to as the South Tacoma Swamp), or portions thereof:

1983	Black & Veatch. Preliminary Site Investigation, South Tacoma Swamp, Tacoma, Washington. Prepared for U.S. Environmental Protection Agency, Cincinnati, OH.
1986	Tacoma-Pierce County Health Department. Investigation/Characterization of the Former Burlington Northern Railroad Parcel. Final Report.
1987	AGI. Soil Sampling and Chemical Testing, 5401 Burlington Way; Lots 2 and 3, Tacoma, Washington. Prepared for Pioneer Builders Supply, Inc. Tacoma, WA.
1987	ReTec. Phase 1 Report, Remedial Investigation of South Tacoma Swamp Superfund Site. Prepared for Burlington Northern Railroad, Seattle, WA.
1987	ReTec. Volumes 1 and 2 - RI/FS Work Plan for the Glacier Park Company Site, South Tacoma Swamp, Tacoma, WA. Prepared for the Glacier Park Company, Seattle, WA.

1987	ReTec. Waste Sampling for Surface Debris Mapping at the Burlington Northern Railroad Site in South Tacoma, WA. Revision 1. Prepared for Burlington Northern Railroad, Seattle, WA.
1987	Kennedy/Jenks/Chilton. Remedial Investigation/Risk Assessment/Feasibility Study, Former Brass Foundry Area, South Tacoma Swamp, Volumes 1 and 2. Draft. Prepared for Tacoma Industrial Properties (TIP) Management, Inc., Tacoma, WA.
1988	Kennedy/Jenks/Chilton. Site Investigation/Surface Waste Removal, Former Iron Foundry Area, South Tacoma Swamp. Prepared for Tacoma Industrial Properties (TIP) Management, Inc., Tacoma, WA.
1989	Hart-Crowser. Expedited Site Characterization, Tacoma Public Utilities, South Tacoma Swamp Superfund Site. Prepared for Tacoma Public Utilities, Tacoma, WA.
1989	Kennedy/Jenks/Chilton. Work Plan - Removal Action: Building Demolition/Underground Tank Removal, Former Griffin Wheel Brass Foundry, Tacoma, Washington. Prepared for Amsted Industries, Inc., Chicago, IL.
1989	SAIC. Preliminary Summary of Previous Investigations Conducted at the South Tacoma Swamp Superfund Site, Tacoma, Washington.
1990	Kennedy/Jenks/Chilton. After Action Report, Former Griffin Wheel Brass Foundry, Tacoma, Washington. Prepared for Amsted Industries, Inc., Chicago, IL.
1990	ICF. Draft Site Background Summary for the South Tacoma Field Superfund Site. Prepared for U.S. EPA, Region 10, Seattle, WA.

Results of these investigations were summarized by ICF (1990a) and formed the basis for establishing sampling objectives and priorities described in EPA's Work Plan for the STF RI/FS (ICF 1990b). However, none of the laboratory analytical data generated through these previous investigations were entered into the STF Project Database, or used in any data analyses [e.g., Geographic Information System (GIS) or statistical]. EPA concluded that pre-RI data did not meet minimum data quality objectives (DQOs) for use in the STF RI. Surface soil data obtained during these previous investigations were used in the preliminary dispersion modeling (Kennedy/Jenks Consultants and Envirometrics 1991b), but final modeling was performed using surface soil data generated during this STF RI (i.e., Phase I Soil Investigation; Kennedy/Jenks Consultants 1992b).

3.0 CHARACTERISTICS OF STUDY

3.0 PHYSICAL CHARACTERISTICS OF STUDY AREA

3.1 LAND USE AND DEMOGRAPHY

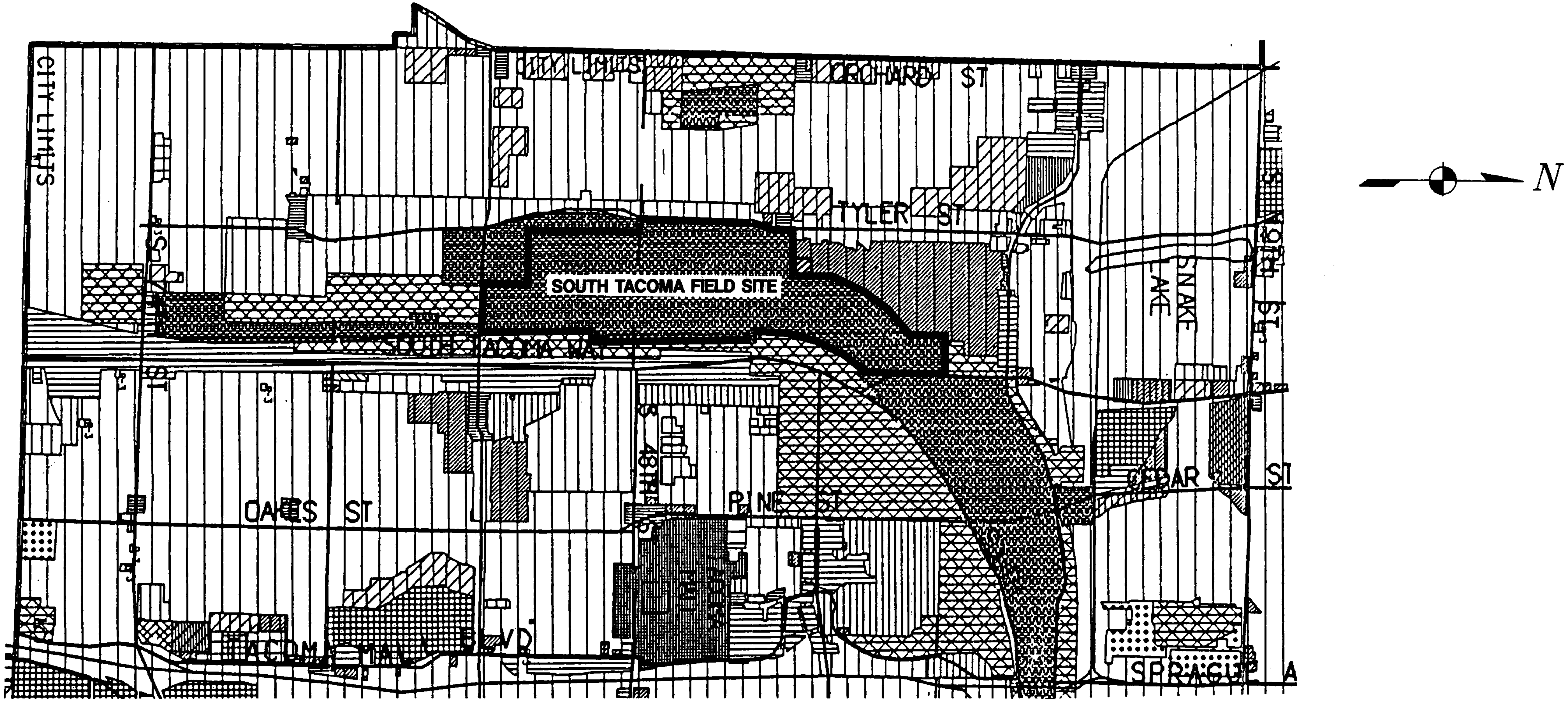
The STF site is located in the southwestern section of the City of Tacoma, in an area referred to as South Tacoma. The location of the STF site is shown in Figure G-2. The South Tacoma area is located approximately 2½ miles to the southwest of the downtown Tacoma business district. The western city limits of Tacoma are located approximately ½-mile to the west of the STF site at Orchard Street. Tacoma is bordered to the west by the City of Fircrest, a city that contains primarily residential and commercial land uses.

The diversified land use in the South Tacoma area is shown in Figure RI-1. As of 1991, over 19,000 employees work at 1,430 companies in the 98409 postal zip code area (see Table RI-5). The boundaries of this zip code area lie within approximately ½ to 1 mile of the STF site. The largest numbers of companies are in the retail trade and service industries. Significant numbers (more than 100 each) of companies in the construction; manufacturing; and finance, insurance, and real estate industries are also located in this area. Approximately half of the companies employ between one and five employees. Only three companies in the area employ more than 500 employees.

Current zoning of the STF site and the surrounding area are described below.

- The entire STF site is zoned as a heavy industrial district (M-2).

- The area east of the STF site (between South 35th Street and South 56th Street) is a combination of heavy industrial (M-2), light industrial (M-1), and commercial (C-2) districts.



SCALE: 1"=2,000'

- ▥ R-2: ONE FAMILY DWELLING DISTRICT
- ▥ R-3: TWO FAMILY DWELLING DISTRICT
- ▥ R-4-L: LOW DENSITY MULTI-FAMILY DWELLING DISTRICT
- ▥ R-4: MULTI-FAMILY DWELLING DISTRICT
- ■ R-5: MULTI-FAMILY DWELLING DISTRICT
- ▨ TM: MEDICAL CENTER TRANSITIONAL DISTRICT
- ■ C-1: COMMERCIAL DISTRICT
- ▤ C-2: COMMERCIAL DISTRICT
- ▤ C-3: COMMERCIAL DISTRICT
- ▩ MC: MIXED COMMERCIAL DISTRICT
- ▩ M-1: LIGHT INDUSTRIAL DISTRICT
- ■ M-2: HEAVY INDUSTRIAL DISTRICT
- ■ T: RESIDENTIAL-COMMERCIAL TRANSITIONAL DISTRICT
- ▒ PBD: PLANNED BUSINESS DEVELOPMENT DISTRICT
- ▨ PRD: PLANNED RESIDENTIAL DEVELOPMENT DISTRICT
- ▦ C-P-N: PLANNED NEIGHBORHOOD SHOPPING CENTER DISTRICT
- ▦ C-P-C: PLANNED COMMUNITY SHOPPING CENTER DISTRICT
- ■ C-P-R: PLANNED REGIONAL SHOPPING CENTER DISTRICT

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SOUTH TACOMA FIELD
TACOMA, WA

ZONING MAP

916055.19/P2SK178

FIGURE RI-1

TABLE RI-6

DATA FROM 1990 CENSUS OF POPULATION AND HOUSING

Census Data Parameter	Census Tract[a]						Total of These Six Census Tracts
	626	627	628.01	628.02	629	630	
Total population	1,682	1,098	5,515	4,134	5,789	3,157	21,375
Total households	660	494	2,477	1,475	2,368	1,227	8,701
Persons living in households	1,642	1,082	5,371	4,033	5,774	3,148	21,050
Persons living in group quarters	40	16	144	101	15	9	325
Total housing units	714	548	2,659	1,560	2,540	1,284	9,305
Units In Structure							
1-Unit, Detached	446	226	519	1,083	1,653	930	4,857
1-Unit, Attached	116	12	36	33	39	4	240
2 to 4 Units	98	141	518	242	287	44	1,330
5 to 9 Units	0	26	328	104	116	70	644
10 or More Units	49	136	1,236	88	404	225	2,138
Mobile Home, Trailer, Other	5	7	22	10	41	11	96

(a) See Figure RI-2 for locations of census tracts.

proximity to the STF site. The boundaries of the census tracts are shown in Figure RI-2. Residential populations are located west of the STF site.

Over half of the housing units in all six census tracts are single family units. Twenty (20) to 25 percent of the housing units are parts of structures that have 10 or more units (such as apartment buildings). Approximately 10-15 percent of the housing units are contained in 2- to 4-unit structures (duplexes and fourplexes). Few people live in group quarters, which include institutionalized or other group living situations, as differentiated from households. Families that live in apartments or other multi-family housing units are considered households.

Mt. Tahoma High School is located near the southern boundary of the STF site. The South End Recreational Area, consisting of baseball fields and other open space, is located near the high school. The Snake Lake Park, located adjacent to State Highway 16, on the north side of the highway (less than 1 mile north of the STF site) is another nearby open space recreation area. Cheney Stadium, where several civic events and minor league baseball games are held, is located next to Snake Lake Park.

3.2 CLIMATE AND LOCAL METEOROLOGY

The Tacoma area has a temperate oceanic climate. Weather is moderated by the nearby Pacific Ocean resulting in winter temperatures in the Puget Sound lowland that are usually above freezing and summer temperatures that usually remain below 80°F. Virtually all of the precipitation at the site occurs as rainfall. In general, rainfall is more frequent and of greater intensity during the winter months than during the summer. The mean annual precipitation in the Tacoma area ranges from 38 to 42 inches. Historical climate and meteorologic data for the STF site used for the preliminary air dispersion modeling were obtained from the Mt. Tahoma Station, and therefore, onsite meteorological monitoring was not necessary. Data from numerous weather stations near the site and in the same climate division (National

TABLE RI-5

NUMBERS OF COMPANIES AND EMPLOYEES WITHIN ZIP CODE 98409 AREA, 1991

Primary Standard Industrial Classification Division	Number of Companies by Employee Range (Numbers of Employees)								Total Number of Employees
	Total Companies	1-5	6-10	11-25	26-100	100-499	500+	No Information	
Agriculture/Forestry Fishing	12	4	3	2	2	0	0	1	140
Mining	0	0	0	0	0	0	0	0	0
Construction	114	64	23	14	5	0	0	8	797
Manufacturing	115	46	15	17	19	5	1	12	3,366
Transportation/Communications/Utilities	29	6	3	7	4	1	1	7	1,482
Wholesale Trade	144	59	30	35	11	1	0	8	1,694
Retail Trade	403	174	78	48	35	8	0	60	5,921
Finance, Insurance, and Real Estate	172	106	21	15	5	0	0	25	898
Services	435	245	60	45	26	4	0	55	3,921
Public Administration	6	0	0	0	1	0	1	4	1,037
Total	1,430	704	233	183	108	19	3	180	19,256

Source: Donnelley Marketing Information Services (1991).

- The area immediately south of the STF site is a mix of heavy industrial (M-2) and light industrial (M-1) districts.

- The southern section of the western border of the STF site is zoned as a heavy industrial (M-2) district. The central section is zoned as two-family dwelling (R-3), medical center transitional (TM), and commercial (C-2) districts. The northern section is zoned primarily as a residential/ commercial transitional (T) district and a small light industrial (M-1) district.

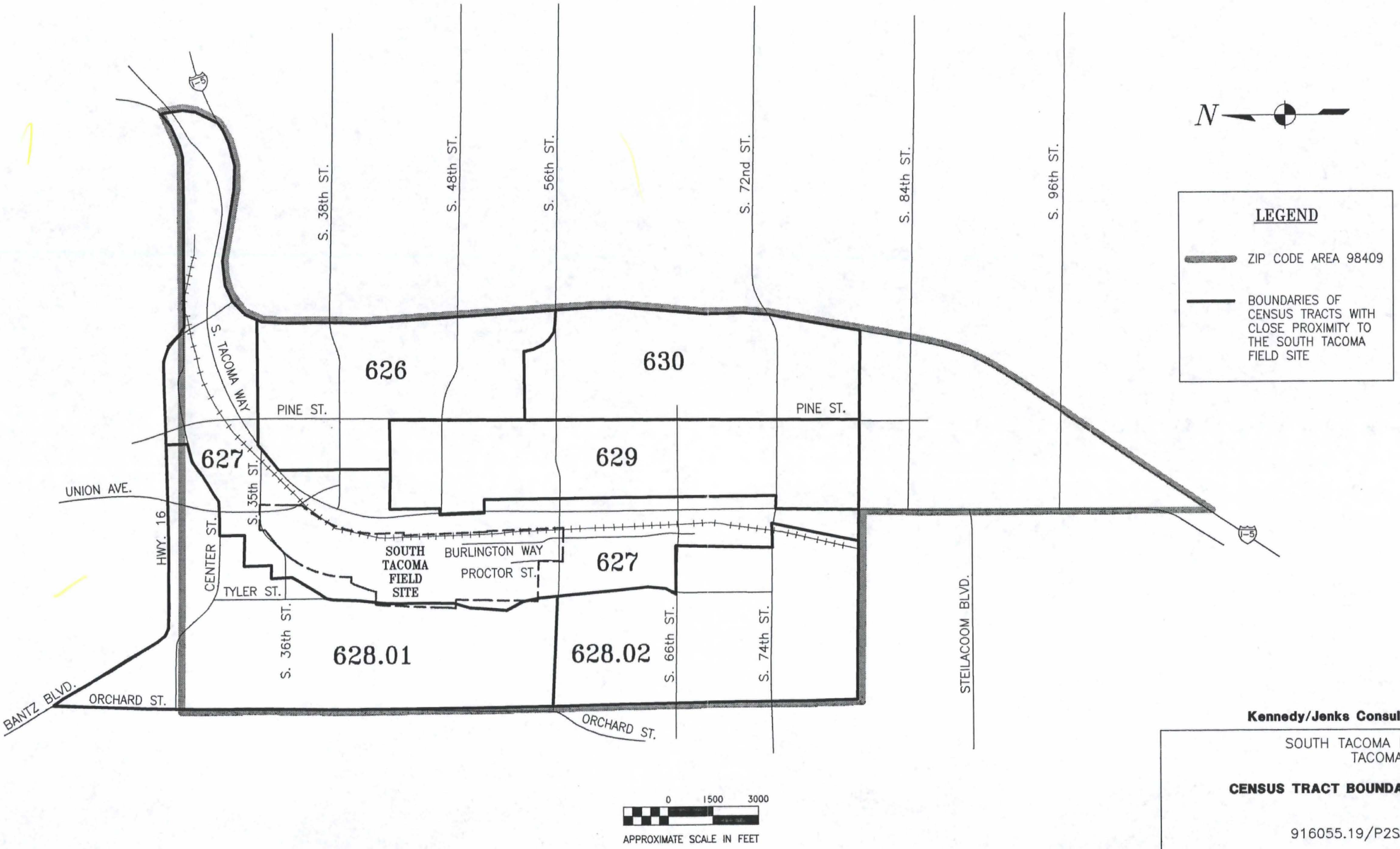
- The area to the north of the STF site is zoned as residential/commercial transitional (T) and light industrial (M-1) districts.

The heavy industrial district extends northeast of the STF site, and includes several industrial facilities such as Nalley's Fine Foods processing plant and TAM Engineering, Inc., an automotive engine remanufacturing facility.

The area surrounding South Tacoma Way and north of South 38th Street is a combination of heavy industrial and light industrial zoning. Among the variety of companies in this area are several automobile service facilities and dealerships. A variety of retail shops, services, and other industries are located along South Tacoma Way, Washington Street, and South 38th Street. The Tacoma Mall is located directly east and within 1 mile of the STF site. A variety of retail shops and commercial offices are located near the Tacoma Mall.

The majority of the area west of Tyler Street, east of South Tacoma Way, and within approximately ½ to 1 mile of the STF site consists of mostly single family and multi-family residential areas. However, most residential areas have localized areas with multiple land uses as shown in Figure RI-1.

Over 21,000 people live within six census tracts that surround the STF site according to the 1990 Census of Population and Housing. Selected data from the 1990 census are presented in Table RI-6 for the six census tracts within close



LEGEND

▬ ZIP CODE AREA 98409

— BOUNDARIES OF CENSUS TRACTS WITH CLOSE PROXIMITY TO THE SOUTH TACOMA FIELD SITE

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

CENSUS TRACT BOUNDARIES

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FIGURE RI-2

Weather Service; Division 3) were reviewed and are summarized in the following subsections. Tables RI-7 and RI-8 present a summary of monthly average temperature and precipitation data.

3.2.1 Temperature

The Tacoma area has a typical marine climate with mild winters and warm summers. The mild temperatures of the area are hydrologically significant in that most of the precipitation at the site occurs as rain. The highest temperatures occur during July and August and the lowest during December and January. Temperature is also an important factor in evaporation and transpiration.

3.2.2 Precipitation

Mean annual precipitation ranges from 38 to 42 inches in the Tacoma area according to annual summaries compiled by the National Oceanic and Atmospheric Administration (NOAA). Monthly precipitation averages for the Puyallup and McMillin Reservoir Weather Stations and Tacoma City Hall are presented in Table RI-8. The U.S. Weather Bureau Station at Tacoma reports an average annual precipitation of 37.06 inches. Approximately 76 percent of the annual precipitation falls during the months of October through March (Entranco Engineers 1989).

Rainfall data collected during the investigative period from April 1991 to April 1992 were obtained from McChord AFB and are summarized in Appendix SW. The maximum 48-hour precipitation event measured by McChord Air Force Base (AFB) during the RI was 2.82 inches in early April 1991. As shown in Table RI-9, this constituted a 100-year storm event. McChord AFB is located approximately 5 miles south of the STF site. The total amount of precipitation recorded at McChord AFB from April 1991 to April 1992 (investigative period) was 38.76

TABLE RI-7

MONTHLY AVERAGE TEMPERATURE (°F) FOR TACOMA AREA, CLIMATE DIVISION 3, WASHINGTON[a,b]

Weather Station	January	February	March	April	May	June	July	August	September	October	November	December
McMillin Reservoir	37.2	41.0	42.8	47.4	53.3	58.2	62.6	62.6	58.4	50.8	42.9	39.2
Puyallup Experimental Station	38.8	42.5	44.4	49.2	55.4	60.5	64.4	63.8	59.3	51.8	43.8	40.4

(a) Data from Climatological Data Annual Summary, Washington 1990, Vol. 94, No. 13, National Oceanic and Atmospheric Administration, National Climatic Data Center.
(b) Average values are based on a minimum of 50 years of recorded data.

TABLE RI-8

MONTHLY AVERAGE PRECIPITATION (INCHES) FOR TACOMA AREA, CLIMATE DIVISION 3, WASHINGTON[a,b]

Weather Station	January	February	March	April	May	June	July	August	September	October	November	December
McMillin Reservoir	6.00	4.28	3.76	3.04	2.18	1.98	0.89	1.64	2.21	3.56	5.66	6.20
Puyallup Experimental Station	6.23	4.51	3.81	2.82	1.82	1.63	0.81	1.43	2.06	3.44	5.66	6.54
Tacoma City Hall	5.57	4.02	3.50	2.43	1.55	1.32	0.70	1.02	1.80	3.75	5.55	5.67

(a) Data from Climatological Data Annual Summary, Washington 1990 and 1991, National Oceanic and Atmospheric Administration, National Climatic Data Center.
(b) Average values are for a minimum of 50 years of recorded data.

TABLE RI-9

STORM EVENT PRECIPITATION- FREQUENCY VALUES

Frequency (Years)	6-Hour Duration Precipitation (Inches)	24-Hour Duration Precipitation (Inches)
2	1.0	2.0
5	1.2	2.5
10	1.4	2.8
25	1.6	3.3
50	1.8	3.5
100	2.0	4.0

Source: Miller et al. (1973).

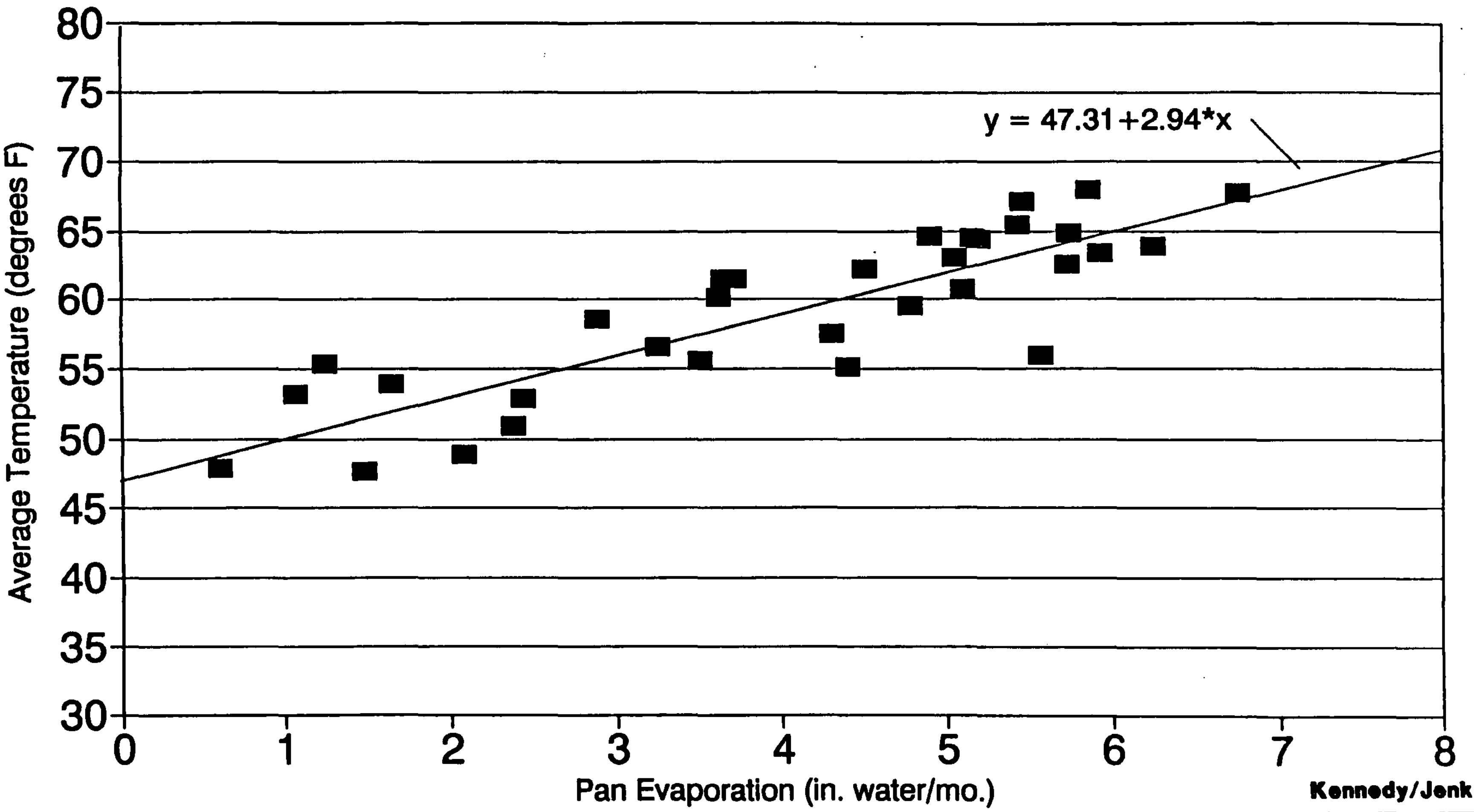
inches. Approximately 60 percent of the total precipitation fell during the months of October 1991 through February 1992.

3.2.3 Evapotranspiration

Evapotranspiration is the total evaporation from all sources; evaporation from water, soil, snow, ice, vegetation, and other surfaces plus transpiration. Transpiration is essentially water loss to the atmosphere through the leaves of plants. Evapotranspiration is a climatic factor that directly contributes to the transfer of water from the subsurface (i.e., groundwater and soil water) aquifer into the atmosphere. The amount of evaporation is largely dependent on temperature. Figure RI-3 shows average temperature vs evaporation. Annual water loss due to evaporation from standing water in the site area has been estimated to range between 20 and 25 inches (Brown and Caldwell 1985). Actual evapotranspiration is in effect the water lost by the soil due to evaporation and transpiration given average temperatures, vegetal cover, and the availability of water. Annual evapotranspiration values for the study area have been estimated at 18 to 26 inches (Brown and Caldwell 1985). In the Tacoma area, the period of maximum evaporation potential coincides with the period of minimum precipitation.

3.3 SURFACE WATER HYDROLOGY

Surface water from two upgradient sub-basins discharges onto the northwest portion of the STF site at Location 2500 (a 60-inch storm drain outfall) and Location 2501 (a 24-inch storm drain outfall). This water discharges into an onsite surface water channel that flows from north to south. The drainage area for upgradient sub-basin 1, which discharges at Location 2500, is 262 acres. The drainage area for upgradient sub-basin 2, which discharges at Location 2501, is 165 acres. Throughout the period of this investigation, low flows were observed continuously discharging onto the site during non-storm periods through the 60-inch



Notes: Data from N.O.A.A weather station No. 6803, Puyallup, WA.

Equation given is for linear curve fit of data.

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

RELATIONSHIP OF AVERAGE TEMPERATURE TO PAN EVAPORATION AT PUYALLUP, WA

916055.19/P2SK190

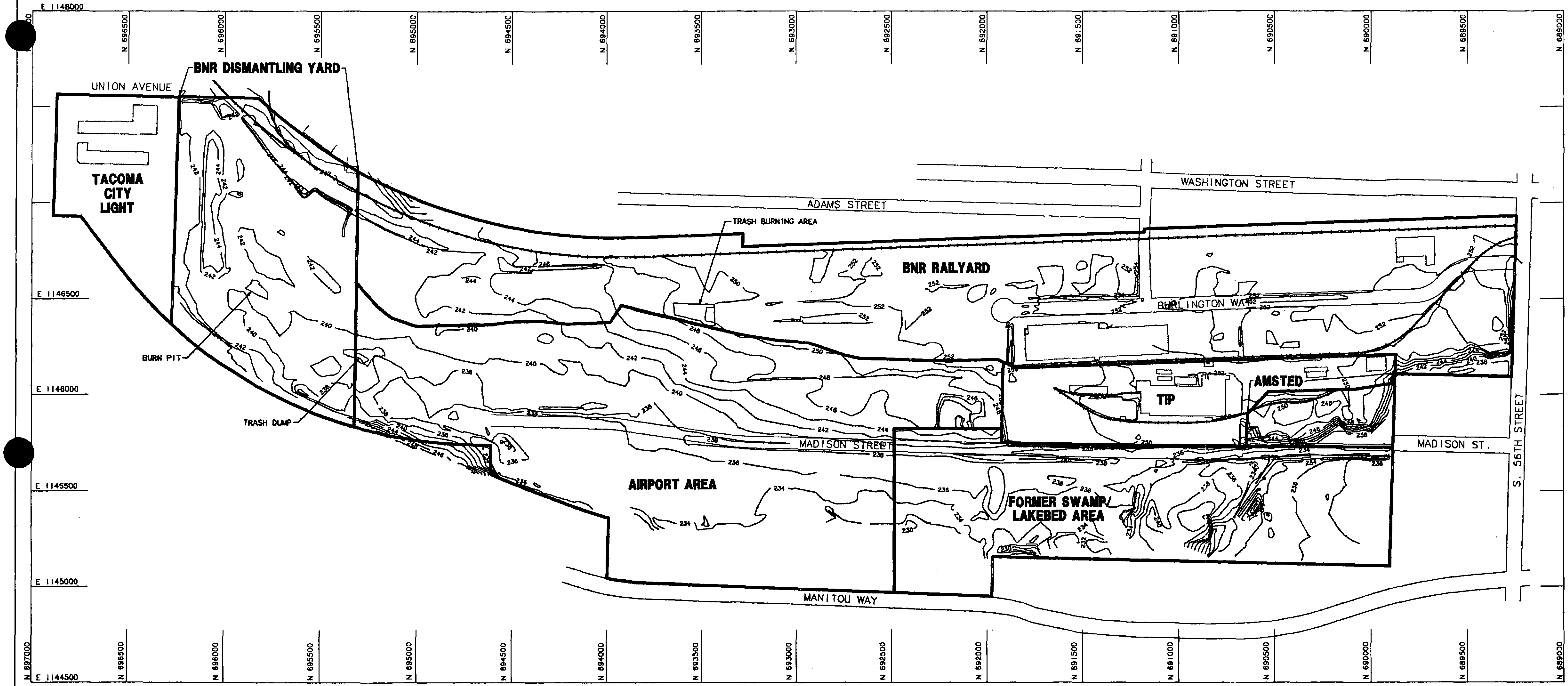
FIGURE RI-3

outfall. Low flows were observed sporadically at the 24-inch outfall. Substantial flows discharged from both outfalls during storm events. The estimated volume of surface water flowing onto the STF site at runon Locations 2500 and 2501 was approximately 100 million gallons for the period April 1991 through March 1992. The estimated volume of runon to the site was calculated using the rational method. Given the limitations of the rational method for large drainage basins, this value may somewhat overestimate the actual flow.

Other appreciable surface water runon from offsite into the onsite surface water channel or other areas of the site was not directly observed during this investigation. As shown in Figure RI-4, the ground surface over most of the site is relatively flat. Sheet runoff from onsite areas does not contribute significantly to flows in the onsite surface water channel. Accordingly, the major sources of onsite surface water appear to be runon flows from the two onsite storm drain outfalls.

Onsite surface water features are shown in Figure SW-3 of Appendix SW. For this investigation, the onsite surface water channel was divided into four reaches based on observed hydrologic characteristics. These reaches were identified using alphabetic designators A through D, with Reach A used to designate the farthest upstream channel segment (where surface water discharges to the site) and Reaches B, C, and D used to designate segments located progressively further downstream.

The channel and reach designations are shown in Figure SW-5a of Appendix SW. A profile of the channel bottom illustrating hydraulic gradients is shown in Figure SW-5b (Appendix SW). The channel bottom elevation at the 60-inch storm drain outfall where water flows onsite is 236 feet above mean low water (MLW) and drops to 230 feet MLW at the downstream end of Reach D where stormwater discharges from the site.



LEGEND

GROUND SURFACE ELEVATION CONTOUR IN FEET ABOVE MEAN LOW WATER

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

SITE TOPOGRAPHY

916055.19/P2SK189

FIGURE RI-4

The total onsite length of the channel is 6,600 feet and the average slope is 0.9 feet vertical per 1,000 feet horizontal (S = 0.0009). Because channel bottom slopes vary onsite, this average is not representative of localized conditions. The roughness constant (Manning's "n") values for the onsite channel are estimated to vary from about 0.025 to 0.050. The width of the channel bottom varies from about 5 to 15 feet in most reaches except in wetland areas where the bottom area available for active flows broadens considerably. The first 3,600 feet of the onsite channel (i.e., upstream segment from the 60-inch outfall to the last third of Reach B) slopes continuously downward. After an initial drop by the outfall (at Location 2501), the slope is relatively constant (i.e., S = 0.0011). There is no net vertical drop from the last third of the channel in Reach B to the downstream end of the onsite channel. A series of depressions along this downstream segment of the channel forms storage basins that retain surface water flows. The low point (elevation 224 feet MLW) in the downstream segment of the channel (Reach C) is 6 feet below the point at which the channel discharges offsite. A description of each reach is provided below.

- Reach A is a 1,400-foot long portion of the surface water channel and is located in the northwest corner of the STF site. Both storm drains discharge to this reach. Surface water was observed to be present in Reach A throughout the RI (April 1991 through March 1992). The channel bottom in this reach drops 4 feet vertically over the 1,400-foot length.

- Reach B continues downstream (south) from Reach A for a distance of approximately 2,750 feet along the western boundary in the Airport area into the Former Swamp/Lakebed area. Reach B begins in the north as a clearly defined channel flanked by riparian woodland and merges along its southern portion into a swamp remnant area. A constant vertical drop totaling 2 feet occurs along the northernmost portion of the reach (i.e., approximately 2,100-foot length) in the south swamp remnant area. A vertical drop of 6 feet occurs along the 600- to 650-foot length of channel that flows through the swamp remnant area. During most of the investigative period, the only portion of Reach B in which appreciable quantities of surface water were present was the south swamp remnant area, although some "ponding" was periodically observed along the channel in the northern portion of the reach. Under non-storm conditions, water throughout Reach B appeared to be stagnant (i.e., no visual evidence of flow conditions). Only during periods of heavy or extended precipitation was surface water present throughout the reach and flow evident.

- Reach C is a 690-foot segment of the channel that parallels the western STF site boundary and then turns to the east in the north end of the Former Swamp/Lakebed area. The channel bottom at the north end of Reach C is the lowest point (elevation) along the entire onsite channel. The elevation increases to the southern end of Reach C creating a depression for surface water storage. Relatively stagnant surface water was generally present throughout Reach C during the RI, except during the dry season when water was absent from much of the reach. During periods of heavy precipitation (including those occurring in the dry season), water overflowed from the channel through Reach C. The primary source of the surface water entering Reach C is most likely the flow from upstream in the surface water channel. Other possible sources of water entering this reach include sheet runoff from the offsite hillside on the western boundary of the channel, groundwater discharge into the channel, and precipitation.

- Reach D consists of the southernmost 1,550 feet of the onsite channel that runs east then south (parallel with Madison Street) to the site boundary. The elevation of the channel bottom increases about 3 to 4 feet from the boundary of Reaches C and D to the point where flows discharge offsite. The last 1,000 feet of the Reach D channel bottom forms a depression with a maximum depth of 2 feet. This depressions creates a retention area for surface water storage. With the exception of a small area adjoining Reach C, Reach D was generally dry during non-storm periods. During the RI, surface water was observed flowing offsite on only four occasions, each of which followed extended periods of precipitation (i.e., storms of approximately 1 week in duration consisting of 2 or more inches of precipitation). The accumulation of a volume of surface water in Reach D sufficient to exceed its storage capacity was necessary to produce offsite flow.

An estimated volume of 14.6 million gallons of surface water discharged from the STF site at runoff Location 2517 during the four storm runoff events recorded during the RI (30 total days of precipitation). Based on flow monitoring data, total runoff volume of 23 million gallons was estimated for the period of April 1991 through March 1992. However, the accuracy of this estimate is questionable because a majority of the recorded flow hydrographs showed characteristics that suggest backflow onto the site may have been occurring and offsite runon in the vicinity of the flow meter may have influenced the measurements. In addition to the four observed storm runoff events discussed above, two recorded flow events with hydrographs characteristic of stormwater runoff flows were recorded during this investigative period. Using these two additional hydrographs, a more realistic total offsite flow volume for this investigative period was estimated to be approximately 15.1 million gallons.

The estimated volume of surface water discharged from the STF site was substantially less than the estimated volume of surface water flowing onto the site during the RI. The net loss of surface water flowing through the site is attributed to evaporation, transpiration, and infiltration through the soil, resulting in recharge to the upper aquifer beneath the site.

The channel continues offsite for 500 feet along Madison Street to approximately 150 feet north of South 56th Street, at which point the open channel enters a 72-inch storm drain. Surface water from STF, combined with other sources of surface water, discharges from the trunk storm drain to the Flett Creek storm basin approximately 1.4 miles south of the site. Approximately 3 miles farther downstream, Flett Creek discharges into Chambers Creek, which leads to Chambers Bay on Puget Sound.

3.4 SOIL

The majority of the site is covered by a thin veneer (i.e., 6 inches or less in thickness) of organic topsoil underlain by comparatively organic-free unconsolidated sediment. These underlying materials are of both natural and anthropogenic origin.

Due to the historical industrialization of the site and subsequent demolition of most pre-existing structures on the STF site, very little of the near surface soil at the site is undisturbed. Despite the grading that has occurred over much of the site, natural processes have resulted in the formation of a thin topsoil in these areas. Fill materials have been mixed with natural soils. Based on the appearance of the overlying topsoil alone, fill areas are generally indistinguishable from other areas underlain by naturally deposited sediment.

The topsoil or loam in areas that are ostensibly underlain by undisturbed soil is typically less than 6 inches thick and consists of black to brown sand with some silt and organic matter. The underlying soil consists of sands and gravels (see Section 3.5 for a discussion of the geology of deeper soils at the STF site).

Naturally occurring soils in the vicinity of the STF site were surveyed by the U.S. Department of Agriculture (USDA 1979). While soils within the STF site boundaries were not included in the survey, the native soil types found on the site (and still present in undisturbed areas) can be inferred from surrounding soil types. Soils west of the site belong to the Alderwood-Everett association and soils to the south belong to the Spanaway association.

The Alderwood-Everett association is characterized by a nearly level to rolling topography. Soils belonging to this association are moderately well-drained to somewhat excessively drained and were formed in areas of glacial till and glacial outwash. This association was identified 0.5 miles west of the STF site.

Spanaway association soils are characterized as being somewhat excessively drained and gravelly. This soil association is most commonly formed in glacial outwash that is mixed with volcanic ash. The Spanaway association was found to predominate south of South 74th Street (approximately 1.25 miles south of the STF site). Surface soil at the STF site, in areas that appear to be relatively undisturbed, exhibits characteristics consistent with the Spanaway association.

As noted previously, soils in some areas of the site have been disturbed and, at least in part, are composed of fill materials. Fill materials are generally 1 to 3 feet in thickness. However, some areas of the site contain fill materials up to 5 feet thick. These areas include portions of the Amsted property and portions of the Former Swamp/Lakebed. Fill material in the southern end of the BNR Railyard is generally about 6 feet thick, but reaches a thickness of about 8 feet in some areas. The western and northern portions of the TIP property also have areas where fill reaches thicknesses of up to 8 feet.

Fill materials encountered onsite generally include cinders, slag, scrap metal, brick, wood, and glass. These materials are typically mixed with approximately equal amounts of soil particles. The most common fill material is a mixture of slag, cinders, and soil.

Fill material reportedly originated from both onsite and offsite sources (ICF 1990a). Two foundries operated and disposed of waste onsite. The site also received additional foundry waste from offsite sources (e.g. Fick and Atlas Foundries). Other onsite sources of fill included debris resulting from demolition of buildings and debris from railroad operations. Municipal and construction debris are also reported to have been placed onsite.

Based on the results of particle size distribution analyses of surface soil samples collected during the RI, sand and gravel-sized particles predominate the surface soil. Generally, sand and gravel constituted at least 80 percent of each sample by weight. Measured moisture contents of surface soil samples were generally less than 15 percent, which is consistent with coarse-grained textures. The soils were found to be non-plastic. Laboratory permeability tests of remolded surface soil samples yielded results ranging from $1x10^{-6}$ to $5x10^{-4}$ cm/sec. Calculated porosities ranged from 20.4 to 46.0 percent. Total organic carbon contents (TOC) ranged from 2,120 mg/kg to 420,000 mg/kg (0.2 percent to 42 percent). More detailed discussion of surface soil characteristics is presented in Appendix SS.

3.5 GEOLOGY

3.5.1 Geomorphology

The STF site lies within the central portion of the Puget Lowland physiographic province of western Washington. The Lowland is bounded on the east by the Cascade Mountains and on the west by the Olympic Mountains and Willapa Hills. The portion of the Lowland in which the STF site lies is characterized by rolling hills and depressions that are occupied by lakes, rivers, and Puget Sound (Brown and Caldwell 1985).

The site is located on a drift plain that regionally ranges in elevation from sea level to approximately 600 feet. The present topography is the result of glacial and glaciofluvial processes of the most recent glaciation, the Vashon Glaciation, which occurred between 13,000 and 20,000 years before present. Numerous drumlins and kettles are scattered across the plain. The kettles are usually evident as lakes and swamps.

The STF site lies within the South Tacoma Channel, a geomorphic feature produced during the Vashon Glaciation. The South Tacoma Channel is an outwash channel that was cut into the drift plain by high velocity glacial meltwater streams. The Channel acted as a spillway for meltwater from glacial Lake Puyallup during the northward retreat of the Puget lobe of the glacier (Thorson 1980).

3.5.2 Geologic History and Stratigraphy

During the Pleistocene epoch, several Cordilleran glaciers advanced into the Puget Lowland. The most recent of these (Vashon) was approximately 5,000 feet thick at the latitude of Seattle, approximately 1,500 feet thick over the STF vicinity, and had a terminus about 12 miles south of Olympia [U.S. Geological Survey (USGS) 1978].

The surficial deposits in the Puget Lowland are largely composed of glacial and interglacial unconsolidated sediments of Pleistocene age. A surface geologic map of the STF site and vicinity is shown in Figure GW-6 in Appendix GW. In the Tacoma area, the thickness of these deposits is estimated to be approximately 2,000 feet (Noble 1990). The sediments were deposited during advances and retreats of glaciers throughout the Pleistocene epoch. Three glacial and two interglacial climatic episodes appear to be represented by the stratigraphic units encountered during this investigation.

Lithologic facies common to these deposits include glacial till, advance outwash deposits, recessional outwash deposits, and fine-grained interglacial deposits. Sediments deposited during the glacial periods are typically coarse-grained and indicate high energy environments. Sediments deposited during the interglacial periods are typically finer grained with abundant organic matter and are indicative of low energy environments. Both glacial and interglacial deposits were encountered in the subsurface during this investigation.

Stratigraphic correlations are based on information gathered from installation of monitoring wells during the RI and previously published information on the regional geology. Unit names and corresponding climatic episodes are based on the revised nomenclature proposed by Noble (1990). Table RI-10 presents a summary of the subsurface geologic units that were encountered during this investigation. Table R1-10 also shows the correlation of units encountered at the STF site with regional hydrostratigraphic layers as defined by Brown and Caldwell (1985) and with units encountered in the subsurface at the Tacoma Landfill to the west (Black & Veatch 1990).

Three glacial and two interglacial climatic episodes are represented by units underlying the site. The episodes represent the Vashon Glaciation, Olympia Interglaciation, Narrows Glaciation, Kitsap Interglaciation, and Flett Creek Glaciation. The units representing these episodes from youngest (i.e., shallowest) to oldest (i.e., deepest) are the Vashon Drift, Discovery nonglacial unit, Narrows glacial unit, Kitsap Formation, and Flett Creek glacial unit. The following five hydrostratigraphic layers identified at the STF site are composed of members of the five units (Brown and Caldwell 1985):

- Layer A (upper)
- Layer A_1
- Layer A (lower)
- Layer B
- Layer C.

Layer A has been divided into an upper portion (Upper Layer A), which is unconfined, and a lower portion (Lower Layer A), which is likely semi-confined to confined. The two portions of Layer A are separated by Layer A_1. Layer B is a confining layer and separates Lower Layer A from the underlying Layer C which

TABLE RI-10

STRATIGRAPHIC CORRELATION IN THE VICINITY OF THE SOUTH TACOMA FIELD SITE

Climatic Episode[a]	Unit Name[a]	Hydrostratigraphic Layer[b]	Tacoma Landfill Subsurface Units[c]
Vashon Glaciation	Vashon Drift (Qv)	A (upper)	Vashon Till (Qvt) Vashon Advance (Qva) Colvos Sand (Qc) Older Gravel (Qog)
Olympia Interglaciation	Discovery nonglacial unit (Qd)	A_1	Older Sand (Qos) Older Lacustrine (Qol)
Narrows Glaciation	Narrows glacial unit (Qn)	A_1 A (lower)	Older Till (Qot) Older Advance (Qoa)
Kitsap Interglaciation	Kitsap Formation (Qk)	B	Kitsap Formation (Qk)
Flett Creek Glaciation	Flett Creek glacial unit (Qfc)	C	Not recognized

(a) Based on interpretations presented in Noble (1990).
(b) Based on correlations presented in Brown and Caldwell (1985).
(c) Based on correlations presented in Black & Veatch (1990).

forms the next aquifer zone. Groundwater in Layer C occurs under confined conditions.

These hydrostratigraphic layers appear to be laterally continuous in the vicinity of the investigation area, with the exception of Layer A_1. According to Brown and Caldwell (1985), Layer A_1 appears to pinch out east of the site and thin out in the northern portion of the site at NMW-5C. This observation is consistent with those made during the Phase I Groundwater Investigation. Layer B appears to be laterally continuous in the vicinity of the site. However, it is much thinner in the South Tacoma Channel than observed elsewhere. Layer B typically ranges in thickness from 50 to 150 feet in the Clover/Chambers Creek drainage area (Brown and Caldwell 1985). At the STF site, Layer B was observed to range in thickness from 2 feet at NMW-3C to approximately 15 feet at NMW-5C. Layer C is also laterally continuous in the vicinity of the site and reportedly ranges in thickness from 50 to 180 feet (Brown and Caldwell 1985). This unit was penetrated approximately 25 feet during the Phase I Groundwater Investigation. Geologic cross sections of the site are shown in Figures GW-7 through GW-9 in Appendix GW.

3.6 HYDROGEOLOGY

3.6.1 Regional Groundwater System

Available information indicates that the STF site lies in the vicinity of a regional groundwater mound of the uppermost aquifer that is oblong in shape and oriented north-south (Griffin et al. 1962; Brown and Caldwell 1985). The axis of the mound forms a regional groundwater divide and the presumed direction of groundwater flow is east on the east side of the mound and west on the west side of the mound. The mound is likely caused by convergence of groundwater flow from north and south of the South Tacoma Channel and recharge of surface water within the margins of the mound. In the central portions of the mound, the direction of the hydraulic gradient is toward the north to northeast.

3.6.1.1 Occurrence of Groundwater. Both locally and regionally, groundwater is encountered in two primary stratigraphic zones (Layer A and Layer C) in the upper 200-350 feet of sediment. Deeper saturated zones have also been encountered; however, the investigation of these units was beyond the scope of this project.

As previously indicated, Layer A_1 and Layer B are regional confining layers. Layer A_1 typically forms a confining layer between Upper Layer A (Colvos Sand) and Lower Layer A (Narrows glacial unit). Layer B minimizes hydraulic communication between the semiconfined to confined Lower Layer A and confined Layer C. Available background information suggests that Layer B is missing in the South Tacoma Channel (Brown and Caldwell 1985). However, as noted above, Layer B was identified during the installation of deep monitoring wells at the STF site. The thickness of this unit is, however, much less than has been identified elsewhere in the Channel.

3.6.1.2 Hydraulic Gradients. Based on potentiometric surface maps for the Clover/ Chambers Creek drainage area (the regional drainage area), the hydraulic gradient in Upper Layer A is in a northwestern direction (Brown and Caldwell 1985). This generalized regional direction of the hydraulic gradient is consistent with observations made at the STF site during the RI. However, the hydraulic gradient in several areas of this large site has been observed to trend to the east, west, or southwest during different times of the year. Variation in the direction of the hydraulic gradient observed at the site are typically a result of:

- Groundwater extraction from large municipal production wells owned by Tacoma Public Utilities (i.e., Wells TAC-4A, TAC-5A, TAC-6A, and TAC-11A)
- Seasonal variations in recharge
- Lithologic and structural influences such as variations in aquifer thickness and aquifer transmissivity.

Available information suggests that the hydraulic gradient in Layer C is also toward the northwest (Brown and Caldwell 1985). However, there are few monitoring locations to confirm this presumed hydraulic gradient in the vicinity of the STF site.

Vertical gradients between Layers A and C are reported to be in a net downward direction throughout the Clover/Chambers Creek drainage area (Brown and Caldwell 1985). The same information source also indicates a net upward vertical gradient in the South Tacoma Channel. This information contradicts findings reported during the Phase I Groundwater Investigation, which indicate a net downward vertical gradient between the two zones of saturation. During the summer months when the potentiometric surface in Layer C is regionally depressed due to pumping, the head differential between the Lower Layer A and Layer C was observed to be as great as 27 feet or more. During times when groundwater extraction is not in progress, head differentials between Lower Layer A and Layer C are 0.27 feet at Wells NMW-3B/NMW-3C and 10.95 feet at Wells NMW-5B/NMW-5C. This information indicates that Layer B is more effective at preventing inter-aquifer communication in the vicinity of Well Cluster NMW-5 than in the vicinity of Well Cluster NMW-3.

3.6.1.3 Aquifer Properties. As discussed in Section 3.5, Layer A contains advance outwash sand and gravels deposited during the Vashon glaciation. As a result, these materials typically have very high hydraulic conductivity values. Hydraulic conductivity values reported by Brown and Caldwell (1985) for Layer A in the vicinity of the South Tacoma Channel ranged from 1,000 to 3,000 gallons per day per square foot (gpd/ft^2). Hydraulic conductivity values calculated for Upper Layer A, based on aquifer tests performed during the RI, range from about 1,100 to 1,200 gpd/ft^2. Hydraulic conductivity values reported by Carr/Associates (1991) for Layer C in the vicinity of the STF site ranged from 300 gpd/ft^2 to 3,000 gpd/ft^2.

3.6.2 Local Groundwater System

Based on available potentiometric surface data, the STF site appears to lie within a groundwater recharge area. Information gathered during the Surface Water and Sediment Investigation of the RI indicates that most precipitation and surface water in the onsite channel along the western portion of the site does not flow offsite as surface water, except during major rainfall events. Surface water is believed to dissipate by evaporation, transpiration, and downward percolation into the saturated zone.

The unsaturated zone at the STF site is composed mainly of the upper portion of the Colvos Sand unit. Other local deposits comprising the uppermost unsaturated zone include fine-grained sediment and organic material in the Former Swamp/ Lakebed area and areas of fill material. Most of the wells at the STF site are screened in the uppermost part of the Colvos Sand in poorly graded to well-graded, fine- to medium-grained sand. Where observed, the lower portion of the upper aquifer consists mainly of gravel.

The top of the saturated zone was encountered at depths ranging from near ground surface in the Former Swamp/Lakebed area to approximately 35 feet below ground surface (BGS) in the southeastern portion of the site. Depth to the top of the uppermost saturated zone (water table) varies seasonally. Water level fluctuation on the order of 10 feet occurs over much of the site. These seasonal variations in depth to the unsaturated zone are dependent on climatic conditions and pumping of the Tacoma Public Utilities wellfield to the east of the site.

Figures GW-11 through GW-24 in Appendix GW are contour maps of the upper aquifer potentiometric surface measured during the RI. The map for August 1991 (Figure GW-16) is representative of Upper Layer A conditions when the Tacoma Public Utilities is pumping from its production wells to the east of the STF site. The map for February 1992 (Figure GW-22) is representative of conditions when the wells are not being pumped.

The South Tacoma Channel in the vicinity of the STF site appears to act as a local recharge area for groundwater. The natural hydraulic gradient (when not influenced by regional pumping) in the upper aquifer appears to be from the south to southeast to the north to northwest across the site, following the regional pattern of hydraulic gradient directions. The natural hydraulic gradient direction in the west central portion of the site appears to be to the west toward the Tacoma Landfill. A steep hydraulic gradient exists throughout the year in the southwestern portion of the site, where the inferred groundwater flow direction was consistently from east to west. In the southwestern portion of the site, the hydraulic gradient direction was observed to vary from the northwest to the southwest.

Based on available potentiometric surface data for the Upper Layer A, a perennial groundwater divide appears to be located in the vicinity of the South Tacoma Channel. This divide shifts to the west toward or in the vicinity of the Tacoma Landfill when the City of Tacoma production wells are pumping (Black & Veatch 1987). The presence of this divide in the vicinity of the South Tacoma Channel appears to be due in part to the absence of the poorly transmissive glacial till unit that typically overlies the Colvos Sand in the region and the convergence of groundwater flow from the north and south of the site. The more highly transmissive Colvos Sand is exposed in the South Tacoma Channel and likely promotes more rapid percolation of precipitation and surface water through the unsaturated zone into the saturated zone.

3.7 ECOLOGY

This section describes the ecological conditions at the STF site. Plant information was obtained from a wetland delineation and endangered plant species survey conducted by LSA Associates (1991) as part of this RI. Additional flora and fauna information was obtained from site visits, literature searches, and conversations with persons knowledgeable of the site conditions.

3.7.1 General Site Conditions

The undeveloped portions of the STF site are generally characterized by a fairly level grassland habitat that lies on the floor of the South Tacoma Channel. Trees and shrubs occur at scattered locations throughout the site. The western edge of the site is bordered by a bluff that rises as much as 150 feet above the floor of the Channel. The bluff and northwestern edge of the site are covered by a moderately large coniferous woodlot.

Although no perennial creeks, streams, or rivers flow through the STF site, a surface water (stormwater) drainage channel is located below the bluff at the western portion of the site. The primary source of surface water entering this drainage channel is stormwater runoff from two storm drain outlets along the northwest boundary of the site. The storm drain system is owned by the City of Tacoma. The onsite drainage channel crosses east through the south end of the STF site and feeds into a storm drain culvert. Water is usually present in the southern portion of the channel only as a response to heavy rains.

A perennial wetland and a possible remnant of the South Tacoma Swamp are located along the onsite drainage channel. The wetland and swamp remnant are primarily supported by stormwater runoff from the surface channel. The wetland is located just south of the pump station located at the northwest corner of the site. The swamp remnant is located to the south, midway along the western edge of the site. These areas contain standing water through most of the year, and support perennial wetland and riparian woodland ecosystems.

The grasslands at the south end of the site contain a series of small depressions that fill with water during the winter to create seasonal wetlands. These seasonal wetlands have developed following the deposition of fill materials into the former South Tacoma Swamp. During the winter, the depressions are filled with several inches of standing water, but in summer these same areas are generally bare and dry. Observations of soil revealed that alluvial materials had been placed in this area and had either been compacted upon placement or had become cemented through natural pedologic processes. Compaction and other processes have reduced soil permeabilities and facilitated the development of these seasonal wetlands.

Portions of perennial and seasonal wetlands were identified as potential jurisdictional wetlands in a survey conducted by LSA Associates (see Appendix WL).

3.7.2 Flora

The types of vegetation observed at the site during the wetland delineation and endangered species survey are summarized in Table R-11 and described in the following paragraphs. This information originally appeared in the Wetland Delineation and Endangered Species Survey Report prepared by LSA Associates (1991) for Kennedy/Jenks Consultants (see Appendix WL).

3.7.2.1 Grasslands. Grasslands are located mainly on the north end of the site and are characterized by a mosaic of perennial grasses, blackberry thickets, and scattered shrubs. The distribution of grass species is patchy. Some areas are dominated by perennial grasses such as bluegrasses (*Poa* spp.) and tall oatgrass (*Arrbenatherum elatius*). Other patches are dominated by annual grasses such as bromegrasses (*Bromus* spp.), annual fescues (*Vulpia* spp.), and hairgrasses (*Aira* spp.). Many other invasive herbaceous plant species are present, most of which are weedy annuals. Blackberry (*Rubus procera, Rubus laciniata*) stands and Scotch broom (*Cytisus scoparius*) are scattered throughout the grasslands.

3.7.2.2 Seasonal Wetlands. Smaller grassland areas are located at the south end of the site and are intermixed with a number of depressions that are classified as seasonal wetlands. The vegetation outside of the depressions is dominated by two perennial grasses, Canadian bluegrass (*Poa compressa*) and spreading bentgrass

TABLE RI-11

PLANT SPECIES ENCOUNTERED DURING SITE SURVEY

Scientific Name (Family/*Species*)	Common Name (Family/*Species*)	Indicator Status[a]
Equisetaceae	Horsetail Family	
Equisetum sp.	horsetails	N,NI
Dennstaedtiaeae	Dennstaedtia Family	
Pteridium aquilinum	bracken fern	N,FACU
Aspleniaceae	Spleenwort Family	
Polystichum munitum	sword fern	N,UPL
Pinaceae	Pine Family	
Pseudotsuga menziesii	Douglas fir	N,UPL
Ranunculaceae	Buttercup Family	
Ranunculus repens	creeping buttercup	I,FACW
Berberidaceae	Barberry Family	
Mahonia nervosa	Oregon grape	N,UPL
Geraniaceae	Geranium Family	
Geranium molle	dove's-foot geranium	I,UPL
Hypericaceae	St. John's Wort Family	
Hypericum perforatum	common St. John's wort	I,UPL
Papaveraceae	Poppy Family	
Eschscholzia californica	California poppy	N,UPL
Papaver rhoeas	corn poppy	I,UPL
Brassicaceae	Mustard Family	I,UPL
Arabidopsis thaliana	mouse-eared cress	I,UPL
Barbarea verna	spring cress	I,UPL
Brassica campestris	common mustard	I,UPL
Camelina micropcarpa	small-fruit false flax	I,FAC
Capsella bursa-pastoris	shepherd's purse	N,FACW
Cardamine oligosperma	western bittercress	I,UPL
Coronopus didymus	lesser wart-cress	I,UPL
Draba verna	spring whitlow-grass	I,UPL
Hesperis matronalis	dame's rocket	I,UPL
Hirschfeldia incana	Mediterranean mustard	I,UPL
Brassicaceae (continued)	Mustard Family (coninued)	
Lepidium campestre	poorman's peppergrass	I,UPL
Raphanus sativus	wild radish	I,UPL
Rorippa Curvisiliqua	western yellowcress	N,OBL
Rorippa palustris	marsh yellow cress	N,OBL
Sisymbrium altissimum	yumble mustard	I,FACU
Sisymbrium officinale	hedge mustard	I,UPL
Teesdalia nudicaulis	shepherd cress	I,UPL
Caryophyllaceae[b]	Pink Family	
Cerastium viscosum	mouse-eared chickweed	I,FACU
Spergularia rubra	purple sand-spurry	I,FAC
Stellaria media	common chickweed	I,FACU
Portulacaceae	Purslane Family	
Montia linearis	linear-leaved montia	N,NI
Polygonaceae	Buckwheat Family	
Polygonum aviculare	prostrate knotweed	I,FAC
Polygonum sp.	smartweed	?,OBL
Rumex acetosella	sheep sorrel	I,FAC
Rumex crispus	curley dock	I,FACW
Chenopodiaceae	Goosefoot Family	
Chenopodium album	white goosefoot	I,FAC
Plantaginaceae	Plantain Family	
Plantago lanceolata	English plantain	I,FAC
Ericaceae	Heath Family	
Arbutus menziesii	madrone	N,UPL
Gaultheria shallon	salal	N,UPL
Convolvulaceae	Morning-Glory Family	
Calystegia sepium	hedge bindweed	I,OBL

TABLE RI-11

PLANT SPECIES ENCOUNTERED DURING SITE SURVEY

Scientific Name (Family/*Species*)	Common Name (Family/*Species*)	Indicator Status[a]
Boraginaceae	Borage Family	
Myosotis versicolor	yellow & blue forget-me-nots	N,NI
Solanaceae	Nightshade Family	
Solanum dulcamara	bittersweet nightshade	I,FAC
Scrophulariaceae	Snapdragon Family	
Gratiola ebracteata	bractless hedgehyssop	N,OBL
Linaria dalmatica	Dalmation toadflax	I,UPL
Parentucellia viscosa	yellow parentucellia	I,NI
Verbascum thapsus	common mullein	I,UPL
Veronica serpyllifolia	thyme-leaf speedwell	I,NI
Veronica peregrina	purslane speedwell	I,OBL
Lamiaceae	Mint Family	
Lamium amplexicule	henbit	I,UPL
Rosaceae	Rose Family	
Alchemilla occidentalis	western dew-cup	N,UPL
Crataegus douglasii	Douglas' thorn-apple	N,FAC
Crataegus monogyna	hawthorne	I,NI
Osmaronia cerasiformis	oso berry	N,UPL
Prunus sp.	wild plum	N,UPL
Rosa sp.	wild rose	N,NI
Rubus lacinatus	cut-leaf blackberry	I,FACW
Rubus procerus	Himalaya-berry	I,FAC
Spiraea douglasii	Douglas' spiraea	N,OBL
Fabaceae	Pea Family	
Cytisus scoparius	Scotch broom	I,UPL
Lathyrus latifolius	everlasting pea	I,UPL
Lotus subpinnatus	chile lotus	N,UPL
Lupinus bicolor	bicolored lupine	N,UPL
Medicago polymorpha	bur-clover	I,UPL
Robinia pseudo-acacia	black locust	I,FAC
Trifolium arvense	rabbit-foot clover	I,UPL

Scientific Name (Family/*Species*)	Common Name (Family/*Species*)	Indicator Status[a]
Fabaceae (continued)	Pea Family (continued)	
Trifolium hybridum	alsike clover	I,FACU
Trifolium repens	white clover	I,FACU
Vicia angustifolia	common vetch	I,FACU
Vicia hirsuta	hairy vetch	I,UPL
Betulaceae	Birch Family	
Alnus rubra	red alder	N,FACW
Fagaceae	Beech Family	
Quercus garryana	Garry's oak	N,UPL
Salicaceae	Willow Family	
Populus alba	silver poplar	I,UPL
Populus balsamifera	black cottonwood	N,FACW
Salix lasiandra	red willow	N,OBL
Salix sitchensis	Sitka willow	N,FACW
Lythraceae	Loosestrife Family	
Rotala sp.	toothcup	I,OBL
Aceraceae	Maple Family	
Acer macrophyllum	big-leaf maple	N,FAC
Apiaceae	Carrot Family	
Conium maculatum	poison-hemlock	I,FACW
Rubiaceae	Madder Family	
Galium aparine	cleavers	N,FACU
Caprifoliaceae	Honeysuckle Family	
Lonicera involucrata	twin-berry	N,FAC
Asteraceae	Sunflower Family	
Achillea millefolium	common yarrow	I,FACU
Chrysanthemum leucanthemum	ox-eye daisey	I,UPL
Eriophyllum lanatum	woolly sunflower	N,UPL
Gnaphalium palustre	marsh cudweed	N,FACW
Hypochoeris radicata	hairy cat's-ear	I,UPL
Lactuca serriola	prickly lettuce	I,FAC
Matricaria matricarioides	pineapple weed	N,FACU

TABLE RI-11

PLANT SPECIES ENCOUNTERED DURING SITE SURVEY

Scientific Name (Family/*Species*)	**Common Name (Family/*Species*)**	**Indicator Status(a)**
Asteraceae (continued)	Sunflower Family (continued)	
Senecio vulgaris	common groundsel	I,NI
Sonchus arvensis	field sowthistle	I,FACU
Taraxacum officinale	common dandelion	I,FACU
Alismataceae	Water Plantain Family	
Alisma plantago-aquatica	common water plantain	N,OBL
Typhaceae	Cat-tail Family	
Typha latifolia	broad-leaved cat-tail	N,OBL
Iridaceae	Iris Family	
Iris pseudoacorus	yellow iris	I,OBL
Juncaceae	Rush Family	
Juncus balticus	Baltic rush	N,OBL
Juncus bufonius	toad rush	N,FACW
Juncus tenuis	slender rush	N,FACW
Luzula comosa	hairy woodrush	N,NI
Cyperaceae	Sedge Family	
Carex douglasii	Douglas' sedge	N,FACU
Carex hoodii	Hood's sedge	N,NI
Carex lasiocarpa	slender sedge	N,NI
Carex pennsyvanica var. *vespertina*	long-stoloned sedge	N,UPL
Carex stipata	awl-fruited sedge	N,OBL
Eleocharis acicularis	needle spike rush	N,OBL
Eleocharis palustris	creeping spike rush	N,OBL

Scientific Name (Family/*Species*)	**Common Name (Family/*Species*)**	**Indicator Status(a)**
Poaceae	Grass Family	
Agropyron caninum	cutting wheatgrass	I,NI
Agrostis stolonifera	spreading bentgrass	N,FACW
Aira caryophyllea	silver hairgrass	I,UPL
Aira praecox	little hairgrass	I,UPL
Alopecurus geniculatus	meadow foxtail	N,OBL
Anthoxanthum odoratum	sweet vernalgrass	I,FACU
Arrhenatherum elatius	tall oatgrass	I,FACU
Bromus mollis	soft chess	I,FACU
Bromus sitchensis	Alaska brome-grass	N,UPL
Bromus sterilis	poverty brome	I,UPL
Bromus tectorum	cheat grass	I,UPL
Dactylis glomerata	orchard grass	I,FACU
Danthonia californica var. *americana*	California oatgrass	N,FACW
Deschampsia elongata	slender hairgrass	N,FACW
Festuca rubra	red fescue	N,FAC
Holcus lanatus	velvet grass	I,FAC
Hordeum leporinum	foxtail barley	I,NI
Lolium perenne	Italian ryegrass	I,FAC
Phalaris arundinacea	reed canary grass	I,FACW
Poa annua	annual bluegrass	I,OBL
Poa compressa	Canada bluegrass	I,FAC
Poa pratensis	Kentucky bluegrass	N,FACU
Poa trivialis	rough bluegrass	I,FACW
Vulpia bromoides	six-weeks brome grass	I,FACW
Vulpia myuros	rat-tail fescue	I,FACU

(a) N-native; I-introduced; ?-uncertain; OBL-obligate wetland species; FACW-facultative wetland species; FAC-facultative species; FACU-facultative upland species; UPL-obligate upland species. Wetland status is from Reed (1988).

(b) *Arenaria paludicola* is a member of the Caryophyllaceae.

(*Agrostis stolonifera*). Other non-wetland vegetation identified at the south end of the site includes rough bluegrass (*Poa trivialis*), soft chess (*Broimus mollis*), bur clover (*Medicago polymorpha*), dove's-foot geranium (*Geranium molle*), common vetch (*Vicia andgustifolia*), hairy vetch (*Vicia hirsuta*), silver hairgrass (*Aira caryophyllea*), orchard grass (*Dactylis glomerata*), and bicolored lupine (*Lupinus bicolor*).

Depression vegetation is dominated by herbaceous perennial and annual hydrophytes. Vegetation composition varies from depression to depression and within depressions. The dominant plants identified in the seasonal wetlands include toad rush (*Juncus bufonius*), toothcup (*Rotala* sp.), western yellowcress (*Rorippa curvisiliqua*), bractless hedgehyssop (*Gratiola ebracteata*), spikerush (*Eleocharis* sp.), purslane speedwell (*Veronica peregrina*), sedges (*Carex* spp.), and Canadian bluegrass.

3.7.2.3 Perennial Wetlands. Both the north end of the onsite surface water channel and swamp remnant to the south contain permanent standing water. The north remnant has emergent vegetation only at the margins, including cattails (*Typhia latifolia*) and yellow iris (*Iris pseudoacorus*). The south swamp remnant, which typically contains between 1 and 3 feet of standing water, is dominated by water plantain (*Alisma plantago-aquatica*), water smartweed (*Ploygonum* sp.), and a rush (*Juncus* sp.)

The surface water channel has long stretches of standing water with no emergent vegetation and other stretches of barren mudflats. In general, canary reed grass (*Phalaris arundinacea*) and blackberry are the dominant species in portions of the channel without standing water. However, cattails dominate the emergent vegetation in portions of the channel with standing water. Although the channel banks are dominated by canary reed grass and blackberries, the banks also support horsetails (*Equisetum* sp.), bittersweet nightshade (*Solanum dulcamara*), and hedge bindweed (*Calystegia sepium*), as well as many of the grassland species.

3.7.2.4 Riparian Woodland. Approximately 12 acres of riparian woodland exist along the drainage channel. This woodland is dominated by red alder (*Alnus rubra*) and black cottonwood (*Populus balsamifera*), with an understory of assorted shrubs that includes willows (*Salix* spp.), wild plumb (*Prunus* spp.), wild rose (*Rosa* sp.), hawthorns (*Crataegus* spp.), Douglas' spirea (*Spirea douglasii*), and Scotch broom (*Cytisus scoparius*).

3.7.3 Fauna

No formal quantitative survey of fauna has been performed at the STF site. Information provided in the following paragraphs was gathered from a literature review, site visits, and conversations with persons knowledgeable of the fauna of the area.

The grasslands, perennial wetlands, and coniferous woodlot of the STF site provide habitat for a variety of fauna. This varied habitat combined with the decreased level of human activity add to the diversity of fauna present at the site. According to the Final Work Plan, "...the site, and associated woodland and wetlands, provide good habitat conditions for birds."

During field activities associated with this RI, a number of birds were observed throughout the study area. Red-tailed hawks (*Buteo jamaicensis*) were observed flying above the grassland areas and a ring-necked pheasant (*Phasianus colchius*) was sighted in the tall grass near the north end of the site. A partial list of other birds expected to inhabit, migrate through, or use the area based on the U.S. Army Corps of Engineers' Washington Environmental Atlas are listed in Table RI-12. This list is not comprehensive. According to EPA, such birds as robin, starling, quail, pigeon, kestrel, kingfisher, and various sparrow species have also been observed at the site.

TABLE RI-12

PARTIAL LIST OF FAUNA POTENTIALLY INHABITING, MIGRATING THROUGH, OR USING THE SOUTH TACOMA FIELD SITE[a]

Common Name	Scientific Name
Birds	
American Goldfinch	*Caruelis tristis*
Common Flicker	*Colaptes Auratus*
Downy Woodpecker	*Dendrocopos pubescens*
Great-Horned Owl	*Bubo virginianus*
Kildeer	*Charadius vociferus*
Lewis Woodpecker	*Asyndemus lewis*
Mallard	*Anas platyrhynchos*
Northwestern Crow	*Corvus caurinus*
Red-Tailed Hawk	*Buteo jamaicensis*
Ring-Necked Pheasant	*Phasianus colchius*
Ruffed Grouse	*Bonasa umbellus*
Screech Owl	*Otus asio*
Short-Eared Owl	*Asio flammeus*
Mammals/Reptiles	
Blacktail Jackrabbit	*Lepus californicus*
Common Garter Snake	*Thamnophis sirtalis*
Cottontail Rabbit	*Sylvilagus* sp.
Coyote	*Canis latrans*
Mice and Rats	family *Cricetidae*
Red Fox	*Vulpes vulpes*
Shrews	family *Soricidae*
Squirrels	family *Sciuridae*

(a) U.S. Army Corps of Engineers (1975).

Other fauna observed at the STF site include reptiles such as the common garter snake (*Thamnophis sirtalis*) and mammals such as the blacktail jackrabbit (*Lepus californicus*). Based on the land use surrounding the STF site, the occurrence of large mammals such as deer would not be expected; however, smaller mammals such as coyotes may inhabit or use the site. Rats, mice, gophers, and shrews would be expected to inhabit and/or use the site, but none were observed during field activities. Other mammals and reptiles that could potentially inhabit or use the area are listed in Table RI-12.

3.7.4 Threatened or Endangered Species

The Federal Endangered Species Act defines "endangered" as any species that is in danger of extinction throughout all or a significant portion of its range. A "threatened" species is any species that is likely to become endangered in the foreseeable future. Additional species of concern are divided into three categories:

1. Those proposed for listing as endangered or threatened
2. Candidate Category 1 (enough data are on file to support listing)
3. Candidate Category 2 (information indicates proposal to list is appropriate but current data are insufficient to support listing).

EPA's Final Work Plan (ICF 1990b) identified a single endangered plant species with potential to occur on the STF site, *Arenaria paludicola* (swamp sandwort). The only known collection of the swamp sandwort in the State of Washington was by J.B. Flett in 1896 (J. Gamon, 30 November 1990, personal communication). Flett noted the collection locality as the "Tacoma Swamps," which is the former description for much of the area of the STF Superfund site. A specimen collected in the 1960s along Chambers Creek, approximately 1.5 miles from the STF site, and catalogued at the Seattle Pacific University as *A. paludicola* was found to be misdetermined (J. Gamon, 12 February 1991, personal communication). The lack of recent observations of *A. paludicola* in the vicinity of the STF site suggests that the species no longer occurs there.

A search was conducted for *A. paludicola* on the STF site by LSA Associates on 14 June 1991. Because *A. paludicola* is an aquatic emergent perennial, only the portion of the site with the perennial wetland (i.e., with freshwater marsh vegetation) is potential habitat. No evidence for *A. paludicola* was found during the survey of the perennial wetlands on the STF site, leading to the conclusion that the species is not present on the STF site.

No threatened or endangered wildlife were observed at the site or found referenced in the literature search.

Perennial wetlands and riparian woodlands, such as those located at the STF site, provide valuable wildlife habitat. Plant growth is prolific in wetlands, and rapid uptake of nutrients by the vegetation contributes to natural water treatment. Marshes provide food, cover, and nesting sites for many species of invertebrates, amphibians, turtles, snakes, birds, and mammals. Seasonal wetlands may provide similar habitat value as perennial wetlands, but for a shorter portion of the year. Most seasonal wetlands on the STF site lack perennial vegetation and provide less cover and nesting habitat than the perennial wetlands.

Potential jurisdictional wetlands were identified on the west and south ends of the site. A jurisdictional wetland is a protected resource, as defined in the Federal Manual for Identifying and Delineating Jurisdictional Wetlands (Federal Interagency Committee for Wetland Delineation 1989).

Plant or animal species protected through Federal or State agency programs were not observed or documented as inhabiting the STF site.

4.0 METHODS

4.0 METHODS

This section includes a summary of field data collection methods for the individual investigative tasks of the RI; the analytical methods and requirements; and quality assurance, data validation, and statistical analyses of the STF RI data.

4.1 FIELD DATA COLLECTION METHODS

This section presents an overview of the site survey and data collection methods used during the conduct of the STF RI. The survey of horizontal and vertical coordinates for the site provided a uniform reference system for documenting sampling locations and presenting data for the entire site. Discussions of the field data collection methods are presented according to investigative task in the following sequence:

- Site Survey
- Phase I and II Soil Investigations
- Soil Gas Survey
- Geophysical Survey
- Subsurface Target Confirmation Investigation
- Hydraulic Characterization
- Phase I Groundwater Investigation

- Surface Water and Sediment Investigation
- Wetland Delineation and Endangered Plant Species Survey
- Blackberry Investigation.

The STF Field Sampling and Analysis Plan (FSAP), the FSAP Amendments for each of the individual field investigations, and the detailed investigation reports (Volumes 2-6) present more detailed descriptions of field data collection methods.

4.1.1 Site Survey

Prior to collection of field samples or data, PEI-Barrett, Inc. surveyed the STF site. Site boundaries were located and surveyed, and a Record of Survey was submitted to the Pierce County Auditor (File No. 9206180240). In addition, a sampling grid system was established as specified in EPA's Work Plan (ICF 1991b) and the FSAP (Kennedy/Jenks/Chilton 1991a).

The STF site was previously divided into seven sampling units (see Figure G-3 in Section 2.0) based on the historical activities and the potential for those activities to cause selected TCL chemicals to be released to the environment. Each sampling unit (except Tacoma City Light) was designated as high, medium, or low based on perceived-risk from elevated concentrations of selected TCL chemicals detected in onsite surface soil. These perceived-risk designations formed the basis for sampling grid sizes. The high-perceived risk areas had the smallest grid size and the low-perceived risk areas had the largest grid size.

Relatively small grid squares (70 feet wide) were established in the two sampling units with high-perceived risk levels: the Amsted property and the BNR Dismantling Yard. The medium (150 feet wide) and large (235 feet wide) grid squares were associated with the medium- and low-perceived risk areas, respectively. Large grids were established in the Former Swamp/Lakebed and BNR Railyard. Medium grids were established in the TIP and Airport areas.

The center of each grid square at the site was surveyed and demarcated with a hub and lath marked with location information. Vertical and horizontal control survey data were obtained for each hub.

The grid system survey was performed primarily to support the Phase I Soil Investigation sampling effort. The following surveying tasks were performed to support the other investigative tasks of the RI:

- Horizontal location and vertical elevation of wellheads at each groundwater monitoring well installed and/or monitored during the Groundwater Investigation.

- Locations of surface and subsurface sampling locations for the Phase II soil Investigation. (Note: sampling locations for the Phase II Soil Investigation at Pioneer Builders Supply and Tacoma City Light property were not surveyed.)

- Locations of sampling and data collection points for the Surface Water and Sediment Investigation.

- Locations of geophysical survey transects and geophysical anomalies (subsurface targets) requiring further investigation.

- Locations of sampling points for the Blackberry Investigation.

- Location of areas characterized as jurisdictional wetlands during the Wetland Delineation and Endangered Plant Species Survey.

4.1.2 Phase I and Phase II Soil Investigations

Soil sampling was conducted in two phases. Each phase included both surface and subsurface soil sample collection.

A surface soil sample was collected from each grid square established at the site during the Phase I Soil Investigation. Soil samples intended for chemical analyses were either composite or discrete samples. Samples intended for geotechnical testing were in all cases discrete samples.

Composite samples were collected from the 70-foot grid squares located in the Amsted property and BNR Dismantling Yard. These samples consisted of equal amounts of soil collected from different locations within the grid square. The soil was collected from the upper 6 inches of soil material. These samples were then homogenized and split into glass jars appropriate for the intended analyses.

Discrete samples were collected from the 150- and 235-foot grid squares in the remaining sampling units of the site (i.e., TIP, Airport, Former Swamp/Lakebed, and BNR Railyard). These samples were collected from the upper 6 inches of soil adjacent to the survey hub and lath which identified the grid square. These samples were also homogenized and placed in containers appropriate for the intended analyses.

Soil samples submitted for permeability and bulk density testing were collected in metal sample liners (rings) using a manually operated drive sampler. Soil samples submitted for testing of other geotechnical parameters were collected using a shovel and bucket.

All subsurface soil samples collected during the RI, regardless of location, were all collected in the same manner. Subsurface soil samples were collected using a truck or track-mounted drill rig and hollow-stem augers. At pre-specified depths, drilling was stopped and a split-spoon sampler was driven. The sampler was filled with metal liners. Upon retrieval of the sampler, the liners were removed and the retained materials were extruded. These soil materials were then homogenized and placed in glass jars for transportation to the analytical laboratory. Soil samples submitted for volatile organic compound (VOC) analyses were not extruded from the liners.

Subsurface soil samples are identified according to the depth of the top of the sampled interval. For example, a sample collected (and homogenized) from 7 feet indicates that the soil was collected from 7 feet to 8.5 feet below grade.

Subsurface soil samples collected for geotechnical testing purposes were generally collected from the drilling spoils. These samples were placed in 5-gallon plastic buckets and sealed for transportation to the testing laboratory. Soil samples used for permeability testing were collected using a split-spoon sampler and metal liners. Samples collected for total organic carbon (TOC), pH, moisture, and cation exchange capacity (CEC) determinations were placed in glass jars.

Subsurface conditions encountered during drilling and sampling were documented in boring logs for each location investigated. These logs present data such as soil types and moisture conditions encountered.

4.1.3 Soil Gas Survey

Tracer Research Corporation (TRC) performed a soil gas survey on the Pioneer Builders Supply property. The soil gas survey was performed in the area of former tank removal excavation. A soil gas survey is a method used to characterize the extent of surface soil and/or groundwater impacted by releases of VOCs. This characterization is accomplished by evaluating the concentration distribution of the released compound in soil gas.

During the soil gas survey, samples of soil gas were collected. These samples were collected from steel probes driven into the soil around the former tank removal excavation. Soil gas samples were collected from two different depths at each location. By applying a vacuum to the probe, a sample of soil gas was collected in a Tedlar bag aboveground. These gas samples were then analyzed in the field for a broad spectrum of VOCs using gas chromatograph/mass spectrometer (GC/MS) analytical methods.

4.1.4 Geophysical Survey

Engineering Hydraulics Inc. (EHI) performed an extensive geophysical survey of the site. This survey was conducted in two phases. The initial phase involved using electromagnetic (EM) and magnetic methods to screen the entire site. The second phase involved performing ground penetrating radar (GPR) surveys in areas where EM results showed subsurface anomalies that were indicative of buried metal objects of appreciable size.

The EM survey was performed over all accessible areas of the site. EM measurements were made on a grid pattern. Three different grid patterns were used. The grid spacing was dependent on the perceived likelihood of objects having been buried in a particular area. According to EPA's Work Plan (ICF 1990b), there was a high-perceived likelihood of drums having been buried in the Former Swamp/Lakebed and in portions of the BNR Dismantling Yard. A 20-foot grid spacing was used in these areas. In areas where objects larger than 500 gallons were suspected, a 40-foot grid spacing was used. The 40-foot grid spacing was generally used in areas located within 100 feet of existing building foundations. The EM survey of the remainder of the site was conducted using a 50-foot grid spacing.

A GPR survey was conducted in all areas where EM anomalies were found. During the investigation of each EM anomaly, at least six GPR transects were run: three running east-west and three running north-south. The transects were spaced 5 feet apart and centered over the index point of the anomaly. The index point is the location, at the surface, where the EM anomaly is strongest. If GPR data suggested that an underground object was present, additional transects were surveyed.

4.1.5 Subsurface Target Confirmation Investigation

The geophysical survey identified 60 subsurface targets that required further investigation to evaluate whether a tank or drum was present. These anomalies were excavated using a backhoe in July 1992. Only two tanks were found (no drums were found). One tank contained approximately 1,800 gallons of waste oil and sludge (the other one was empty). Results of this investigation will be summarized in an addendum to this RI Report and submitted in January 1993.

This investigation consisted of collecting subsurface soil samples where necessary and logging the soil conditions encountered during exploration. Soil samples were collected from soil brought to the surface using the backhoe bucket. Samples were then placed in glass jars and sealed for transportation to a laboratory for chemical analyses.

4.1.6 Hydraulic Characterization

The investigation of the saturated zone at the STF site consisted of characterizing aquifer hydraulics. The distinct hydrostratigraphic layers (A, B, and C) underlying the site were investigated.

Data were collected to evaluate the hydraulic characteristics of both the water table aquifer and the deeper aquifer at the STF site. The following activities were performed as part of this investigation:

- Soil samples testing for hydraulic properties

- Slug tests

- Pumping tests.

Soil samples (collected during monitoring well installation) were laboratory tested for properties that affect their water storage and transmission capacities (i.e., vertical hydraulic conductivity, porosity, and particle size). These samples were collected using a truck-mounted drill rig. Samples tested for vertical hydraulic conductivity were collected using a continuous core sampler and 2.5 foot long acrylic sample liners. This method permitted the collection of largely undisturbed samples. All other samples were collected from the drilling spoils using a shovel and bucket.

Slug tests were performed in the same 30 wells in which monthly water level measurements were recorded as part of the Phase I Groundwater Investigation. These slug tests were performed by quickly removing a "slug" from within the wetted zone of the well casing and recording the recovery of the potentiometric surface to its pretest static level. The slug consisted of a section of polyvinyl chloride (PVC) pipe filled with sand. Water level recovery was recorded using a pressure transducer placed below the slug within the wetted portion of the casing. Transducer readings were recorded for later analysis using a digital data logger.

Pumping tests were performed in two onsite wells. In each case the test well was pumped at a rate of about 60 gallons per minute (gpm) for a maximum duration 72 hours. The drawdown in the pumping well and observation well(s) was monitored continuously using pressure transducers and digital data loggers. Drawdown data were also evaluated in the field to monitor the progress of the pumping tests.

Additional data on hydraulic characteristics of the aquifer system at the site were acquired during pumping of a Tacoma Public Utilities production well adjacent to the STF site. Data were recorded for 2 weeks. Drawdown data were collected from wells completed in the deeper aquifer using pressure transducers and data loggers. Water levels in wells completed in the water table aquifer were measured daily using an electronic water level probe.

4.1.7 Phase I Groundwater Investigation

The chemical quality of groundwater beneath the STF site was evaluated by collecting and analyzing groundwater samples on a quarterly basis for 1 year. As part of the RI activities, 11 new monitoring wells were installed, 26 new and existing wells were sampled during four quarterly events, water levels in 30 monitoring wells were monitored monthly, and five background and five upgradient wells were sampled during two seasons. This section discusses the equipment and methods used during sample collection.

Groundwater samples were collected using the following types of equipment:

- Dedicated bladder pumps (onsite wells and some background wells)
- Dedicated mechanical pumping systems (some Tacoma Landfill wells)
- Submersible pumps (some offsite, upgradient, and background wells)
- Bailers (when other options not available).

Twenty-six (26) monitoring wells were equipped with dedicated pumping equipment. This equipment consisted of either a stainless steel pump with polytetrafluoroethylene (PTFE) bladder (4-inch monitoring wells) or a PVC pump with a PTFE bladder. Monitoring equipment installed in the deeper saturated strata were also equipped with air-activated packers to decrease the volume of water being purged prior to sampling.

During the second quarter of groundwater sampling, five wells at the Tacoma Landfill site were sampled. Four of these wells were equipped with dedicated pumping systems.

Several of the upgradient monitoring wells were not equipped with dedicated monitoring systems. These wells were sampled using a stainless steel submersible pump with a PTFE-lined discharge and sampling hose. The pump and hose were decontaminated between monitoring locations.

In instances when the submersible pump was inoperative or inappropriate for sampling a given well, bailers were used for well purging and sampling. A high volume PVC bailer was used for purging and a PTFE bailer was used for sampling. Bailers were decontaminated between sampling locations.

The following procedures were routinely used during groundwater sampling:

- Water levels were measured
- Between 3 and 10 wetted well casing volumes of water were purged from the well
- Representative groundwater quality indicator parameters were measured and recorded
- Required groundwater samples were collected and preserved.

Water levels were measured in 30 monitoring wells on a monthly basis. These measurements were made using an electronic water level probe. The top of the protective wellhead monument was used as the reference datum and measurements were made to the nearest 0.01 foot and converted to elevations using survey data for each well monument.

Prior to collecting samples, each monitoring well was purged of 3 to 10 wetted casing volumes. This water was removed with the dedicated equipment, the submersible pump, or by bailer. The purge water was placed in containers and labelled.

During purging, field groundwater quality indicator parameters were periodically measured and recorded. These parameters were pH, temperature, and electrical conductivity. These parameters were considered stabilized when:

- pH values varied by less than 0.1 unit between consecutive measurements
- Temperature varied by less than 0.5° Celsius between consecutive measurements
- Electrical conductivity varied by less than 10 percent between consecutive measurements.

Samples were collected after at least three well volumes had been purged and the indicator parameter measurements met the above criteria. Generally, it was not necessary to purge more than five well volumes from a well before sampling and in no case were more than 10 well volumes removed prior to sampling.

Samples collected using the dedicated equipment or the submersible pump were collected directly from the discharge hose. During collection of samples for VOC analyses, the purge rate of the pumps used was decreased to approximately 100 mL per minute. Samples from those wells where pumps were not used were collected using a PTFE bailer. Field personnel preserved samples with the appropriate preservative for the intended analytical method immediately after collection.

Filtering of selected groundwater samples was performed in the field by attaching a disposable 45-micron filter to the discharge hose of whichever type of pump was used. Filtered samples were not collected from wells where a pump system (dedicated or portable) was not used.

4.1.8 Surface Water and Sediment Investigation

The Surface Water and Sediment Investigation at the STF site consisted of three elements:

- Surface water flow monitoring
- Surface water (and stormwater) sampling
- Sediment sampling.

Surface water flow was monitored at one location onsite. Flow data were recorded continuously using a flow meter and digital data logger. This equipment was installed in a storm drain 500 feet from the southern (runoff) end of the site. The data logger was periodically downloaded in the field using a portable computer.

Surface water sampling consisted of three tasks:

- Sampling during monthly and storm events at two onsite locations that receive runon from offsite (storm drains)
- Sampling during a dry and wet season at five offsite locations to evaluate background surface water quality
- Sampling during dry, transitional, and wet seasons at up to 30 onsite locations.

There were 30 designated sampling locations in the onsite surface water channel, which traverses most of the western boundary of the site. Not all locations were sampled during each sampling event because surface water was not present during certain times of the year.

Surface water samples were typically collected by dipping a glass jar below the surface of the water. If a large sample volume was required, a 5-gallon glass carboy was filled in the same manner. During sample collection, field pH, and temperature measurements were recorded. Time, date, location, and analytical requirements for each sample collected were recorded on field data sheets.

Surface water samples were preserved by field personnel with the appropriate preservative for the intended chemical analyses.

Sediment samples were collected for the same 30 onsite locations where surface water samples were collected. Samples were retrieved using either a clam shell sampler, a disposable PTFE scoop, or a stainless steel spoon. Samples were collected at the water/sediment interface.

Upon collection, the sediment samples were placed in glass jars of the appropriate size and prepared for transportation to the analytical laboratory. Field data sheets were maintained noting the time, date, location, and analytical requirements for each sample.

4.1.9 Wetland Delineation and Endangered Plant Species Survey

A delineation of potential jurisdictional wetlands (wetlands), as they presently exist at the STF site, and an endangered plant species survey was performed by LSA Associates.

Field studies to delineate potential wetlands involved site reconnaissance by LSA's scientists and botanists to observe environmental indicators used to classify wetlands. Wetland identification required evaluating three environmental indicators:

- Presence of hydrophytic plant species
- Presence of hydric soil conditions
- Appropriate surface water hydrologic characteristics.

Wetlands were classified as perennial or seasonal wetlands.

During the wetland delineation, vegetation was characterized at 16 points along the onsite surface water channel that traverses the western boundary of the site. This characterization was performed to evaluate the extent of the wetland environment in that area. Vegetation was also characterized in 41 areas of the Former Swamp/Lakebed to aid in identifying seasonal wetlands.

The boundaries of identified wetlands were marked with wooden stakes by LSA's field crew. Locations of these stakes were later surveyed by PEI-Barrett.

LSA Associates also performed an endangered plant species survey at the STF site. This survey consisted of identifying whether the plant species *Arenaria paludicola* was present at the STF site.

Potential habitat areas (i.e., perennial wetlands) for *A. paludicola* were identified during the wetland delineation. Only the perennial wetlands were surveyed for *A. paludicola* because the occurrence of the plant in other areas of the site was not plausible. Due to the limited amount of habitat onsite, the survey was performed along one north-south transect.

The survey was performed during June when *A. paludicola* normally blooms to facilitate detection of the plant if it were present.

4.1.10 Blackberry Investigation

The potential biological uptake of a variety of metals was evaluated by collecting and analyzing samples of blackberries. Blackberry samples were collected from both onsite and offsite locations. Offsite sampling was further subdivided into area and natural background samples.

Six onsite samples were collected; one sample from each of the designated sampling units. Samples consisted of a composite of blackberries from within a sampling unit. These samples were then halved. One half of the sample was washed with deionized water. Both portions of the sample were submitted for chemical analyses.

Area background concentrations were evaluated by collecting and analyzing four samples. Two of these samples were from areas upwind of the site and two were from areas downwind of the site.

Natural background concentrations were evaluated by collecting and analyzing two samples. Both samples were collected upwind of the site.

4.2 ANALYTICAL METHODS AND REQUIREMENTS

Analytical methods outlined in EPA's Contract Laboratory Program (CLP) Statements of Work (SOWs) [organics (EPA 1990b, SOW OLM01.0); pesticides/PCB (EPA 1988a, SOW No. 2/88); inorganics (EPA 1990a, SOW ILM01.0)] were used to detect and quantify concentrations of all organic target compound list constituents and inorganic target analyte list constituents (where applicable), to provide consistent results of known and documented quality, and to ensure that data were accurate, precise, comparable, and legally defensible. Target Compound List (TCL) as used throughout this document refers to both inorganic and organic constituents included in the CLP SOW target compound list and target analyte list. In addition, analytes were also measured using the methods summarized in Table RI-13. For each analysis, the table includes the required method reference number, approximate detection limit, and holding time.

4.2.1 Contract Laboratory Program (CLP) Methods

EPA's CLP methods were used, except in cases where specific analytical methods were needed to provide lower detection limits for risk assessment calculation and to evaluate the attainment of Applicable or Relevant and Appropriate Requirements (ARARs). CLP methods were required for VOCs, BNA extractable compounds, chlorinated pesticides and PCBs, metals (except copper in water), and cyanide. The quality control (QC) criteria and required deliverables for these methods are specified in the appropriate CLP method.

4.2.2 Specific Analytical Methods

To achieve lower detection limits for some required analytes, the following specific analytical methods were used:

- EPA Method 8310 for PAHs [benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene]

- EPA Method 8290 for dioxin and furan homologs in soil

- EPA Method 7211 for copper in water

TABLE RI-13

ANALYTICAL METHODS FOR THE SOUTH TACOMA FIELD SITE

Analysis	Matrix	Method Referenced[a]	Description	Approximate Detection Limit[b]	Holding Time
Volatile organic compounds (VOC)	• Water • Soil	SOW OLM01.0	Purge and trap (GC/MS)[c]	• 1-10 ug/L • 10 ug/kg	• 14 days • 14 days
Semivolatile organic compounds		SOW OLM01.0	GC/MS		
• Base/neutral/acid (BNA) extractable	• Water • Soil			• 10-50 ug/L • 330-1,700 ug/kg	• 7 days extraction/40 days analyzed • 14 days extraction/40 days analyzed
• Polynuclear aromatic hydrocarbons (PAH)	• Water • Soil			• 10 ug/L • 330 ug/kg	• 7 days extraction/40 days analyzed • 14 days extraction/40 days analyzed
Polynuclear aromatic hydrocarbons (PAH)	• Water • Soil	EPA Method 8310	HPLC[d] fluorescence detection and ultraviolet detection	• 1-10 ug/L • 10-330 ug/kg	• 7 days extraction/40 days analyzed • 14 days extraction/40 days analyzed
Chlorinated pesticides/PCBs	• Water • Soil	SOW No. 2/88 (EPA 1988e)	GC/ECD[e]	• 0.05-5 ug/L • 1.7-170 mg/kg	• 7 days extraction/40 days analyzed • 14 days extraction/40 days analyzed
Metals	• Water • Soil	SOW ILM01.0	ICP[f]/GFAA[g]/AA[h]	• 0.2-5,000 ug/L • 0.2-1,000 mg/kg	6 months, except Hg = 28 days
Copper[i]	• Water	SOW ILM01.0 and EPA Method 7211	ICP AA	25 ug/L 1 ug/L	6 months
Chromium (VI)	• Soil	EPA Methods 1311 and 7197	TCLP Extraction/AA	0.2 mg/kg	6 months
Cyanide (total)	• Water • Soil	SOW ILM01.0	Distillation and colorimetric	• 10 ug/L • 5 mg/kg	14 days
Dioxin/furan homologs	Soil	EPA Method 8290	High-resolution GC/MS	1-5 pg/kg[j]	14 days extraction/40 days analyzed

TABLE RI-13

ANALYTICAL METHODS FOR THE SOUTH TACOMA FIELD SITE

Analysis	Matrix	Method Referenced(a)	Description	Approximate Detection Limit(b)	Holding Time
TCLP Extraction(k) • PAH analysis • Metals analysis	Soil	EPA Method 1311 • EPA Method 8310 • SOW ILM01.0	Extraction HPLC ICP/GFAA/AA	NA • 10-330 ug/kg • 0.2-1,000 mg/kg	NA • 14 days extraction/ 40 days analyze • 6 months, except Hg=28 days
MWEP(l) • PAH analysis • Metal analysis	Soil	SW-924 • EPA Method 8310 • SOW ILM01.0	Extraction • HPLC • ICP/GFAA/AA	NA • 10-330 mg/kg • 0.2-1,000 mg/kg	NA • 14 days extraction/40 days analyze • 6 months, except Hg=28 days
Boron	• Water • Soil	EPA Method 6010	ICP	20 ug/L 2 mg/kg	6 months
Total dissolved solids (TDS)	Water	EPA Method 160.1	Filterable, gravimetric	10 mg/L	7 days
Total suspended solids (TSS)	Water	EPA Method 160.2	Nonfilterable, gravimetric	10 mg/L	7 days
Total organic carbon (TOC)	• Water • Soil	• EPA Method 9060 • USDA, Method No. 24	Combustion or oxidation	• 1 mg/L • 4 mg/kg	• 28 days • 28 days
Hardness	Water	SM(m) 2340 B	Hardness by calculation	NA	NA
Fecal coliform Streptococcus coliform	Water	SM 908C or 909C(n) SM 910A or 910B	Multiple-tube fermentation (MPN) or membrane filtration (MF)	1.8 MPN/100 mL(o) or <1.0 coliform/100mL	6 hours
pH Specific conductance Temperature Moisture	Water Water Water Soil	EPA Method 150.1 EPA Method 120.1 EPA Method 170.1 EPA Method 160.3	Electrometric Electrometric Electrometric Gravimetric	NA NA NA 1%	Field reading Field reading Field reading NA
GEOTECHNICAL PARAMETERS					
• Permeability/hydraulic conductivity - (nonpermeable soil) - (permeable soil)	Soil	- EPA Method 9100 - ASTM(p) D-2434, D-5084	Flexible-wall falling head Constant head	NA	NA

TABLE RI-13

ANALYTICAL METHODS FOR THE SOUTH TACOMA FIELD SITE

Analysis	Matrix	Method Referenced[a]	Description	Approximate Detection Limit[b]	Holding Time
• Particle size distribution	Soil	ASTM C-117, C-136 ASTM D-422	Sieve, gravimetric Hydrometer	NA	NA
• Porosity-specific gravity	Soil	ASTM D-854	Drive cylinder	NA	NA
• In-situ density	Soil	ASTM D-2922	Nuclear moisture density gage	NA	NA
• In-situ moisture	Soil	ASTM D-3017	Nuclear moisture density gage	NA	NA
• Compaction	Soil	ASTM D-1557	Mechanical rammer	NA	NA
• Atterberg limits	Soil	ASTM D-4318	Soil consistency	NA	NA
• Moisture	Soil	ASTM D-2216	Gravimetric	1%	NA
• pH	Soil	EPA Method 9045	Electrometric	NA	NA
• Cation exchange capacity	Soil	EPA Method 7770		NA	NA

(a) Methods are referenced in the following documents: SOW OLM01.0 (EPA 1990b); SOW ILM01.0 (EPA 1990a); SOW No. 2/88 (EPA 1988a); Test Methods for Evaluating Solid Waste, SW-846 (EPA1986c); Methods for Chemical Analysis of Water and Wastes (EPA 1983a); and Standard Methods for the Examination of Water and Wastewater American Public Health Association (APHA) 1989].

(b) Detection limits are matrix- and analyte-specific and may be higher due to analytical interferences.

(c) GC/MS - Gas Chromatography/Mass Spectrometry.

(d) HPLC - High Performance Liquid Chromatography.

(e) GC/ECD - Gas Chromatography/Electron Capture Detection.

(f) ICP - Inductively Coupled Plasma (atomic emission spectroscopy).

(g) GFAA - Graphite Furnace Atomic Absorption.

(h) AA - Atomic Absorption.

(i) When copper was detected at concentrations less than or equal to 50 ug/L using SOW ILM01.0 methods, the water sample was reanalyzed using Method 7211.

(j) pg/kg - picogram per kilogram.

(k) Toxicity Characteristic Leaching Procedure (SW924).

(l) Monofilled waste extraction procedure.

(m) SM = Standard Method.

(n) The method for coliform analysis depended on the turbidity of the sample. Samples that were not turbid were analyzed using the membrane filtration technique. Samples that were turbid were analyzed using the multiple tube fermentation technique.

(o) MPN/100 mL = Most probable number per 100 mL.

(p) ASTM = American Society for Testing Materials.

- EPA Method 1311 and 7197 for chromium (VI) in soil.

QC criteria for sample frequency, type, and detection limits followed CLP methods, where applicable, with the addition of the QC criteria stated in the specific analytical methods.

Deliverables for specific analytical methods consisted of all raw data, (similar to data submitted for CLP deliverables) including instrument calibration, blanks, spike and surrogate results, chromatograms, and quantitation data.

4.2.3 Non-Contract Laboratory Program (CLP) Methods

Non-CLP methods (i.e., those not routinely used under the CLP Routine Analytical Services program as specific in SOWs) were also used to analyze Toxicity Characteristic Leaching Procedure (TCLP) and Monofilled Waste Extraction Procedure (MWEP) extracts, as well as to quantify boron concentrations, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), hardness, fecal coliform bacteria, and fecal streptococcus bacteria. QC criteria for these methods are presented in each analytical method. Standard operating procedures (SOPs) for specific analytical methods and non-CLP methods are provided in Attachment 1 of the QAPjP (Kennedy/Jenks/Chilton 1991b).

Deliverables for the foregoing non-CLP methods consisted of all raw data, including instrument calibration, blanks, spike results, and instrument readouts, where applicable.

4.2.4 Geotechnical Parameters

Surface and subsurface soil samples were also tested for physical properties including permeability, particle size distribution, porosity-specific gravity, bulk density, compaction, Atterberg limits, and moisture content. In addition, subsurface soil samples were also tested for pH and cation exchange capacity (CEC). QC sample frequencies and criteria are specified in the appropriate method.

4.2.5 Field Parameters

Field measurements (i.e., pH, specific conductance, and temperature) were collected as outlined in the standard operating guidelines (SOGs) presented in Appendix A of the FSAP (Kennedy/Jenks/Chilton 1991a).

4.2.6 Method Detection Limits

Method detection limit requirements were based on human health risk assessment criteria, best available technology criteria, sample matrix, and sample location. CLP analyses used contract required quantitation limits and detection limits (CRQLs/CRDLs) as specified in the CLP SOWs for pesticide/PCB, inorganic, and organic analyses (1988a; 1990a,b, respectively).

The required detection limits for PAHs, copper in water, and chromium (VI) were obtained from Appendix C of the Final Work Plan (ICF 1990b). Method detection limits for dioxin and furan homologs were specified in the analytical method.

Detection limits for non-CLP (conventional) methods are specified in the appropriate method. Detection limits for all analytes are listed in Table RI-13.

4.2.7 Analytical Laboratory Assignments

Laboratories were expected to meet or exceed specified QC limits for accuracy, sensitivity, and precision as stated in each analytical method and as outlined in the

QAPjP (Kennedy/Jenks/Chilton 1991b). Compliance with these limits was monitored by analyzing laboratory method blanks, spiked samples, surrogate spiked samples, duplicate samples, and laboratory control or performance evaluation samples. Approximately 15 to 20 percent of the total number of samples collected during the RI were laboratory QC samples.

Because the scope of work required for this project entailed extensive generation of analytical data, the majority of the analytical work was divided between three laboratories. Table RI-14 identifies the laboratories, analyses, and methods used for the STF project.

Pacific Environmental Laboratory (San Francisco, California) and SVL, Inc. [formerly Silver Valley Laboratories (Kellogg, Idaho)] performed the majority of the inorganic analyses, including metal, boron, and hardness analyses. In addition, SVL, Inc. also performed cyanide and TOC analyses.

Analytical Technologies, Inc. (ATI) performed the organic analyses. ATI has a network of several laboratories with locations in several states. ATI's laboratories in Renton, Washington and San Diego, California were used for this project. ATI's Renton laboratory was the primary point of contact for information regarding sample analyses performed by both of ATI's laboratories. All samples analyzed by ATI were sent to Renton. Samples analyzed by the San Diego laboratory were shipped by the Renton laboratory.

ATI subcontracted the dioxin and furan analysis to Triangle Laboratories in Research Triangle Park, North Carolina. (Only a limited number of laboratories in the United States perform this analysis.)

Physical parameter analyses for permeability, particle size distribution, porosity-specific gravity, bulk density, Atterberg limits, compaction, and moisture content (which is necessary to calculate porosity) were subcontracted to Golder Associates Inc., a geotechnical laboratory in Redmond, Washington.

TABLE RI-14

LABORATORIES, ANALYSES, AND ANALYTICAL METHODS FOR THE STF SITE

Laboratory	Analysis	Method
Pacific Environmental Laboratory	Metals	ILM01.0
(San Francisco, California)	Copper (water)	EPA Method 7211
	Chromium (VI)	EPA Methods 1311 (extraction) and 7197
and	Boron	EPA Method 6010
	Hardness	SM 2340B
	Moisture	EPA Method 160.3
SVL, Inc. [formerly Silver Valley	Cyanide	ILM01.0
Laboratories (Kellogg, Idaho)]	TOC (groundwater)	EPA Method 9060
	TOC (sediment using TOM method)	USDA Handbook No. 60, Method No. 24
	Grain size distribution	Methods of Soil Analysis ASA-SSSA 15-5
	TCLP(a)	EPA Method 1311 (extraction)
	Metals	ILM01.0
	MWEP(a)	SW-924 (extraction)
	Metals	ILM01.0
Analytical Technologies, Inc.(b)	Volatiles	OLM01.0
	Semivolatiles	
	BNA	OLM01.0
	PAH	EPA Method 8310
	Pesticides/PCBs	SOW No. 2/88
San Diego (until 10/8/91)	Cyanide	ILM01.0
	TCLP(a)	EPA Method 1311 (extraction)
	PAH	EPA Method 8310
	MWEP(a)	SW-924 (extraction)
	PAH	EPA Method 8310
San Diego (until 10/8/91)	TOC	EPA Method 9060
	TDS	EPA Method 160.1
	TSS	EPA Method 160.2
	Moisture	EPA Method 160.3
	pH	EPA Method 9045
	Cation exchange capacity (CEC)	EPA Method 7770
Triangle Laboratories(c)	Dioxin and Furans	EPA Method 8290
Golder Associates(c)	Permeability/hydraulic conductivity	
	Non-permeable soil	EPA Method 9100
	Permeable soil	ASTM D-2434, D-5084
	Particle size distribution	ASTM C-117, C-136 or ASTM D-422
	Porosity-specific gravity	ASTM D-854
	In-situ density	ASTM D-2922
	In-situ moisture	ASTM D-3017
	Compaction	ASTM D-1557
	Atterberg limits	ASTM D-4318
	Moisture	ASTM D-2216
Water Management Laboratories	Fecal Coliform	SM 908C or 909C
	Fecal Streptococcus	SM 910A or 910B

TABLE RI-14

LABORATORIES, ANALYSES, AND ANALYTICAL METHODS FOR THE STF SITE

(a) TCLP = Toxicity Characteristic Leaching Procedure.
MWEP = Monofilled Waste Extraction Procedure.

(b) Except as indicated for cyanide and TOC analyses by ATI's San Diego laboratory, samples were analyzed either by ATI's Renton, WA or San Diego, CA laboratory (until 10/8/91) as specified in ATI's SOP for Work Transfer (see STF QAPjP, Appendix F, Kennedy/Jenks/Chilton 1991b).

(c) Triangle Laboratories and Golder Associates were ATI's subcontractors for the STF project.

Surface water samples collected for bacteria analyses had a limited holding time of 6 hours. Accordingly, Water Management Laboratories of Tacoma, Washington was chosen to perform bacteria analyses due to their proximity to the site.

Prior to beginning each field investigative task, laboratories were notified of the anticipated number of samples, matrices, required analytical methods, and deliverable dates.

The quality assurance (QA) manuals for Kennedy/Jenks/Chilton's Pacific Environmental Laboratory and ATI are provided in Appendices E and F of the QAPjP (Kennedy/Jenks/Chilton 1991b). QA manuals for SVL, Inc., Water Management Laboratories, Golder Associates Inc., and Triangle Laboratories are maintained in the STF Project Files.

4.3 QUALITY ASSURANCE, DATA VALIDATION, AND STATISTICAL ANALYSES

QA objectives were established to ensure reliable and accurate data value, and applied to all aspects of sample handling, analyses, data management, and reporting. The QA objectives and measures necessary to achieve satisfactory data quality were presented in the STF QAPjP (Kennedy/Jenks/Chilton 1991b). The QAPjP also describes the policy, organization, and functional activities associated with quality assurance/quality control (QA/QC).

4.3.1 Field QA/QC Procedures

During field operations, QC samples were collected to monitor both field and laboratory operations to evaluate the precision and accuracy of analytical data throughout the project. QC samples consisted of field duplicates and blank samples (rinsate, trip, and transfer blanks).

As a minimum, one field duplicate sample was collected for every 20 regular samples. Each field duplicate was assigned a unique sample number and treated as a separate sample. These samples were not identified to the analytical laboratory as duplicates. Duplicate samples were collected in accordance with SOG-14 (Kennedy/Jenks/Chilton 1991a).

Blank samples were collected and submitted for laboratory analyses during each sampling event. Rinsate samples were collected during soil sampling and water sampling when decontamination of sampling equipment was performed. Trip and transfer blanks were also submitted for each sampling event.

Rinsate blanks were collected when reusing sampling equipment to monitor the effectiveness of decontamination procedures and to identify potential cross-contamination between sampling locations. Rinsate blanks were collected by rinsing decontaminated sampling equipment with deionized water and placing the collected rinsate water in appropriate containers with required preservatives. Rinsate blanks were analyzed for the same constituents as the regular environmental samples.

Trip blanks (i.e., clean water in glass sample vials) were carried during sampling and submitted for VOC analyses. Trip blanks were prepared to monitor for possible VOC contamination caused by diffusion of molecules through the PTFE-faced silicone rubber septum of the sample vials during transport to and from the laboratory, as well as to monitor the quality of the laboratory water. Trip blanks were prepared by the laboratory by filling volatile organic analysis (VOA) vials with deionized water and shipping the blanks with the sample containers. Whenever a sample within a batch of samples was to be analyzed for VOCs, a trip blank would accompany the sample containers through sample collection and shipment to the laboratory. Trip blanks were analyzed for VOCs only.

Transfer blanks were collected to evaluate the possibility of sample contamination from ambient conditions during the sampling event. Transfer blanks were collected by placing high-purity deionized water in sample containers with appropriate preservatives at the sample location. Transfer blanks were numbered using the numbers of the sampling locations at which the blanks were collected. Transfer blanks were analyzed for the same constituents as the regular environmental samples.

4.3.2 Laboratory QA/QC Review

Analytical methods outlined in EPA's CLP SOWs (EPA 1988a; 1990a,b) were used to determine organic and inorganic constituent concentrations. EPA's CLP methods specify QC procedures that the laboratory was expected to meet or exceed. These procedures include analysis frequency and QC limits for laboratory method blanks, spiked samples, duplicates, and laboratory control samples. Analytical results and QC criteria were evaluated by the laboratory as part of their data reduction and documentation procedures, and in accordance with those procedures outlined in the STF QAPjP (Kennedy/Jenks/Chilton 1991b). Laboratory qualifiers were assigned to data during this review as outlined in the CLP SOWs (EPA 1988a; 1990a,b). Descriptions of laboratory-assigned data qualifiers are presented in Tables RI-15, RI-16, and RI-17.

4.3.3 Independent QA/QC Review of Laboratory Data

Analytical data were received from the laboratory in hard copy or magnetic format, or both. A QA review of magnetic data was performed prior to its input into the STF database. This independent review included, at a minimum, the following inspection:

- Verification of sample location numbers and laboratory accession numbers

- General review to check completeness of data packages

TABLE RI-15

LABORATORY DATA QUALIFIERS FOR INORGANIC ANALYSES

Inorganic compound qualifiers are a combination of the "Q" and "C" qualifiers:

Qualifier ("Q")	Explanation
E	The reported value is estimated because of interference.
M	Duplicate injection precision not met.
N	Spiked sample recovery not within control limits.
S	The reported value was determined by the Method of Standard Additions (MSA).
W	Post-digestion spike for Furnace AA analysis is out of control limits (85-115%), while sample absorbance is less than 50% of spike absorbance.
*	Duplicate analysis is not within control limits.
+	Correlation coefficient for the MSA is less than 0.995.

Values of "S," "W," and "+" are mutually exclusive. No combination of these qualifiers can occur in the same field for an analyte.

Concentration Qualifier ("C")	Explanation
B	Reported value is less than EPA Contract Required Detection Limit, but greater than, or equal to, the Instrument Detection Limit.
U	Analyte was analyzed for, but not detected.

Reference: EPA (1990a).

TABLE RI-16

LABORATORY DATA QUALIFIERS FOR ORGANIC ANALYSES

Qualifier	Explanation
U	This flag indicates compound was analyzed for, but not detected. The sample quantitation limit must be corrected for dilution and for percent moisture.
J	This flag indicates estimated value.
N	This flag indicates presumptive evidence of a compound. This flag is only used for tentatively identified compounds (TICs), where the identification is based on a mass spectral library search.
P	This flag is used for a pesticide/Aroclor target analyte when there is greater than 25% difference for detected concentrations between the two GC columns. The lower of the two values is reported and flagged with a "P."
C	This flag applies to pesticide results where the identification has been confirmed by GC/MS. If GC/MS confirmation was attempted but was unsuccessful, do not apply this flag, instead use a laboratory-defined flag.
B	This flag is used when the analyte is found in the associated blank as well as in the sample. It indicates possible/probable blank contamination and warns the data user to take appropriate action. The data validation auditor will evaluate data and decide whether data are valid for analysis. If not, the data validation auditor will flag the data as R (as defined in Table RI-18, Data Validation Qualifiers for all Analytical Data).
E	This flag identifies compounds whose concentrations exceed the calibration range of the GC/MS instrument for that specific analysis. If one or more compounds have a response greater than full scale, the sample or extract must be diluted and re-analyzed according to the specifications.
D	This flag identifies all compounds identified in an analysis at a secondary dilution factor. If re-analyzed at a higher dilution factor, the "DL" suffix is appended to the sample number. This flag alerts the user of the data that any discrepancies between the concentrations reported may be due to dilution of the sample or extract.
A	This flag indicates that a tentatively identified compound (TIC) is a suspected aldol-condensation product.
X,Y,Z	Special flags may be required to properly define the results. These flags will be fully described in an attachment to the original data results from the laboratory.

Reference: EPA (1990b).

TABLE RI-17

LABORATORY DATA QUALIFIERS FOR PAH (NON-CLP) ANALYSES ONLY

The following data qualifiers are used by ATI for in-house data reporting only. Use of any other data flags must be approved by the Supervisor/Group Leader and the QA Coordinator through a Corrective Action Form. EPA CLP or other contracts override these flags.

Qualifier	Explanation
B	Analyte is found in the associated blank as well as the sample.
C	Estimated, value above linear range.
NA	Not applicable.
NC	Not calculable.
ND	Not detected.
F	Out of limits due to matrix interference.
G	Result unattainable due to high levels of target analytes in sample.
H	Out of limits.
I	Surrogate not recovered due to sample dilution.
J	Estimated value.
D1	Value from a 2-fold diluted analysis.
D2	Value from a 4-fold diluted analysis.
D3	Value from a 5-fold diluted analysis.
D4	Value from a 10-fold diluted analysis.
D5	Value from a 20-fold diluted analysis.
D6	Value from a 50-fold diluted analysis.
D7	Value from a 100-fold diluted analysis.
D8	Value from a 250-fold diluted analysis.
D9	Value from a 500-fold diluted analysis.
D0	Value from a ________-fold diluted analysis.
D*	Value from a ________-fold diluted analysis. (Used when more than one large dilution is reported on a same data sheet.)
D**	Value from a ________-fold diluted analysis. (Used as the second large dilution when more than one is reported on a same data sheet.)

TABLE RI-17

LABORATORY DATA QUALIFIERS FOR PAH (NON-CLP) ANALYSES ONLY

Notes:

When using the dilution factor qualifiers, report the qualifier with the dilution factor in parentheses, [i.e., D6(50)]. This will act as a double check on the qualifier and the dilution factor. Dilutions, other than the ones listed above, should be flagged D0 with the dilution factor noted in parentheses. For the diluted flags, the D will show up on the final report unless more than one dilution is reported. In that case the D and the code number will appear on the report. The numbers will allow data management to key in the correct data qualifier explanation.

Explanation of the data flags will appear at the bottom of the data page.

The following qualifiers require corrective action forms (properly filled out and signed off) before they can be used: B, C, F, G, and H.

The G qualifier is used when the spike concentration is far exceeded by target compounds in the sample and a spike recovery can not be calculated.

Reference: ATI. 5 September 1991. Memorandum to ATI Laboratory and Data Management Personnel from K. Gunderson, ATI QA Coordinator, Renton, Washington.

- Comparison of a minimum of 10 percent of magnetic data with hard copy data.

Data received only in hard copy format were manually entered into the STF database using a dual-entry or single-entry method, depending on the quantity of data received. When data packages were dual-entered, a comparison program was used to check the dual-entered data for accuracy and was repeated until no discrepancies were reported (i.e., in a report of differences) between the dual-entered databases. Smaller data sets were entered into the STF database by one person and independently reviewed for errors. Once data were input into the database, a final QA review was performed.

4.3.4 Data Validation

Validation of analytical results data was performed to evaluate procedural compliance with QA objectives as outlined in the STF QAPjP (Kennedy/Jenks/Chilton 1991b) and to assess the laboratory's performance in meeting the QC specifications for detection limits, accuracy, precision, and completeness as outlined in the CLP SOWs (EPA 1988a; 1990a,b). Data validation was performed by EcoChem.

Data validation was based on the criteria described in the functional guidelines for evaluating inorganic and organic analyses (EPA 1988d,e,f). Data that did not meet required criteria were flagged with validation qualifiers. Descriptions of data validation qualifiers are presented in Tables RI-18 and RI-19.

A 100-percent data validation (all samples in a sample delivery group) was completed for 100 percent of the groundwater, surface water, and sediment analytical results data packages. With EPA's concurrence, various percentages of Phase I and II soil sample results were submitted to EcoChem for data validation.

TABLE RI-18

DATA VALIDATION QUALIFIERS FOR ALL ANALYTICAL DATA

Data validation qualifiers are defined in EPA's Functional Guidelines for Evaluating Organic/Inorganic Analyses (EPA 1988d,e,f). The following validation qualifiers will be used for all data:

Qualifier	Explanation
U	The analyte was analyzed for and is not present above the level associated value. The associated numerical value indicates the approximate concentration necessary to detect the analyte in this sample. If a decision requires quantitation of the analyte below the associated numerical level, reanalysis or alternative analytical methods should be considered.
J	The analyte was analyzed for and was positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample. The data should be seriously considered for decision-making and are useable for many purposes. The following subscripts may be appended to the "J" that indicates which of the following quality control criteria were not met:
1	Blank Contamination: indicates possible high bias and/or false positives.
2	Calibration range exceeded: indicates possible low bias.
3	Holding times not met: indicates low bias for most analytes with the exception of common contaminants and chlorinated ethenes (i.e., trichloroethene, 1,1-dichloroethene, vinyl chloride).
4	Other QC outside control limits: bias not readily determined.
R	Data are unusable for all purposes. The analyte was analyzed for, but the presence or absence of the analyte has not been verified.
UJ	A combination of the "U" and the "J" qualifier. The analyte was analyzed for and was not present above the level of the associated value. The associated numerical value may not accurately or precisely represent the concentration necessary to detect the analyte in this sample.

TABLE RI-19

DATA VALIDATION QUALIFIERS FOR ORGANIC ANALYSES ONLY

The following qualifiers are applicable to organic analyses only:

Qualifier	Explanation
N	The analysis indicates that an analyte is present, and there are strong indications that the identity is correct. Confirmation requires further analysis.
NJ	A combination of the "N" and "J" qualifier. The analysis indicates that the analyte is tentatively identified and the associated numerical value may not be consistent with the amount actually present in the environmental sample. A subscript may be appended to the "NJ" that indicates which of the following situations applies:
1	DDT/Endrin breakdown evident.
2	Interference from other sample components.
3	Non-Target Compound List (non-TCL) compounds. (Confirmation is necessary using specific target compound methods to accurately determine the concentration and identity of the detected compounds).
4	A confirmation analysis was missing or quality control criteria were not met for the confirmation analysis.

EcoChem prepared Data Validation Reports for the Phase I and II Soil Investigations, Phase I Groundwater Investigation, Surface Water and Sediment Investigation, and the Blackberry Investigation. For investigations with more than one sampling event (i.e., groundwater and surface water/sediment), a separate data validation report was prepared for each event.

4.3.5 Statistical Analyses

A statistics program was used to analyze laboratory data contained in the STF project database files. The program allows the user to select any of the finalized STF database files on the network drive and to then calculate statistics as needed.

Statistics were calculated based on the following criteria:

- No QA/QC duplicate or blank analytical results were used to calculate statistics.
- Any analyte field that contained zero was not used in the statistical calculations because no data were entered in that field for that analyte.
- Any analytical result (analyte) value that contained an "R" in the data validation qualifier field was not used in the statistical calculation because the analysis produced a value that was rejected during data validation.
- All other analyte values (those without zeros or R's) were used to calculate statistics.
- All analyte values that contain "U" in either the laboratory qualifier field or data validation qualifier field were undetected values and were used in the program calculations at one-half the reported analyte value.

- All other analyte values (those without U's) were used at the reported analyte value. Where the laboratory reran an analysis because the QC criteria were not met, both results were printed in the database. Reruns and dilutions were identified with an "R" or "D," respectively, after the laboratory-assigned sample number. For statistical purposes, only the R (rerun) or D (dilution) records were used to calculate statistics.

Statistics were calculated for onsite surface and subsurface soil samples. Statistics were also calculated for groundwater and soil samples collected from offsite background locations specified in the Field Sampling and Analysis Plan (FSAP). Statistics were calculated for inorganics, excluding cyanide. For groundwater, statistical calculations were limited to inorganic elements that occur naturally in groundwater in background wells. For surface soil, background PAH concentrations were also statistically evaluated. Statistical calculations are outlined below.

- The number of analyte values meeting the foregoing criteria was counted.

- The sum of selected analyte values was computed using one-half of the value where appropriate (i.e., analyte values qualified with U). In addition, the sum of the squares of the analyte values was computed for variance and standard deviation calculations.

- The maximum and minimum values were determined by a replacement algorithm. The maximum value was set to 0 and the minimum value was set to 1,000,000 at initiation of the analyte calculation pass.

- The number of values contained in various user selected class intervals (i.e., concentration ranges) was determined with a series of "IF" statements.

- The arithmetic mean was calculated by dividing the sum of the analyte values by the number of values.

- The range was calculated by subtracting the minimum value from the maximum value.

- The variance, s^2, was calculated by dividing the sum of the squared deviations of the values about this mean $\overline{x}$ by the number of values (n) minus one:

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}$$

- The standard deviation was calculated by taking the square root of the variance.

- The 95-percent upper confidence limit on the mean (95% UCL) was calculated by using a two-tail t-test of the data assuming a normal distribution. The t-test table for 2.5 percent values was included in the program. The t-test value was obtained by subtracting one from the number of values and indexing into the t-test array to obtain the number. For data sets greater than 31, a t-test value of 1.96 was used. The 95% UCL was calculated by adding and subtracting the t-test value times the standard deviation divided by the square root of the number of values from the mean:

$$\bar{x} \pm [t_t * S\ ] / \sqrt{N}$$

The simple statistical values discussed above were generated for use as a preliminary tool to obtain a better understanding of the data gathered during the RI.

In order to simplify these preliminary statistical analyses, all data sets were assumed to be normally distributed (i.e., no testing to determine the actual distribution of the sample data was undertaken). This approach was based on the following.

1. The desire to perform simple, uniform statistical tests to provide a straight forward evaluation of untransformed data.

2. The knowledge that more sophisticated statistical analyses would be applied, as appropriate, during later phases of the RI/FS process.

3. The reasonable assumption that in most cases the mean and 95 percent UCL values calculated for untransformed data would approximate or exceed values calculated for log-transformed data and therefore, would overstate the magnitude of these parameters (i.e., provide conservative indicators for onsite conditions).

5.0 SUMMARY OF FINDINGS

5.0 SUMMARY OF INVESTIGATION FINDINGS

This section summarizes the objectives, approach, findings, and conclusions of each of the individual investigations of environmental media that comprised the RI. Detailed discussions and data presentations for individual media investigations are contained in the appendices to this RI Report (Volumes 2 through 6).

5.1 SURFACE INVESTIGATIONS

5.1.1 Surface Soil Investigations

The surface soil investigation was undertaken in two phases. Results of the Phase I Soil Investigation were evaluated and used in the development of the plan for the Phase II Soil Investigation.

5.1.1.1 Phase I Soil Investigation. The two principal objectives of the Phase I Surface Soil Investigation were to:

- Characterize the concentration distributions of TCL chemicals detected in onsite surface soil.
- Acquire chemical concentration data to use in conjunction with data from the Phase I Groundwater Investigation, Geophysical Survey, and Soil Gas Survey to develop the Phase II Soil Investigation FSAP Amendment (Kennedy/Jenks Consultants 1992e).

Based on historical land use and previous site investigations, a sampling grid system was established over the STF site with three different sampling densities corresponding to high-, medium-, and low-perceived risk areas. The STF site was divided into six sampling units (excluding the Tacoma City Light property) based on the perceived risk (see Figure SS-5 in Section 2.0 in Appendix SS). In the two high-perceived risk sampling units, a composite of five grab samples was collected from the center of each grid. Grab samples were collected at the nodes of the sampling grids of the two lower density sampling areas.

The following tasks were completed during the Phase I Surface Soil Investigation:

- Collected and chemically analyzed 11 surface soil background samples (as defined in the Final Work Plan and FSAP) from 10 offsite locations within the South Tacoma Channel.

- Collected and analyzed 622 surface soil samples from within six of the seven sampling units at the STF site.

- Collected and tested 40 surface soil samples from within the STF site for characterization of physical soil properties.

Approximately 20 percent of all surface soil samples were analyzed for boron and cyanide, and for the full TCL as described in EPA's CLP (EPA 1988a; 1990a,b). The remaining surface soil samples were analyzed for a subset of the TCL constituents: metals, PAHs, and boron.

A detailed presentation of the findings of the Phase I Surface Soil Investigation, including chemical concentration distribution maps, is provided in Appendix SS.

Inorganic Analytical Results for Background (Offsite). All but four of the TCL inorganics (cyanide, arsenic, boron, and selenium) are metals and so for the purposes of this and subsequent discussions, the term "metals" will be used instead of inorganics unless the reference specifically includes cyanide or selenium. Because arsenic and boron can be regarded as metalloids (i.e., properties that are intermediate between metals and nonmetals), they are included in the term "metals" in this discussion for convenience. Most TCL inorganics were detected in samples collected from offsite locations. Most detected metal concentrations were within the common ranges of concentrations naturally occurring in soil (Lindsay 1979). Results are summarized in Table RI-20. This table also presents mean and 95 percent UCL values calculated by normal and lognormal distribution methods as well as 95 percent UCL values calculated by nonparametric methods. The results of population distribution testing for each data set are also indicated.

Thallium, selenium, silver, and cyanide were not detected in any of the offsite samples analyzed. The maximum cadmium concentration detected in an offsite sample (0.99 mg/kg) exceeded the reported common range maximum of 0.7 mg/kg. Calcium and sodium concentration in the offsite samples were below the common range for these metals, and potassium concentrations were at the low end of the common range.

<u>Inorganic Results for Onsite</u>. Surface soil samples collected from many onsite locations contained metals concentrations that were elevated in comparison to the 95 percent upper confidence limit about the mean (95% UCL) of offsite surface soil samples. Results are summarized in Table RI-21 along with the same statistical values described above for Table RI-20. Sitewide mean concentrations are biased high because the grid sizes were smaller in areas with the highest concentrations.

In terms of intensity (concentration in soil) and areal extent, copper, lead, and zinc concentrations in onsite soil are greatest when compared to background levels. The sitewide mean concentrations of copper, lead, and zinc exceeded background means by one to two orders of magnitude. Onsite maximum concentrations of these same metals exceeded background maximums by at least two orders of magnitude. Elevated concentrations of these three metals were commonly detected in BNR Dismantling Yard, BNR Railyard, the Amsted property, and bordering zones of adjacent sampling units. Elevated metals concentrations were expected in these areas based on historical activities and previous investigations.

TABLE RI-20

SUMMARY OF INORGANIC ANALYTICAL RESULTS AND STATISTICAL RESULTS FOR BACKGROUND SURFACE SOIL SAMPLES

Chemical	Number of Detected Values/Number of Samples	Minimum Concentration (mg/kg)	Maximum Concentration (mg/kg)	Normal Distribution Statistics[(a)]			Nonparametric[(b)] at 95% UCL (mg/kg)	Lognormal Distribution Statistics[(c)]		Population Distributions[(d)]	Common Concentration Range for Soil[(e)] (mg/kg)
				Mean Concentration (mg/kg)	Standard Deviation	95% UCL on the Mean (mg/kg)		Mean Concentration (mg/kg)	95% UCL (mg/kg)		
Aluminum	11/11	8,920	21,900	12,800	3,670	15,200	14,600	12,400	14,900	Lognormal	10,000 - 300,000
Antimony	3/11	2.2	5.8	3.2	1.6	4.3	4.0	2.93	4.3	Neither	1 - 8.8[(f)]
Arsenic	8/11	1.3	12.6	5.0	3.2	7.2	6.6	4.0	9.90	Lognormal	1 - 50
Barium	11/11	45.2	161	76.8	37.4	102	95.3	70.1	103	Lognormal	100 - 3,000
Beryllium	4/11	0.11	0.46	0.19	0.12	0.27	0.25	0.16	0.27	Neither	0.1 - 40
Cadmium	3/11	0.22	0.99	0.40	0.32	0.62	0.56	0.32	0.65	Neither	0.01 - 0.7
Calcium	11/11	1,990	4,400	3,220	588	3,610	3,510	3,160	3,610	Lognormal	7,000 - 500,000
Chromium Total	11/11	16.2	30.2	22.5	4.4	25.4	24.6	22.1	25.3	Lognormal	1 - 1,000
Cobalt	11/11	4.8	7.8	6.3	0.95	7.0	6.8	6.3	6.9	Lognormal	1 - 40
Copper	11/11	9.5	34.0	19.1	8.9	25.0	23.5	17.4	26.1	Lognormal	2 - 100
Iron	11/11	10,400	16,700	13,400	1,980	14,700	14,300	13,200	14,600	Lognormal	7,000 - 550,000
Lead	11/11	3.1	155	49.8	45.9	80.6	72.6	29.3	254	Lognormal	2 - 200
Magnesium	11/11	3,090	4,690	4,030	562	4,410	4,310	3,990	4,390	Lognormal	600 - 6,000
Manganese	11/11	197	634	316	151	418	391	293	404	Neither	20 - 3,000
Mercury	2/11	0.010	0.24	0.054	0.070	0.10	0.089	0.032	0.12	Lognormal	0.01 - 0.3
Nickel	11/11	21.9	37.2	28.2	4.7	31.3	30.5	27.8	31.1	Lognormal	5 - 500
Potassium	11/11	386	724	503	119	583	562	492	574	Lognormal	400 - 30,000
Sodium	10/11	28.0	147	103	33.5	126	120	95.9	145	Normal	750 - 7,500
Vanadium	11/11	21.8	35.8	29.6	3.8	32.1	31.4	29.3	31.9	Lognormal	20 - 500
Zinc	11/11	26.4	135	70.9	37.3	96.0	89.4	62.0	108	Lognormal	10 - 300

TABLE RI-20

SUMMARY OF INORGANIC ANALYTICAL RESULTS AND STATISTICAL RESULTS FOR BACKGROUND SURFACE SOIL SAMPLES

(a) Normal distribution statistical values calculated using untransformed values. These statistics apply to sample populations that are normally distributed. The arithmetic mean, standard deviation and the 95% upper confidence limit (UCL) are reported. The 95% UCL was calculated using the students t-test.

(b) Nonparametric statistics calculated using untransformed values. These statistics apply to sample populations without normal or lognormal distributions. The arithmetic mean and standard deviation reported under normal distribution statistics apply for these populations. The 95% UCL was calculated using an equation from Gilbert (1987, p. 139-140)

(c) Lognormal distribution statistics calculated using log transformed values. These statistics apply to sample populations that are lognormally distributed. The geometric mean and 95% UCL are reported. The 95% UCL was calculated from Land (1971, 1975).

(d) Population distributions are indicated as normal, lognormal, or neither. This column indicates which statistical tests apply to the sample populations based on the distribution testing methods and rejection criteria provided in the Washington State Department of Ecology, Toxics Cleanup Program, Statistical Guidance for Ecology Site Managers, August 1992.

(e) Lindsay (1979), except where noted. Common concentration ranges for soil are based on reports of other authors compiled by Lindsay (1979).

(f) ATSDR (1990a).

TABLE RI-21

SUMMARY OF INORGANIC ANALYTICAL RESULTS AND STATISTICAL RESULTS FOR PHASE I ONSITE SURFACE SOIL SAMPLES

Chemical	Number of Values	Number of Detects	Minimum Detected Concentration (mg/kg)	Maximum Concentration (mg/kg)	Normal Distribution Statistics[a]			Nonparametric[b] 95% UCL (mg/kg)	Lognormal Distribution Statistics[c]		Population Distributions[d]
					Mean Concentration (mg/kg)	Standard Deviation	95% UCL (mg/kg)		Mean Concentration (mg/kg)	95% UCL (mg/kg)	
Aluminum	590	590	1,350	104,000	13,600	5,880	14,100	14,000	12,700	14,100	Neither
Antimony	471	270	4.6	491	11.3	28.4	13.8	13.4	6.5	10.7	Neither
Arsenic	577	570	0.73	696	31.1	45.6	34.8	34.2	19.3	34.4	Neither
Barium	590	590	9.9	2,600	264	275	286	282	186	279	Lognormal
Beryllium	590	475	0.13	14.4	0.98	1.0	1.1	1.1	0.63	1.1	Neither
Boron	542	107	3.90	1,300	9.5	58.6	14.4	13.6	2.2	5.5	Neither
Cadmium	590	460	0.21	29.9	2.9	3.9	3.2	3.2	1.4	3.5	Neither
Calcium	590	589	245	323,000	7,840	21,200	9,550	9,270	5,320	6,470	Neither
Chromium	590	589	2.9	707	53.7	59.8	58.6	57.8	39.9	53.9	Neither
Cobalt	590	564	2.0	135	11.4	7.3	12.0	11.9	10.1	11.8	Neither
Copper	590	585	7.2	163,000	1,420	9,720	2,210	2,080	178	765	Neither
Cyanide	123	18	0.50	2.3	0.40	0.35	0.46	0.45	0.33	0.41	Neither
Iron	590	590	135	298,000	57,400	50,100	61,400	60,800	40,000	65,200	Neither
Lead	590	585	5.3	118,000	2,100	7,360	2,690	2,600	437	2,600	Lognormal
Magnesium	590	590	251	25,700	3,710	2,050	3,880	3,850	3,390	3,830	Neither
Manganese	590	590	22.7	21,800	784	1,240	884	868	564	761	Neither
Mercury	590	462	0.036	5.3	0.25	0.49	0.29	0.28	0.11	0.27	Lognormal
Nickel	590	585	2.8	865	47.6	55.5	52.1	51.3	38.6	46.9	Neither
Potassium	590	529	48.6	6,190	562	350.0	590	586	496	587	Neither
Selenium	555	120	0.12	141	0.72	6.4	1.2	1.2	0.25	0.38	Neither
Silver	562	86	0.90	101	1.3	5.2	1.8	1.7	0.59	0.89	Neither
Sodium	590	556	48.7	3,350	307	304	331	327	233	316	Neither
Thallium	547	36	0.11	(6.7)	0.75	1.3	0.86	0.84	0.30	0.69	Neither
Vanadium	590	588	1.5	321	45.7	26.8	47.8	47.5	41.2	47.8	Neither
Zinc	590	590	13.4	61,600	1,410	4,540	1,780	1,720	350	1,320	Lognormal

TABLE RI-21

SUMMARY OF INORGANIC ANALYTICAL RESULTS AND STATISTICAL RESULTS FOR PHASE I ONSITE SURFACE SOIL SAMPLES

(a) Normal distribution statistical values calculated using untransformed values. These statistics apply to sample populations that are normally distributed. The arithmetic mean, standard deviation and the 95% upper confidence limit (UCL) are reported. The 95% UCL was calculated using the students t-test.

(b) Nonparametric statistics calculated using untransformed values. These statistics apply to sample populations without normal or lognormal distributions. The arithmetic mean and standard deviation reported under normal distribution statistics apply for these populations. The 95% UCL was calculated using an equation from Gilbert (1987, p. 139-140).

(c) Lognormal distribution statistics calculated using log transformed values. These statistics apply to sample populations that are lognormally distributed. The geometric mean and 95% UCL are reported. The 95% UCL was calculated from Land (1971, 1975).

(d) Population distributions are indicated as lognormal, or neither. This column indicates which statistical tests apply to the sample populations based on the distribution testing methods and rejection criteria provided in the Washington State Department of Ecology, Toxics Cleanup Program, Statistical Guidance for Ecology Site Managers, August 1992.

Contamination of onsite soil by several other metals is generally less intense and occurs in many of the same areas where concentrations of copper, lead, and zinc were elevated. The sitewide mean concentrations for arsenic, cadmium, and beryllium are greater than the background means by factors of 5 to 10; onsite maximum concentrations are 30 to 55 times greater than offsite maximum concentrations. As shown in Table RI-22, elevated concentrations of arsenic, beryllium, and cadmium are typically confined to the BNR Dismantling Yard, BNR Railyard, and the Amsted property when the mean concentrations are calculated by sampling unit. Sitewide mean concentrations for antimony, barium, iron, and mercury exceeded background means by factors of 3 to 5, but the distributions of elevated concentrations of these metals were also limited in areal extent. Thallium, silver, and selenium, which were not detected in offsite soil samples, were detected in about 7, 15, and 22 percent, respectively, of onsite samples analyzed for these metals. Analyses for boron were not performed on background samples. Almost all boron concentrations detected onsite were within the common range for soil of 2 to 100 mg/kg (Lindsay 1979). One anomalous boron concentration of 1,300 mg/kg was detected at the east edge of the BNR Dismantling Yard. Lower concentrations of most metals were detected in samples collected from the Airport and TIP sampling units.

The composition of soil enriched by metals in the Former Swamp/Lakebed area is markedly different from other areas of STF. Elevated concentrations of barium, cadmium, chromium, magnesium, manganese, and nickel were detected in soil samples collected in the central portion of the sampling unit coincident with the Former Swamp/Lakebed fill area (i.e., Atlas Foundry and Fick Foundry disposal sites). Slightly elevated concentrations of selenium (i.e., 1.2-2.9 mg/kg) were also detected in soil samples from the Former Atlas Foundry disposal site. At the south end of the Former Swamp/Lakebed area along the STF site boundary, elevated concentrations of barium, chromium, manganese, and vanadium were detected. Elevated magnesium and nickel concentrations were detected in soil samples from the north end of this sampling unit. Concentrations of chromium, manganese, and nickel detected in the Former Swamp/Lakebed area surface soil are among the

TABLE RI-22

STATISTICS FOR DISTRIBUTIONS OF SELECTED CHEMICALS OF CONCERN BY SAMPLING UNIT

Sampling Unit$^{(a)}$	Aluminum (mg/kg)						Antimony (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev	95% UCL
DY	269	1,350	104,000	15,000	7,270	15,900	167	2.0	46.6	10.8	7.3	11.9
RR	155	3,550	28,400	11,600	3,190	12,100	155	2.0	491	17.0	48.1	24.6
AP	41	8,770	26,600	15,200	4,370	16,500	41	2.0	24.2	5.0	5.2	6.6
TP	6	8,260	15,400	11,900	2,930	15,000	6	2.1	19.0	9.0	7.3	16.6
SL	73	1,560	21,100	11,500	4,800	12,600	70	2.0	23.2	3.9	3.4	4.7
AM	44	9,240	27,500	14,500	3,650	15,600	32	2.4	43.7	10.8	9.2	14.0

Sampling Unit$^{(a)}$	Arsenic (mg/kg)						Beryllium (mg/kg)						Cadmium (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL
DY	266	2.5	696	40.9	52.0	47.2	269	0.090	14.4	1.6	1.2	1.8	269	0.20	29.9	4.4	4.5	5.0
RR	155	1.8	395	29.4	39.4	35.6	155	0.10	27	0.38	0.28	0.42	155	0.20	22.6	1.8	2.9	2.3
AP	41	2.9	50.1	12.0	8.3	14.6	41	0.10	0.56	0.31	0.13	0.35	41	0.20	4.0	0.88	1.0	1.2
TP	6	0.24	26.2	10.7	9.0	20.0	6	0.10	0.57	0.25	0.17	0.43	6	0.21	2.0	0.76	0.66	1.5
SL	73	0.70	54.4	8.0	8.7	10.0	73	0.10	1.0	0.32	0.17	0.35	73	0.11	12.1	0.71	1.4	1.0
AM	34	6.1	38.9	38.3	66.8	60.8	44	0.12	2.2	1.1	0.42	1.2	44	0.12	13.4	3.1	3.6	4.2

Sampling Unit$^{(a)}$	Chromium (Total) (mg/kg)						Cobalt (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev	95% UCL
DY	269	2.9	707	64.1	60.4	71.3	269	1.4	135	13.6	9.3	14.7
RR	155	2.9	282	34.4	30.8	39.3	155	0.70	37.4	10.8	4.8	11.6
AP	41	10.2	94.1	26.5	15.3	31.2	41	5.2	17.7	9.4	3.2	10.3
TP	6	18.0	49.4	28.9	10.8	40.3	6	7.0	18.2	10.4	4.1	14.8
SL	73	14.3	501	81.5	103	105	73	1.4	21.2	6.9	2.8	7.5
AM	44	21.0	130	42.5	24.5	49.8	44	5.5	20.7	9.3	3.6	10.4

TABLE RI-22

STATISTICS FOR DISTRIBUTIONS OF SELECTED CHEMICALS OF CONCERN BY SAMPLING UNIT

Sampling Unit[a]	Manganese (mg/kg)						Mercury (mg/kg)						Total Probable Carcinogenic PAHs (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL
DY	269	42.2	5,850	727	507	787	269	0.0085	5.3	0.26	0.43	0.31	268	0.040	38.5	1.6	4.1	2.1
RR	155	22.7	2,270	515	364	572	155	0.0050	3.7	0.27	0.44	0.33	155	0.040	24.5	1.7	3.0	2.2
AP	41	180	763	423	146	468	41	0.015	0.75	0.082	0.13	0.12	41	0.041	12.6	1.0	2.6	1.8
TP	6	418	4,080	1,930	1,260	3,260	6	0.015	0.050	0.029	0.013	0.040	6	0.041	10.6	3.8	5.3	9.4
SL	73	74.6	6,090	718	936	933	73	0.0036	0.25	0.039	0.042	0.050	73	0.040	34.2	1.1	4.4	2.1
AM	44	202	21,800	2,380	3,740	3,490	44	0.040	4.3	0.63	1.0	0.94	44	0.060	10.2	2.1	2.8	3.0

Sampling Unit[a]	Copper (mg/kg)						Lead (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL	# Samples	Minimum	Maximum	Mean	Std. Dev	95% UCL
DY	269	7.2	11,000	616	1,130	750	269	18.1	24,000	1,910	2,980	2,270
RR	155	11.7	13,000	548	1,740	822	155	11.2	27,100	1,270	3,070	1,760
AP	41	11.2	418	68.6	83.3	94.0	41	6.6	1,160	234	322	332
TP	6	15.7	160	108	55.6	166	6	112	285	190	57.4	250
SL	73	7.2	215	42.8	41.5	52.3	73	5.3	466	60.1	78.3	78.0
AM	44	42.2	163,000	13,200	33,500	23,100	44	16.4	118,000	11,600	23,400	18,500

Sampling Unit[a]	ZINC (mg/kg)					
	# Samples	Minimum	Maximum	Mean	Std. Dev.	95% UCL
DY	269	35.3	24,200	1,790	3,050	2,150
RR	155	25.8	7,530	438	747	555
AP	41	30.2	972	174	217	240
TP	6	43.6	177	120	52.4	175
SL	73	13.4	781	84.4	107	109
AM	44	49.5	61,600	6,100	13,800	10,200

(a) Sampling units correspond to the following: DY = BNR Dismantling Yard; RR = BNR Railyard; AP = Airport; TP = Tacoma Industrial Properties; SL = Former Swamp/Lakebed; AM = Amsted Property.

highest detected onsite. The highest magnesium and vanadium concentrations were detected in samples from this area.

Organic Results for Background (Offsite). Most samples collected from offsite locations contained relatively low concentrations of PAHs, including PAHs considered to be probable human carcinogens (EPA 1991). Concentrations of individual PAH compounds typically ranged from 0.01 to 0.1 mg/kg. Six of the seven probable carcinogenic PAHs identified by EPA were detected in background samples; these were benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)-fluoranthene, benzo(a)pyrene, and indeno(1,2,3-cd)pyrene. The seventh probable carcinogenic PAH, dibenzo(a,h)anthracene, was not detected. Probable carcinogenic PAHs were detected in 8 of 11 background samples. The sums of the detected concentrations of these PAHs for the background samples (i.e., the total probable carcinogenic PAH concentrations) ranged from 0.033 to 0.459 mg/kg.

Only three semivolatile organic compounds [not including PAH compounds or tentatively identified compounds (TICs)] were detected in background samples: N-nitroso-di-n-dipropylamine, di-n-butyl-phthalate, and bis(2-ethylhexyl)phthalate. All three semivolatile compounds were detected at concentrations below 0.5 mg/kg.

Only two VOCs were detected in samples from offsite locations. Methylene chloride was detected in every sample (and in the laboratory blanks) and benzene was detected in one sample.

Only two low concentrations (i.e., less than 0.2 mg/kg) of one pesticide and one PCB compound each were detected in separate background samples.

Organic Results for Onsite. PAHs were the most frequently detected organic compounds in onsite surface soil. One or more PAH compounds were detected in each sample analyzed. The following PAH compounds were detected in greater than 5 percent of the 590 surface soil samples analyzed: naphthalane, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)-pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Acenaphthylene (16 detects) and acenaphthene (3 detects) were also detected, but in less than 5 percent of the samples.

PAH concentrations detected in surface soil at the STF site are generally relatively low to moderate with respect to typical levels at industrial sites. Approximately 80 percent of the samples analyzed contained total PAH concentrations (i.e., sum of all PAH concentrations, including one-half of undetected values) that were less than 4 mg/kg. The maximum total PAH concentration detected was 105.26 mg/kg. Total probable carcinogenic PAH concentrations detected throughout the site were also relatively low. Approximately half of the calculated total carcinogenic PAH concentrations for onsite soil were less than or the same as the upper range of background concentration (0.459 mg/kg). Eighty percent of onsite values were below 1.75 mg/kg, and only 5 percent (27 samples) exceeded 7.5 mg/kg. The maximum concentration of total probable carcinogenic PAH detected onsite was 38.47 mg/kg.

Generally, elevated concentrations of PAHs were detected in samples collected from the eastern and northern portions of the BNR Dismantling Yard, the eastern edge in the north-central portion and in the southern portion of the BNR Railyard, the northern portion of the Amsted property, the central portion and along the eastern border (adjacent to the Amsted property and TIP) of the Former Swamp/Lakebed, the northern and northeastern portions of the Airport, and the northwestern portion of TIP.

Semivolatile organic compounds were detected in relatively few onsite samples. Mostly phthalates and phenols were detected and only sporadically and at relatively low concentrations. Semivolatile organic compounds detected in more than 5 percent of the 121 samples analyzed were 2-methylnaphthalene, dibenzofuran, carbazole, di-n-butylphthalate, butylbenzylphthalate, bis(2-ethylhexyl)phthalate, and miscellaneous TICs. Mean concentrations for specific compounds were well below 1.0 mg/kg and maximum concentrations were in the low part per million range.

Semivolatile organic compounds were detected in samples collected throughout the BNR Dismantling Yard and in scattered locations in the Former Swamp/Lakebed. Semivolatile organic compounds were also detected in samples collected from scattered locations throughout the BNR Railyard. The few elevated concentrations detected were generally found in samples collected from the central and southern portions of the BNR Railyard. Semivolatiles (not including TICs) were detected in samples collected from scattered locations in the other sampling units (except from the Amsted property, where no semivolatile organic compounds were detected).

Trace concentrations (i.e., less than 100 µg/kg) of several VOCs were detected sporadically in onsite surface soil samples. VOCs (except for acetone and methylene chloride) were detected primarily in samples collected from the central and western portions of the BNR Dismantling Yard and the central section of the BNR Railyard. VOCs were also detected in samples collected from scattered locations in the other sampling units.

Six pesticides (aldrin, dieldrin, endosulfan sulfate, methoxychlor, 4-4-DDT, and endrin ketone) were detected in five samples collected from scattered locations at the STF site. All pesticides, except methoxychlor (390 µg/kg), were detected at trace concentrations of less than 50 µg/kg.

In surface soil, PCBs were only detected in samples collected from the BNR Dismantling Yard and BNR Railyard. Two PCB compounds, Aroclor-1254 and Aroclor-1260, were detected in 19 samples. Total PCB concentrations were calculated using only detected values. In 12 of the 19 samples containing PCBs, detected total PCB concentrations were less than 1 mg/kg. The three highest concentrations (42 mg/kg, 17 mg/kg, and 15 mg/kg) were detected in samples collected from the northern quarter of BNR Railyard; two of the three locations are adjacent locations.

Total dioxins and furans were detected at low concentrations (less than 1 μg/kg) in samples collected from the BNR Dismantling Yard and the BNR Railyard.

As described in Section 3.4, geotechnical test results were generally consistent with those expected for a sandy soil mixed with gravel.

5.1.1.2 Phase II Soil Investigation. This section summarizes the objectives, technical approach, and significant findings of the surface soil sampling and analyses conducted during the Phase II Soil Investigation. The Phase II Soil Investigation Report is contained in Appendix SB of this RI Report.

Surface Soil Sampling. The primary objective of the Phase II surface soil sampling was to obtain additional information to further delineate the areal extent of selected TCL chemicals at the STF site. To achieve this objective, the technical approach involved using Phase II data to evaluate how accurately surface soil concentration distributions had been characterized during the Phase I Soil Investigation. This objective was accomplished by:

- Selecting a group of indicator chemicals with elevated concentration distributions similar to and representative of the other remaining TCL analytes.

- Developing a standardized method for siting sample locations. This method used a decision tree to locate samples based on the established grid system at the site. One of the decision tree criterion considered relative concentrations of the selected indicator chemicals. In addition, sampling locations were selected at the boundaries of similar concentration areas.

- Collecting surface soil samples (from the upper 6 inches of soil) at the locations sited using the decision tree. A total of 72 samples was sited and collected using this method. All samples were analyzed for inorganics and PAHs. Selected samples were analyzed for the full suite of TCL analytes.

- Using spatial averaging techniques to mathematically predict concentrations at the Phase II surface soil sampling locations. Comparing the predicted concentrations to the actual Phase II analytical results allowed an assessment of the relative measure of how well the Phase I Soil Investigation characterized surface soil chemical concentrations.

After analyzing the results of the Phase II surface soil sampling, it was concluded that the maps prepared using Phase I Soil Investigation results provide a reasonably reliable characterization of the distribution of TCL chemicals in surface soil at the STF site.

Although elevated concentrations of PCBs were detected in Phase I soil samples from the northern quarter of the BNR Railyard, these concentrations appear to diminish appreciably in the immediate area of the grids in which they were detected. PCB concentrations decreased to 17 and 18 mg/kg on two sides of the grid in which PCBs were detected at 42 mg/kg. A PCB concentration of 2.2 mg/kg was detected in a sample from the boundary of the grid in which a Phase I soil sample contained 15 mg/kg of PCBs.

Leaching Testing. Leaching tests were performed on selected Phase II surface soil samples. The objectives of the leaching tests were to:

- Evaluate the potential in situ leachability of metals and PAHs from onsite soil

- Evaluate potentially applicable offsite disposal requirements for contaminated onsite soil.

The technical approach used to achieve these objectives was to select locations with varying initial concentrations of metals and PAHs. Based on Phase I surface soil sampling results, four lead concentration ranges were used to select sampling locations for metals leachability testing. Phase I surface soil PAH concentrations were used to select locations for collection of PAH leaching test samples. Four locations with different Phase I concentrations were selected. The following four initial lead concentration ranges were used to select leaching test sample locations:

- <1,000 mg/kg Pb
- >1,000 to <10,000 mg/kg Pb
- >10,000 to <100,000 mg/kg Pb
- >100,000 mg/kg Pb.

The following four initial PAH concentration ranges were used to select leaching test sample locations:

- <1.0 mg/kg total PAHs
- >1.0 to <10.0 mg/kg total PAHs
- >10.0 to <30.0 mg/kg total PAHs
- >30 mg/kg total PAHs.

Soil samples were collected for leaching tests from the upper 6 inches of soil using the same methods employed during the Phase I Soil Investigation. A total of eight samples was collected and tested. Each sample was analyzed prior to starting the leaching procedure to establish the actual initial soil concentration. The Monofilled Waste Extraction Procedure (MWEP) was used to test the in situ, time-dependent leachability of chemical constituents. The Toxicity Characteristic Leaching Procedure (TCLP) was performed for evaluation of potentially applicable offsite disposal requirements.

The findings and conclusions of the leaching testing data are summarized below.

- Some metals in onsite soil could be mobilized by downward migration of surface water.
- MWEP data from the leaching test alone are not adequate to calculate site-specific soil/water distribution coefficients.
- Soil containing high lead concentrations that may be removed from portions of the site will likely require management as a hazardous waste.
- Consistent with their established behavior in soil/water systems, PAHs contained in onsite soil did not exhibit a tendency to leach in appreciable concentrations.
- Leachable concentrations of PAHs using TCLP extraction procedures did not exceed established regulatory levels.

The MWEP test results indicated that some of the metals contained in the soil samples submitted for testing were leachable under the conditions of the test. Zinc was the metal most leachable under test conditions followed by copper, lead, and manganese. A review of these leaching results indicated that the most leachable metal, zinc, only released a total of 0.028 mg(Zn)/g(soil) during testing of soil with an initial zinc concentration of 17,900 mg/kg (17.9 mg/g).

Copper, lead, manganese, and zinc were also leached the most using TCLP. Predictably, greater amounts of these metals leached during TCLP testing because this leaching procedure is considerably more aggressive than the MWEP. Lead leached at a concentration of 948 mg/L in a sample that contained 50,400 mg/kg of lead. This result indicated that onsite soil with high lead concentrations may exceed TCLP regulatory levels for offsite management.

5.1.2 Air Dispersion Modeling Investigation

The original Air Investigation presented in the Work Plan (ICF 1990b) included both air quality monitoring and air pathways modeling. However during the initial stages of the Air Investigation, the scope of work was modified based on the low potential for air emissions from the site (Psyk, C., 28 January 1991, personal communication; Kennedy/Jenks/Chilton 1991a). An air monitoring program was not considered to be warranted given that vegetation covers the majority of the STF site and access to the site is limited. These factors inhibit windblown dust emissions and reduce the potential for mechanical suspension caused by vehicular access. The potential migration of contaminants from the STF site was assessed using dispersion modeling techniques. Surface soil data, applicable emission factors, and air quality dispersion models were used to estimate the potential exposure to receptors at and near the STF site.

5.1.2.1 Objectives. The objectives of the Air Investigation were to evaluate the potential for migration of contaminants from the site through airborne transport and the potential for estimated concentrations of chemicals of concern to pose significant risks to human health or exceed National Ambient Air Quality Standards (NAAQS). Dispersion modeling was conducted in two phases to address these objectives. Preliminary dispersion modeling was performed using existing surface soil data (pre-RI data) to confirm the assumption that offsite impacts were low and support the determination that monitoring was not warranted. The second phase was to estimate airborne concentrations for the chemicals of concern using the comprehensive surface soil data obtained during the Phase I Soil Investigation and conservative assumptions concerning future conditions at the STF site. The remainder of this section describes the activities performed during the STF Air Investigation and the results of the air modeling.

5.1.2.2 Activities Conducted. The following activities were completed as part of the STF Air Investigation:

- QA review of existing meteorological data (i.e., wind speed, wind direction, temperature) collected from the monitoring station at Mt. Tahoma High School for the years 1978 through 1987

- Development of a meteorology data set composed of the 5 years of Mt. Tahoma displaying the highest quality data to be used in modeling (Envirometrics 1991)

- Preparation of the Air Investigation Plan (Kennedy/Jenks Consultants and Envirometrics 1991a), which described methods for the preliminary dispersion modeling

- Conduct of the preliminary dispersion modeling for selected sampling units at the site (i.e., BNR Dismantling Yard, the Amsted property, and Former Swamp/Lakebed) and preliminary chemicals of concern based on pre-RI surface soil data (Kennedy/Jenks Consultants and Envirometrics 1991b)

- Preparation of the technical approach and methods for modeling the final chemicals of concern (TRC Environmental Consultants 1992a)

- Conduct of a dispersion model screening analysis for the chemicals of concern using data collected during the Phase I Soil Investigation (TRC Environmental Consultants 1992b).

5.1.2.3 Results. Meteorological data were required to assess the potential air migration of contaminants from the STF site. Wind data were necessary both for windblown dust emission estimates and as input to the models applied to simulate the transport and diffusion of air emissions from the STF site. After a review of the available data, wind data collected at Mt. Tahoma High School by the Washington Department of Ecology between 1978 and 1987 were considered to be the most representative of conditions at the STF site. The Mt. Tahoma site was only 1,500 feet south of STF. Surface meteorological observations were also obtained from National Weather Station at McChord AFB located approximately 20,000 feet south of the site. A statistical analysis was performed where the data from both stations were contrasted to one another and expected wind regimes at the STF site. The wind patterns exhibited by the Mt. Tahoma data set were found to be more consistent with the local topography at the site and were selected over the McChord AFB data set.

A meteorological data file suitable for dispersion modeling purposes was constructed from five of the available 10 years of Mt. Tahoma wind and temperature monitoring data. The individual years of 1978, 1979, 1980, 1981, and 1987 were selected based primarily on QA considerations. The data set was supplemented during periods of missing data with wind speed data from McChord AFB. Addition variables needed by the dispersion models included estimates of atmospheric stability and mixing height. Cloud cover and ceiling height data from McChord, combined with the wind data were used for the estimation of stability class. Upper air requirements of the dispersion modeling data set were taken from the National Climatic Data Center's twice daily mixing height estimates based on the Quillayute upper air soundings.

A preliminary dispersion modeling analysis was performed using the Mt. Tahoma meteorological data set and existing surface soil data (pre-RI data) to confirm the initial assessment that offsite air impacts were likely insignificant under existing site conditions and that air quality monitoring was not warranted. This assessment focused on particulate matter less than 10 μm (PM_{10}), lead, PAHs potentially emitted by wind suspension from several small exposed areas, and vehicular traffic on paved and unpaved roads. An emissions inventory was prepared based on the current vegetation cover on the site and existing use by the industries on the southern portion of the STF site. Airborne concentration estimates were calculated for receptors located offsite, at the site boundary, and at locations onsite where the public could be exposed.

The initial dispersion model simulations indicated that air emissions from the STF site were relatively minor and downwind concentrations of PM_{10}, lead, and PAHs from the primary source areas were below the applicable air pathways criteria identified for these chemicals of concern. Windblown dust emissions tended to be insignificant due the absence of exposed areas and the relatively coarse soil structures of those areas with potential for wind suspension. The principal mechanism for air emissions of PM_{10}, lead, and PAHs from the STF site was vehicle-induced resuspension of dust from traffic along Proctor Street. However, existing air concentrations along Proctor Street and at the southern property boundary were predicted to pose no risk to the public and ambient monitoring was not considered to be warranted pending further information from the Phase I Soil Investigation.

Based on results of the Phase I Soil Investigation, relatively elevated concentrations of both inorganics and PAH compounds were detected at the STF site. While preliminary air modeling indicated only limited potential for suspension, further analyses were performed to investigate postulated future use of the STF site and to examine chemicals not considered previously. Airborne chemicals of concern and screening levels were specified by EPA Region 10 for the STF site based on the results of the Phase I Soil Investigation and considerations of toxicity. The chemicals of concern selected were hexavalent chromium [Cr(VI)], cobalt (Co), manganese (Mn), mercury (Hg), arsenic (As), beryllium (Be), cadmium (Cd), and PAHs (EPA 1992a,b,c). Screening levels were developed for both residential and industrial exposure scenarios based on existing and postulated future industrial use of the site and on the demography surrounding the STF. Current plans are to retain the industrial character of the site. The residential scenario was considered as an extra measure of conservatism and as a policy of EPA Region 10.

Atmospheric dispersion models were applied to predict hypothetical airborne concentrations based on the local meteorology, the concentration of chemicals in the surface soil, and a conservative hypothetical future emission scenario. The term "conservative" refers to health protective. The dispersion modeling approach used predictive tools developed specifically for fugitive dust assessments and the Mt. Tahoma/McChord AFB meteorological data set for the simulations. The modeling focused on long-term exposures and the inhalation pathway for potential receptors located both within the site boundary and offsite. The modeling was conducted according to a protocol submitted and agreed to by EPA (TRC Environmental Consultants 1992a).

The dispersion modeling analysis investigated windblown emissions from a hypothetical future STF site condition. Windblown PM_{10} emissions from the STF were conservatively estimated assuming the absence of vegetation cover; unlimited fetch; and no credit was taken for the protection offered by buildings, trees, irregular terrain, or the large fraction of nonerodible elements that currently exist on the site. The erodibility of the soil within each sampling unit onsite was based on results of the composite grain size analyses conducted as part of the Phase I Soil Investigation. Windblown PM_{10} emissions were speciated into emissions of As, Be, Cd, Cr(VI), Co, Mn, Hg, and PAHs according to the distribution of these chemicals of concern in the surface soil on the site. Uncertainty in the spatial averages was considered by assigning chemical concentrations based on the 95% UCL within each site sampling unit.

Relatively moist annual climatic conditions, infrequent high wind speeds, and moderate to low soil erodibilities resulted in low windblown dust emissions and annual PM_{10} concentration predictions. The patterns exhibited by the annual PM_{10} predictions were aligned with the prevailing winds in the meteorological data set, rotated slightly clockwise from a north-south orientation. Concentrations were found to drop off rapidly in the east-west direction from the site due the absence of high winds affecting receptors in these directions. Concentration gradients within the site boundaries were attributed primarily to differences in soil erodibilities. PM_{10} emissions from the Airport and BNR Dismantling Yard were 5 to 10 times lower than for the other sampling units of the site and the predictions downwind of these areas were correspondingly lower. The maximum annual predictions were not significant when compared to the annual PM_{10} NAAQS.

The annual concentration patterns predicted for suspected carcinogens basically followed those for PM_{10} except that different regions within the STF boundary were higher or lower, influenced by the spatial distribution of these chemicals in the soil. The higher annual predictions occurred within the Amsted property, Former Swamp/Lakebed, and BNR Railyard sampling units. The highest offsite concentrations were typically on the eastern boundary of the BNR Railyard or on the southern edge of the Amsted property. Although soil concentrations for several of the chemicals of concern were higher within the BNR Dismantling Yard, the soil erodibility estimated for this area was low and airborne impacts relatively minor.

Predicted concentrations in air were compared with residential and industrial screening levels provided by EPA (1992b) (i.e., 1×10^{-7} for carcinogenic risk and 0.1 Hazard Index non-carcinogenic effects). The annual predictions for Be, Cd, Cr(VI), and PAHs were more than 1 order of magnitude below all applicable screening levels. Arsenic was the only chemical of concern found to exceed the EPA carcinogenic screening level for residential exposure. The highest annual As concentration occurred within the Amsted property and was approximately 30 percent higher than the residential screening level based on a 1×10^{-7} inhalation risk. The residential screening level for As was not exceeded offsite and the industrial screening level was not exceeded at any receptor location. Although annual As concentrations were predicted to be above the residential screening level specified for the STF site, the total additive inhalation risks were predicted to be well below the 1×10^{-6} level. Under the industrial exposure scenario, the total additive inhalation risk for the receptor with the highest prediction was below the 1×10^{-7} level.

The screening levels based on chronic exposure and a Hazard Index of 0.1 were not exceeded for any chemical considered in the analysis for either the residential or industrial scenarios. The highest annual predictions for Co, Mn, and Hg, which occurred within the Amsted property or BNR Railyard sampling units, were at least 40 times lower than any applicable screening level specified for the future site condition. The highest predicted chronic exposure to Cr(VI) occurred within the Former Swamp/Lakebed unit and was 300 times lower than the residential screening level based on a Hazard Index of 0.1.

5.1.2.4 Conclusions. During the Air Investigation, an evaluation was conducted to assess the potential for migration of chemicals of concern from the STF site through airborne transport and the potential for estimated concentrations of chemicals of concern to pose significant risks to human health. Initial assessments of the STF site found that current conditions, which include extensive vegetation cover and limited access, reduce the potential exposure from the airborne pathway. These factors inhibit windblown dust emissions and reduce the potential for mechanical suspension caused by vehicular access. Preliminary dispersion modeling using soil concentration data obtained prior to the RI confirmed these assumptions and indicated that ambient air monitoring was not warranted.

Dispersion modeling techniques were also used to assess air pathway exposures from hypothetical future residential and industrial scenarios for the STF site. The simulations were based on chemical and physical data from the Phase I Soil Investigation and health-conservative emission estimates. Relatively moist annual climatic conditions, infrequent high wind speeds, and moderate to low soil erodibilities resulted in low windblown dust emissions and annual PM_{10} concentration predictions. Predicted airborne concentrations for the chemicals of concern were found to be less than EPA's suggested industrial exposure screening levels for all receptors considered in the modeling analysis. Under the residential exposure scenario, the airborne screening level for As was exceeded by approximately 30 percent within the Amsted property. However, the residential screening level for As was not exceeded at receptors offsite. Within the Amsted property, the total lifetime inhalation risk from all the chemicals of concern was much less than the 1×10^{-6} criteria typically used to indicate concern.

Based on the results of the preliminary dispersion modeling and the screening analysis for chemicals of concern, air emissions from the current STF site do not pose a significant risk to human health. Dispersion modeling of postulated future site conditions, which consisted of a lack of vegetation, also did not indicate significant airborne levels for the chemicals of concern.

5.1.3 Blackberry Investigation

The overall objective of the Blackberry Investigation was to collect data that were suitable for use in the assessment of possible health risks associated with the ingestion of potentially contaminated blackberries from the STF site. The investigation was undertaken based on the assumption that a potential existed for contamination of blackberries from either root uptake of inorganics from soil or inorganics adhesion to the surface of the blackberry due to atmospheric deposition of dust from onsite and offsite sources.

The Blackberry Investigation included the following specific objectives:

- Identify background concentrations of metals of concern in blackberry samples collected from nearby but offsite locations
- Identify concentrations of metals of concern in blackberry samples collected onsite

- Compare concentrations of metals of concern for samples collected from offsite (background) and onsite locations

- Compare concentrations of metals of concern for washed and unwashed samples to evaluate the extent, if any, to which root uptake (washed) and atmospheric deposition (unwashed) resulted in significant metal accumulation on and in the blackberries.

Metals of concern (i.e., 11 metals and 3 nonmetals) were antimony, arsenic, beryllium, boron, cadmium, chromium (total), copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Offsite samples were collected and analyzed to assess the significance of inorganics concentrations by comparing background concentrations to those detected in blackberries growing on the STF site.

Inorganics in blackberry samples may be present due to natural and anthropogenic sources (e.g., atmospheric deposition from industrial and vehicular emissions). An attempt was made to collect background blackberry samples representative of both area (anthropogenic) and natural background (plant uptake) conditions. Area background blackberry samples were collected to assess the concentrations of inorganics detected in the vicinity of the site that were not related to releases from the site, but that may still contain inorganics concentrations of anthropogenic origin. Natural background blackberry samples were collected to assess the concentrations of inorganics consistently detected in blackberries in the environment that are not attributed to local human activity. These definitions of area background and natural background samples are based on the Model Toxics Control Act (MTCA) Cleanup Regulation (1991).

Samples were collected from offsite (background) areas within the South Tacoma Channel, the same geomorphic feature in which the STF site is situated. Samples collected offsite, but within the South Tacoma Channel, were intended to provide representative natural and area background concentrations in blackberries growing under similar soil conditions as those growing on the STF site.

Six background blackberry samples were collected from three offsite locations in the South Tacoma Channel (i.e., two composite samples at each location). The following background sampling locations are within approximately 1 mile of the STF site and are shown in Figure BB-1 of Appendix BB.

- Flett Creek drainage area approximately 1/4 mile south of South 74th Street
- 58th Street and South Adams Street
- Between South Tacoma Way and the BNR tracks near Warner Street.

The Flett Creek drainage area is located in an undeveloped, non-industrial area of the South Tacoma Channel. Analytical results for samples collected from this background location were used to evaluate the naturally occurring or "rural background" concentration levels for inorganics of concern in blackberries.

The two other background sampling locations are located in industrial areas with high volumes of vehicular traffic similar to conditions near the STF site. One of these locations, 58th Street and South Adams Street, is upwind of the site. The other location, South Tacoma Way and Warner Street, is downwind of the site. Analytical results for samples collected from these locations were used to represent "urban area" background concentrations of inorganics of concern in blackberries.

All blackberry samples collected were composite samples that were split; one-half of the sample was analyzed unwashed and one-half was washed in deionized water prior to analysis. Analytical results for unwashed and washed composite samples were used to evaluate whether detected inorganics concentrations could be attributed to plant uptake or to atmospheric deposition, respectively.

A composite sample was collected from each of the six onsite sampling units (the Tacoma City Light property was excluded). Of these six samples, one was collected in each of two high-perceived risk areas, one in each of the two in medium-perceived risk areas, and one in each of the two in low-perceived risk areas. Perceived-risk areas are listed in Table RI-23 and approximate sample locations are shown in Figure BB-2 of Appendix BB.

TABLE RI-23

PERCEIVED RISK AREAS AT THE STF SITE(a)

High Risk	Medium Risk	Low Risk
Amsted Property	Former Swamp/Lakebed	Airport Area
BNR Dismantling Yard	BNR Railyard	TIP Property

(a) Based on the STF Work Plan (ICF 1991b).

A summary of analytical results for all samples is shown in Table BB-1 of Appendix BB. Comparative discussions of these results are summarized below.

- Background vs Onsite Samples. A comparison of analytical results for samples collected from offsite (background) and onsite locations indicates:
  - Inorganics of concern were detected more frequently in blackberry samples collected from background locations compared with those collected from onsite locations. Background samples exhibited the presence of detectable inorganics of concern more than twice as frequently as onsite samples.
  - Concentrations of inorganics of concern detected in samples collected from onsite locations were generally equivalent to those detected in samples collected from background locations. Most detected concentrations occurred between the instrument detection limit (IDL) and the contract required detection limit (CRDL). However, arsenic was detected at 2.9 mg/kg in one (unwashed)

onsite sample, and zinc concentrations ranged from 3.0 mg/kg (background) to 11.4 mg/kg (onsite).

  - Zinc and copper were detected in most background blackberry samples, but were only detected in three onsite samples. Lead was detected more often in blackberry samples collected from background locations than in those collected from onsite locations.

- Rural Background vs Urban Area Background Samples. Blackberry samples collected from the Flett Creek area are considered to be more representative of rural background conditions. Blackberries collected from other offsite locations are considered to be representative of urban area background conditions (i.e., inorganics of concern detected may be a result of both naturally occurring and human activities).

  A comparison of analytical results from rural and urban area background locations indicates:

  - Inorganics concentrations in samples collected from rural background locations were equivalent to those for urban area background locations.
  - Excluding zinc, concentrations of detected inorganics of concern were slightly above the IDL and below the CRDL.
  - Samples collected upwind of the STF site were more likely to contain detectable concentrations of inorganics of concern than samples collected downwind.

Results of the Blackberry Investigation suggest that the ingestion of blackberries from the STF site does not pose potential health risks based on the very low concentrations of inorganics of concern. EPA reviewed the investigative data and concurred with this finding (Psyk, C., 27 January 1992, personal communication).

5.1.4 Surface Water and Sediment Investigation

The primary purpose of the Surface Water and Sediment Investigation was to characterize the types and concentration distributions of TCL chemicals present in surface water and sediment samples. This investigation consisted of the following specific objectives:

- Identify the source(s) of surface water flowing onto the site
- Identify concentrations of TCL chemicals in background samples collected from nearby (offsite) surface water bodies within the South Tacoma Channel, in onsite surface water and sediment samples, and in surface water flowing directly onto and off the STF site
- Evaluate transport of TCL chemicals to and from the site through surface water drainage.

The following tasks were completed during the Surface Water and Sediment Investigation:

- Installed a flow monitoring meter in a storm drain (72-inch pipe) at Madison Street north of South 56th Street (south end of STF site) to continuously monitor surface water flow from the site beginning April 1991 through March 1992.
- Collected 10 surface water samples from five background locations within the South Tacoma Channel; each location was sampled once in the dry season and once in the wet season.
- Collected a total of 41 surface water samples and 69 sediment samples during three separate sampling events (transitional, dry, and wet seasons) from 29 locations within the onsite surface water channel.

- During a 1-year monitoring period, collected 4 (out of a possible 26) biweekly surface water runoff samples from the surface water channel at the site boundary approximately 500 feet north of the flow monitoring location (no flow present during 22 possible sampling events).

- During a 1-year monitoring period, collected 11 (out of a possible 12) monthly surface water runon samples from storm drain outlet south of City of Tacoma pump station and 10 (out of a possible 12) monthly surface water runon samples from the manhole for the South 38th Street storm drain, located 50 feet west of the onsite surface water channel.

- During a 1-year monitoring period, collected 11 storm event surface water samples from each of the two monthly runon sampling locations (for a total of 22 runon samples) and 1 storm event surface water sample from the runoff location.

Background, onsite, and runoff surface water samples were analyzed for the full TCL, hardness, boron, cyanide, and fecal bacteria. Field pH and temperature measurements for surface water were also taken. Runon surface water samples were analyzed for TCL inorganics, boron, PAHs, and fecal bacteria. Onsite sediment samples were analyzed for TCL inorganics, boron, cyanide, moisture content, PAHs, VOCs, semivolatile compounds, pesticides and PCBs, grain size distribution (dry and wet seasons only), and total organic matter (wet season only).

Inorganic chemicals were detected consistently in all surface water (background, runon, onsite, and runoff) and sediment samples collected during this investigation. EPA's acute freshwater quality criteria (AFWQC) and chronic freshwater quality criteria (CFWQC) were exceeded for the following inorganics in surface water samples collected during this investigation:

- Aluminum

- Cadmium (runon and onsite only)
- Copper (runon, onsite, and runoff only)
- Lead (runon and onsite only)
- Silver (runon and onsite only)
- Zinc.

In addition, CFWQC alone were also exceeded for the following inorganics:

- Iron
- Mercury (runon and onsite only)
- Selenium (runon only)
- Cyanide (onsite only).

The inorganic chemicals detected in stormwater runon samples were generally detected at higher concentrations than those detected in monthly (base flow) runon samples with the exception of major cations (calcium, magnesium, potassium, and sodium). These major cations were detected at higher concentrations in the monthly (base flow) surface water runon samples.

The metals in the onsite surface water samples were generally detected at higher concentrations in the vicinity of and directly downstream from the storm drain outfalls in the channel than in samples collected throughout the remainder of the downstream channel.

Inorganic chemicals in onsite sediment were generally detected at lower concentrations immediately adjacent to the storm drain outfalls than in the more heavily vegetated downstream portion of the channel. However, sampling locations near the storm drain outfalls exhibited the lowest contents of TOC and fine-grained materials. Elevated concentrations of the following inorganics were consistently detected in onsite sediment:

- Arsenic (maximum concentration 93.8 mg/kg; 85 percent of samples contained less than 20 mg/kg)
- Cadmium (maximum concentration 18.0 mg/kg; 90 percent of samples contained less than 5 mg/kg)
- Total Chromium (maximum concentration 614 mg/kg; 90 percent of samples contained less than 100 mg/kg)
- Copper (maximum concentration 884 mg/kg; 90 percent of samples contained less than 350 mg/kg)
- Lead (maximum concentration 2,050 mg/kg; 90 percent of samples contained less than 1,500 mg/kg and 64 percent contained less than 1,000 mg/kg)
- Mercury (maximum concentration 1.6 mg/kg)
- Zinc (maximum concentration 2,460 mg/kg; 80 percent of samples contained less than 1,000 mg/kg).

Anomalously high concentrations of nickel (408 mg/kg) and barium (2,550 mg/kg) were each detected in sediment samples at single locations and one time only. Detailed graphical presentations of sediment sampling results are presented in Appendix SW.

Several organic compounds were consistently detected in surface water and sediment samples collected during this investigation. PAHs were detected in background surface water, runon surface water, onsite surface water and sediment, and runoff surface water. PAHs were detected at higher concentrations in dry season background samples than wet season samples. Detected PAH concentrations in surface water runon were usually less than 1 μg/L. PAHs were detected more frequently and generally at higher concentrations in stormwater runon samples than in monthly runon samples. PAH concentrations in onsite surface water were generally higher in wet season samples than in dry season samples. Maximum PAH concentrations in onsite samples were similar to the range of maximum PAH concentrations in runon samples. PAHs were detected less frequently in runoff than runon, and runoff concentrations were generally similar to the runon concentrations (generally less than 0.2 μg/L). PAH concentrations of up to 130 mg/kg were detected in onsite sediment with the highest concentrations detected in the northern section of the channel.

Only trace concentrations (i.e., less than 10 μg/L) of a few VOCs were detected in surface water and sediment samples collected during this investigation. Acetone (background only), chloroform, toluene (onsite only), and methylene chloride (onsite only) were detected in surface water samples. Only relatively low concentrations of VOCs (i.e., less than 1 mg/kg) were generally detected in sediment samples. A maximum VOC concentration of 6,400 μg/kg of toluene was detected in one sediment sample.

Non-PAH semivolatile compounds were detected in some surface water and sediment samples. Bis(2-ethylhexyl)phthalate was detected in many of the surface water samples (i.e., background, onsite, and runoff) and sediment samples. Nine non-PAH semivolatile compounds were detected in sediment samples at concentrations up to 160 mg/kg.

Pesticides and PCBs were not detected in surface water samples collected during this investigation. However, PCBs were detected at concentrations up to 4 mg/kg in onsite sediment samples from the northern section of the channel during the dry and wet seasons.

Fecal bacteria concentrations in background, runon, onsite, and runoff surface water samples generally exceeded freshwater quality criteria. The ranges of all surface water fecal bacteria concentrations (i.e., background, runon, onsite, and runoff) were similar.

The estimated stormwater volume flowing onto the STF site through the storm drain outfalls was approximately 100 million gallons for the 1-year investigation period (April 1991 through March 1992). The volume of surface water runoff was estimated to be 15.1 million gallons for the investigative period.

The estimated volume of surface water discharged from the STF site was substantially less than the estimated volume of surface water entering the STF site during this investigation. Hence, the majority of surface water flowing onsite was not flowing through and off the site. Much of the surface water runon is apparently dissipated onsite due to evaporation, transpiration, and infiltration through the soil to recharge the upper aquifer beneath the site.

The estimated mass loadings of inorganics in the surface water runon to the site were greater by several orders of magnitude than estimated inorganic loadings in runoff from the site.

The following conclusions were developed based on the findings of the Surface Water and Sediment Investigation:

- Background surface water quality shows contamination from urban surface water runoff as evidenced by exceedances of water quality criteria.

- Runon flows from the two storm drain outfalls (from two upgradient subbasins discharging onto the northwest portion of the STF site) appears to constitute the major source of onsite surface water. Other possible sources of water entering the site are precipitation, sheet runoff from the offsite hillside on the western boundary of the channel, and groundwater discharge into the channel. The surface water runon from the two storm drain outfalls exhibited degraded quality characteristic of urban runoff. Concentrations of metals, PAHs, and fecal bacteria detected in the runon samples were generally equal to or higher than those detected in onsite surface water, and appeared to be significantly elevated as a result of offsite human activities.

- Concentrations of metals and PAHs were generally higher in stormwater runon samples than in monthly runon samples suggesting that these contaminants are mobilized and transported from the surrounding urban environment during storm events following their surface accumulation during drier periods. Sources of PAHs in the runon surface water are ubiquitous in urban environments. Some of these sources include petroleum products such as gasoline, tars and heavy oils, and products of combustion processes such as those produced by internal combustion engines.

- The onsite surface water system is relatively complex with respect to the potential geochemical processes that affect surface water quality. Possible sources of chemicals potentially affecting onsite surface water quality are runon and dissolution and/or resuspension of previously deposited contaminants.

- Metals and PAHs in runon are probably the source for much of the chemical loading to the surface water channel. As discussed in more detail in Section 6.2.1, overland transport of contaminated surface soils from onsite does not appear to be a significant mechanism for migration of metals and PAHs into the surface water channel.

- Sediment containing metals and PAHs may serve as a source for dissolution or suspension of these chemicals in onsite surface water. The highest concentrations of metals and PAHs appear to be present in the upstream reaches (Reaches A and B), with the highest concentrations of PAHs being present near the storm drain outfalls. Based on the runoff conditions observed during storm events and site topography, overland transport of surface soil from other areas of the STF site does not appear to be a significant mechanism for migration of metals and PAHs into the surface water channel. Metals and PAH concentration were not typically elevated in BNR Dismantling Yard soil samples collected adjacent to the channel. Accordingly, the possible sources of metals and PAHs in onsite surface water sediment may be 1) deposition of contaminants contained in runon of degraded quality, 2) deposition of airborne contaminants, or 3) historical deposition of metal-bearing materials into the channel by either direct discharge or human activities resulting in enhanced erosion of such materials.

- Accumulation of chemicals in onsite sediment appears to be largely attributable to the deposition of contaminants carried onsite by runon discharged from the storm drain outfalls as supported by relatively high concentrations detected in sediment in Reaches A and B. The chemical distributions throughout the channel are consistent with the expected patterns of initial introduction of chemicals into the onsite surface water channel by storm drain discharges followed by chemical attenuation as it moves through wider reaches and vegetated areas farther downstream. Chemical concentrations typically decline gradually in the southern end of Reach B and throughout the remainder of the surface water channel, although several metals exhibit elevated concentrations in the southernmost reaches. These metals, which include arsenic, manganese, and nickel, were also detected at elevated concentrations in surface soil in the fill areas of the Former Swamp/Lakebed area through which Reaches C and D pass.

- Surface water was only observed flowing from the site during periods of heavy and/or prolonged precipitation. Based on these observations and the water balance calculations made as part of this investigation, the onsite surface water channel was identified as a recharge zone for the shallow aquifer in the area.

- Mass loading estimations (made as part of the analysis of data gathered during this investigation) indicate that a significant quantity of the metals and PAHs discharged from upstream offsite sources into the onsite surface water channel are retained onsite.

- The quality of runoff from the site was consistent with or better than runon quality throughout the investigation, suggesting that the overall function of the onsite surface water channel is one of settling, absorbing, and otherwise retaining much of the contaminant load discharged to it from offsite upstream sources.

5.1.5 Surface Findings and Conclusions

The surface of the STF site is a combination of relatively flat-lying grassland and wetland habitats with some industrial development, including buildings and paved lots on the northern and southern site extremities. Wetlands are associated with the surface water channel that traverses most of the western perimeter of the site. An active BN railroad line is located along the eastern site perimeter and floor slabs from a number of former railroad maintenance shops are still present in the BNR Railyard area.

Soils throughout the area are primarily sand and gravel regolith of glacial origin overlain by a thin veneer of organic top soil. Demolition debris and rubble are present in scattered piles in various parts of the site. Soil exhibits little potential for erosion by wind or water because of the vegetative cover and pavement over most areas, the granular texture of the soil (few fines), and the generally flat site topography. Most precipitation falling on the site infiltrates or is lost to the atmosphere through evaportranspiration. Minor runoff to the onsite surface water channel occurs in some areas, but there is little overall potential for appreciable sheet runoff from the site.

The distribution of elevated chemical concentrations in onsite surface soil is related to and consistent with specific activities that occurred in individual areas of the site (i.e., chemical distributions were patchy with no apparent concentration gradients). Most of the onsite soil that has been affected by past activities contains elevated metal concentrations. In contrast to background levels, onsite surface soil concentrations of copper, lead, and zinc are the most elevated and were mainly detected in samples from the Amsted property, BNR Dismantling Yard, and BNR Railyard. Concentrations of arsenic, beryllium, and cadmium are also somewhat elevated in these areas. Elevated metal concentrations were also detected in surface soil samples from the Former Swamp/Lakebed area; however, the assemblage of elevated metal concentrations in this sampling unit is markedly different from the rest of the STF site. Elevated concentrations of barium, cadmium, chromium, magnesium, manganese, nickel, and vanadium were more commonly detected in this area.

PAHs were also detected at relatively low to moderate concentrations in soil samples collected from locations throughout the site. Elevated PAH concentrations were detected sporadically in the same areas as elevated metals concentrations: the Amsted property, BNR Dismantling Yard, BNR Railyard, and Former Swamp/Lakebed. Organic chemicals, such as phthalates and phenols, were also detected sporadically in these areas. PCBs were detected in several surface sampling locations at relatively low concentration (i.e., only five samples contained concentrations greater than 5 mg/kg and the maximum detected concentrations was 42 mg/kg). Only trace concentrations of dioxins and dibenzofuran were detected in surface soil. Those concentrations were consistent with those typically found in industrial soil.

The onsite surface water channel consists of both narrow trapezoidal segments and a broad wetland area. During the period of the RI, an estimated 100 millon gallons flowed into the channel through two storm drain outfalls. Most runon is retained onsite and is lost through percolation or evaportranspiration. Approximately 6 acres of perennial wetlands and 1 acre of seasonal wetlands were identified and mapped during the RI. Water only flows offsite through the channel during periods of intense and/or prolonged precipitation. The estimated flow offsite from the channel during the RI was 15.1 million gallons. Although runon surface water quality is characteristic of runoff from urban areas, the quality of onsite surface water and runoff from the site (at the end of the onsite channel) is relatively good. The chemicals that frequently exceeded AFWQC in onsite water were aluminum, copper, lead, and zinc. Frequent exceedences occurred in site runoff for aluminum, copper, and zinc. Exceedences for these three metals also occurred in background water quality samples and are common in local surface water. Elevated concentrations of arsenic, cadmium, chromium (total), copper, lead, mercury, zinc, and PAHs were detected in a number of sediment samples collected from the onsite channel.

Blackberries were sampled and analyzed to examine possible root uptake of inorganics (arsenic, boron, selenium, and 11 metals) or airborne deposition of inorganics of blackberry surfaces. No evidence of contamination due to these potential transport mechanisms was found.

5.2 SUBSURFACE UNSATURATED ZONE INVESTIGATIONS

5.2.1 Geophysical Survey

An extensive geophysical survey was conducted by EHI at the STF site from March through November 1991. The objective of the survey was to locate possible underground storage tanks (USTs) and buried drums. A two-phase approach was used. Phase I was an electromagnetic (EM) and magnetometer (magnetic) survey, which was conducted over the accessible areas of the site. This phase was designed to locate areas of magnetic anomalies that may have been indicative of buried metallic objects including tanks or drums. Phase II was a ground penetrating radar (GPR) survey conducted over geophysical anomaly areas identified in Phase I. Phase II was designed to further characterize those anomalies and identify possible underground "targets" representative of tanks or drums.

A grid system was established to perform the geophysical survey. The grid layout consisted of three intervals, as listed below, based on relative probability of finding a UST or drum:

- A 20-foot grid spacing (north-south and east-west) over portions of the BNR Dismantling Yard and the Former Swamp/Lakebed where the highest relative probability existed.
- A 40-foot grid spacing at locations within 100 feet of former building foundations where a moderate relative probability existed.
- A 50-foot grid sampling across the remainder of the site where the lowest relative probability existed.

A 20-foot grid was used in areas where the ground surface appeared to have been disturbed, locations known to have received fill material, and locations known or suspected to have functioned as waste material disposal sites. A 40-foot grid was used at locations within 100 feet of previous site building foundations to identify small USTs. Remaining portions of the site were surveyed using a 50-foot grid to locate potential tanks in areas where there was less likelihood of tanks and drums. The 20-foot grid covered approximately 45 acres; the 40-foot grid covered approximately 120 acres; and the 50-foot grid covered approximately 130 acres.

To manage data collection and facilitate contour map production during the first phase of the geophysical survey, the site was subdivided into survey blocks based on grid spacings and site features (e.g., fences and property lines):

- The 20-foot transect grid consisted of 8 blocks
- The 40-foot transect grid consisted of 23 blocks
- The 50-foot transect grid consisted of 18 blocks.

Small areas of the site could not be surveyed due to existing buildings, dense vegetation, steep terrain, wetlands, and surface water bodies.

The Phase II geophysical survey consisted of a GPR survey over the anomalies identified during the Phase I survey. The anomalies were designated Priority 1 (P1) if they were identified during both the EM and magnetic survey; Priority 2 (P2) anomalies were identified during either the EM or the magnetic survey, but not both. GPR was also used in the following areas where the Phase I survey was found to be ineffective:

- Former Swamp/Lakebed area
- Inside the General Plastics facility
- Inside the Pioneer Builders Supply offices and warehouse

- Tacoma City Light yard.

For P1 and P2 anomalies, an "index point" was selected over the highest magnitude of the chosen anomaly from which GPR transects were run on 5-foot centers, with the middle line traversing the index point.

As the name implies, the Former Swamp/Lakebed area was formerly a swamp and lakebed. It was subsequently covered with fill material containing metallic debris (e.g., slag, floor sweepings, scrap material, and casting sands) from the former Fick and Atlas Foundries, and other unknown sources. The GPR lines were run both in areas where the EM and magnetic surveys indicated the presence of extensive debris and where no debris was apparent.

The General Plastics facility is a large open building used for plastics manufacturing operations. The GPR was run in accessible areas including aisles and walkways. Forty-eight (48) GPR lines were run inside the building.

Pioneer Builders Supply is a retail and wholesale roofing business consisting of a warehouse, offices, and yard. GPR lines were run to assess the potential for detecting USTs in an area where three tanks were removed several years ago. Several GPR lines were also run in the office and warehouse portions of the site.

The Tacoma City Light facility consists of buildings and equipment storage areas and is currently used as a major maintenance, staging, and storage facility. GPR lines were approximately 1,300 feet long and were run along accessible roadways in the yard area of the Tacoma City Light property.

The GPR investigation included approximately 130 P1 and 67 P2 anomalies identified during the Phase I geophysical survey. Those anomalies determined to be cultural sources (e.g., buildings, roads, fences) were not included in the Phase II GPR investigation.

During the Phase II survey, the GPR records were examined for the presence of anomalies that indicated the possible presence of a tank or drum. These anomalous reflections were listed with their position, a ranking, and comments regarding the character of the reflecting object. Strong GPR reflections with dimensions and characteristic properties of large buried metallic tanks or drums were ranked as No. 1 targets. Weaker GPR reflectors that were less defined, yet were consistent with the characteristics of a tank-like or drum-like object were ranked as No. 2 objects. Rankings were further divided as large or small based on the lateral dimensions of the GPR reflection. Small targets had a cross-section dimension smaller than 3-4 feet.

Based on a review of the records, 36 P1 locations and 22 P2 locations were identified for further evaluation and ranking. Two additional targets were identified; one was located on Tacoma City Light property and one was on the Amsted property. Twenty-five (25) reflections were listed as large No. 1 targets; 31 reflections were listed as large No. 2 targets; and 4 reflections were listed as small No. 2 targets.

During the Phase I geophysical survey, eight locations in the Former Swamp/ Lakebed Area were identified as P1 anomalies. GPR was run at six of the eight anomalies; two of the six were not run due to the presence of surface metal. GPR results showed numerous reflections that were characterized as near surface debris and fill. Due to the high density of the near-surface debris, resolution of individual targets was poor.

The quality of the GPR records was generally good for runs conducted at the General Plastics facility. No large reflective targets were detected. Small reflections were interpreted as pipes, drains, or conduits associated with the building.

Three P1 anomalies were identified in the yard area at the Pioneer Builders Supply facility. One of the anomalies correlated with the UST currently in use at the site;

no reflective targets were identified at the other two locations using GPR. No evidence of large reflective objects was found in the vicinity of the former tank removal excavation. GPR lines run within the warehouse and offices did not identify reflective targets. Some shallow small reflections interpreted as pipes, drains, and conduits were identified beneath the offices.

The GPR runs in the Tacoma City Light yard recorded numerous reflections ranging in depth from 1 to 8 feet. Many of the reflections corresponded with underground utilities. One reflection interpreted as a large No. 1 target was identified as being 10 feet by 3 feet and located 2-4 feet below grade.

In summary, approximately 60 anomalies were identified and ranked as No. 1 or No. 2 targets, indicating the GPR reflection may have been caused by a large metallic object such as a tank or drum. These potential targets were investigated using a backhoe during the Subsurface Target Confirmation Investigation. Only two tanks and no drums were found during that investigation. One tank had a capacity of approximately 250 gallons but was empty. The other tank had a capacity of approximately 6,000 gallons and contained approximately 1,800 gallons of waste oil and sludge. The remaining 58 targets excavated as part of this investigation resulted in unearthing various objects that were most likely associated with the previous operation of this site. These objects include subsurface debris piles, shallow underground utility lines, large diameter drip pans, concrete rubble and various other types of metallic and non-metallic debris.

The locations of the two tanks found during the Subsurface Target Investigation are shown in Plate 2A through 2C of Appendix GS (Volume 6 of 6 of the RI report). The 6,000 gallon tank is located at easting 1146575 and northing 690240. The 250 gallon tank is located at easting 1146780 and northing 693343. Removal of the tanks was performed in December 1992. The 250-gallon tank was empty upon excavation and was disposed of by General Metals in Tacoma, Washington.

The contents of the 6,000-gallon tank were removed by Burlington Environmental Inc. and recycled or disposed of offsite at a permitted facility. Subsequently, the tank was inerted using carbon dioxide gas, holes were cut in the side to gain access to the inside of the tank and the tank was steam-cleaned in-place to remove possible residual contaminants. The tank was removed from the ground and was also recycled at General Metals.

5.2.2 Soil Gas Survey

Petroleum hydrocarbons and halogenated VOCs were detected during soil sampling and analysis performed by the property owner and the Tacoma-Pierce County Health Department during removal of three former USTs at Pioneer Builders Supply facility. A groundwater sample collected from a monitoring well installed within the former tank removal excavation contained detectable concentrations of petroleum hydrocarbons. Based on these analytical results, Tracer Research Corporation (Tracer) was contracted to conduct a shallow soil gas survey in August 1991.

The objective of the soil gas survey was to assist in delineation of the areal extent of VOCs in the vicinity of the former tank removal excavation. These tanks were located north of the Pioneer Builders Supply facility in the southeastern portion of the STF site.

Preliminary investigative activities included establishing a 50-foot interval grid system at the former tank locations. Soil gas samples were then collected at 24 locations along the grids typically at depths of 6 and/or 13 feet below surface grade. A total of 35 soil gas samples was collected and analyzed. Nine sample locations were within 50 feet of the former USTs and two locations were within the former tank removal excavation itself. The remaining samples were collected within 100 feet of the former tank removal excavation.

The investigative methods used by Tracer involved pumping a small amount of soil gas out of the ground through a hollow probe driven into the ground and then analyzing the soil gas for the presence of VOCs. The detection limit for the halocarbon compounds was approximately 0.0002 μg/L of soil gas, while the detection limit for the hydrocarbons was approximately 0.07 μg/L. Duplicate samples were analyzed to ensure that results were reproducible.

Gas chromatograph analyses of the soil gas samples detected low or no concentrations of hydrocarbons and halogenated VOCs. Hydrocarbons were detected in five of the samples at concentrations up to two orders of magnitude greater than the detection limits. Except for low concentrations of carbon tetrachloride, analytical results did not indicate the presence of halogenated VOCs in soil gas samples. Carbon tetrachloride was not detected during previous investigations at the site, and the source of the compound was unknown.

Based on field observations and laboratory results of the soil gas survey, Tracer concluded that significant or widespread hydrocarbon contamination did not appear evident. Because vertical depth profiles did not indicate clear trends of chemical distribution for hydrocarbons or carbon tetrachloride, it was concluded that the source area of these low levels of chemicals could be either soil or groundwater.

5.2.3 Subsurface Soil Investigations

The subsurface soil investigation was conducted in two phases. Results of the Phase I Soil Investigation for both surface and subsurface samples were evaluated and used in the development at the Phase II Soil Investigation FSAP Amendment.

5.2.3.1 <u>Phase I Soil Investigation</u>. The two principal objectives of the Phase I Subsurface Soil Investigation were to:

- Characterize the types and concentration distributions of target chemicals of concern detected in subsurface soil in the dry wells at Tacoma City Light and at Pioneer Builders Supply.

- Acquire chemical concentration data to use in conjunction with data from the Phase I Groundwater Investigation, Geophysical Survey, and Soil Gas Survey to develop the Phase II Soil Investigation FSAP Amendment.

The following tasks were completed during the subsurface portion of the Phase I Soil Investigation:

- Collected and analyzed 32 subsurface soil samples from 8 dry wells (DW) located on Tacoma City Light property.

- Collected and analyzed 27 subsurface soil samples from 5 borings located on Pioneer Builders Supply property. Borings were located in and near the underground tank removal excavation.

- Samples collected from Tacoma City Light property were analyzed for the full TCL. All samples collected from Pioneer Builders Supply property were analyzed for PAHs, semivolatile organic compounds, and VOCs. Eight selected samples from Pioneer Builders Supply were analyzed for the full of TCL, including boron.

A detailed presentation of the findings of the subsurface portion of the Phase I Soil Investigation is provided in Appendix SS.

Inorganic Results for Tacoma City Light. Most TCL metals were detected in samples collected from Tacoma City Light dry wells. Cyanide and boron were not detected. The subsurface maximum metal concentrations were generally consistent with or slightly elevated above background levels.

Elevated metals concentrations (compared with background) were detected in samples collected from five dry wells. Lead concentrations above background were detected in one or more samples from DW-13 (98.5 mg/kg), DW-19 (141 mg/kg), DW-20 (267 mg/kg), DW-22 (223 mg/kg), and DW-26 (538 mg/kg). Lead concentrations in these wells decreased abruptly to background levels with increasing depth. Samples from DW-13 contained elevated concentrations (compared with background) of total chromium (310-2,300 mg/kg), arsenic (13.9-74.8 mg/kg), copper (309-856 mg/kg), and mercury (0.18 mg/kg). Samples from DW-26 also contained elevated concentrations of arsenic (50.7 mg/kg), copper (329 mg/kg), and mercury (0.40 mg/kg). Metal concentrations in samples from both DW-13 and DW-26 decreased appreciably with increasing depth.

Inorganic Results for Pioneer Builder Supply. Metal concentrations detected in subsurface soil samples collected from Pioneer Builders Supply did not vary significantly with depth or among borings. Concentrations of metals in subsurface soil at Pioneer Builders Supply were consistent with the area background surface soil concentrations. Boron was not detected.

Organic Results for Tacoma City Light. One or more PAH compounds were detected in each of the 32 subsurface soil samples collected from Tacoma City Light dry wells. Total probable carcinogenic PAH concentration of 1 to 10 mg/kg were typically detected in the sediment samples from the bottoms of the eight dry wells samples; however, a maximum of 80 mg/kg was reported for DW-26. PAH concentrations typically decreased with depth. Generally, total PAH concentrations detected in the deepest samples collected were between 1 and 2 orders of magnitude lower than those detected in the shallowest samples (490 mg/kg). In addition to the highest (80 mg/kg) concentration of carcinogenic PAHs, samples collected from DW-26 also exhibited the highest detected concentrations of total PAHs (490 mg/kg).

Twelve semivolatile organic compounds (not including PAHs or TICs) were detected in samples collected from Tacoma City Light dry wells. DW-10, DW-15, and

DW-19 exhibited the fewest number of detected semivolatile organic compounds. DW-26 samples typically contained the highest number and highest concentrations of semivolatile organic compounds. Generally, when semivolatile organic compounds were detected in more than one sample from a dry well, concentrations decreased with depth.

Elevated VOC concentrations (i.e., greater than 0.2 mg/kg) were only detected in samples from three dry wells. Xylenes were detected at a concentration of 0.31 mg/kg in the shallowest sample from DW-10 and toluene was detected at 0.52 mg/kg in the shallowest sample from DW-26. Elevated concentrations of chlorobenzene (10-59 mg/kg), benzene (0.55-0.95 mg/kg) and trichloroethene (0.25-0.310 mg/kg) were detected to a depth of 11 feet in samples from DW-20. Only one pesticide (aldrin) was detected in samples collected from DW-13. PCBs were detected in 11 samples collected from five dry wells (DW-18, DW-19, DW-20, DW-22, and DW-26) with a maximum detected concentration of 840 mg/kg. In samples from four of these five dry wells, total PCB concentrations only ranged from 1.0 to 5.0 mg/kg. PCB concentrations in samples from DW-20 declined from 840 mg/kg at 7 feet BGS to 36 mg/kg at 13 feet BGS.

Organic Results for Pioneer Builders Supply. PAHs were detected in 14 of the 27 subsurface soil samples collected from borings advanced at Pioneer Builders Supply. Probable carcinogenic PAHs were detected in only four of the samples collected. The maximum total probable carcinogenic PAH concentration was 0.20 mg/kg. In instances where PAHs were detected in samples collected at two or more depths in a boring, concentrations typically decreased with increasing depth.

Eight semivolatile organic compounds were detected in samples collected at Pioneer Builders Supply. 1,2,4-Trichlorobenzene (typically 1-10 mg/kg) and 2-methylnaphthalene (typically 0.1-10 mg/kg) were the most frequently detected compounds. In many boring locations, semivolatile organic compound concentrations increased with increasing depth.

Five VOCs, including methylene chloride and acetone, were detected in the subsurface soil samples collected from Pioneer Builders Supply. Methylene chloride and acetone were detected in most laboratory blanks (i.e., indicative of laboratory contamination) and probably do not represent actual soil concentrations. The highest concentrations of the other three VOCs (toluene, ethylbenzene, and xylenes) were detected in samples collected from boring B-3, which was located inside the former tank removal excavation (see Figure SS-8 in Appendix SS).

Pesticides were not detected in samples collected from Pioneer Builders Supply. PCBs were detected in three of the subsurface soil samples collected from the deepest sampling intervals from two borings (B-2 and B-3). Both borings were located within the former tank removal excavation. Detected concentrations ranged from 1.0 to 11.0 mg/kg.

5.2.3.2 Phase II Soil Investigation. The primary objectives of the Phase II Soil Investigation were to:

- Provide additional information to characterize the stratigraphy and lithologic relationships in the shallow unsaturated zone

- Characterize and evaluate the horizontal and vertical distribution of selected TCL chemicals in subsurface soil.

The following investigative actions were undertaken to fulfill these objectives:

- Drilled and sampled 92 soil borings at locations throughout the STF site; a total of 305 subsurface soil samples was collected for chemical analyses.
    - During drilling, soil conditions were logged and soil samples were collected. Shallow stratigraphy and lithologic relationships were interpreted from the boring logs.
    - Collecting and analyzing samples from various depth intervals allowed the subsurface spatial distribution of TCL chemicals to

be evaluated and characterized. Samples were also collected to characterize the physical and chemical properties of subsurface soil.

- Specialized procedures were used to select sampling depths and locations for different areas of the site depending on the chemicals most likely encountered, route of entry to the environment, and area-specific investigative objectives.

With few exceptions, Phase II subsurface soil samples were analyzed for TCL inorganics and PAHs. Selected samples were analyzed for the full TCL.

Amsted Property. Much of the material encountered in the subsurface at the Amsted property was fill material. In samples of the fill material, most TCL inorganics were detected at concentrations exceeding typical naturally occurring concentrations. Copper, lead, manganese, and zinc were the metals most commonly detected at elevated concentrations.

Three different types of fill material were identified based on appearance and results of the inorganic analyses. These fill materials were an apparent demolition debris; a fine-grained sand, slag, and cinder mixture; and a coarse-grained gravel, cinder, and slag mixture. The coarse-grained gravel, slag, and cinder mixture appeared to comprise the largest volume of the three types of fill material identified. The maximum thickness of fill encountered was about 15 feet.

Leaching of metals from the fill materials was not evident based on the analytical results for samples collected from the native soil underlying these fill areas.

Slightly elevated concentrations of the metals mentioned above (copper, lead, manganese, and zinc) were also detected in subsurface soil samples collected from outside the filled areas. Increased subsurface metal concentrations in these areas appeared to coincide with elevated metal concentrations in overlying surface soil. These subsurface metal concentrations may be attributed to limited downward movement of the metals in overlying surface soil. In these areas, metal concentrations decreased quickly with depth indicating that these metals are resorbed.

Relatively low organic chemical concentrations were detected in soil samples collected from the Amsted property.

BNR Dismantling Yard. Discernable areas of fill were not encountered in the BNR Dismantling Yard during the Phase II Soil Investigation. The subsurface distribution of elevated concentrations of TCL chemicals in the BNR Dismantling Yard was limited both in vertical and spatial extent. Based on Phase II Soil Investigation results, elevated subsurface TCL chemical concentrations were only present in three relatively small areas and were not detected in samples collected from deeper than 2 feet.

Lead, manganese, and zinc were detected at elevated concentrations in the subsurface of the BNR Dismantling Yard. Areas with increased concentrations of these metals were generally coincidental. With few exceptions, metals concentrations were consistently within typical naturally occurring concentration ranges below a depth of 2 feet in areas sampled in the BNR Dismantling Yard.

PAHs were detected at elevated concentrations at only one location at 2 feet below grade. No other organic chemicals were detected at elevated concentrations.

BNR Railyard. Two areas of fill material were encountered in the BNR Railyard. The smaller of these two areas was encountered in the northern portion of the sampling unit. The larger area was encountered in the southwest corner of the sampling unit.

Borings drilled in and adjacent to the northern fill area in the BNR Railyard were sited to further evaluate the distribution of PCBs detected during the Phase I Soil Investigation. The Phase II soil sampling results indicated that detectable PCBs concentrations were limited in vertical extent to the upper 4 feet of the soil profile and suggested that the horizontal extent was about 1 acre around the grid square in which they were detected. PAH compounds were also detected in this area and had a concentration distribution similar to PCBs.

Borings drilled in the southern fill area of the BNR Railyard encountered about a 6-foot thickness of fill, which covered an estimated area of 3.5 acres. Lead, copper, and PAHs were the TCL chemicals most commonly detected at elevated concentrations in samples collected from this fill.

Elevated concentrations of TCL chemicals (primarily metals) in other areas of the sampling unit were limited to the upper 2 feet of soil.

Leaching of chemicals from fill areas was not evident based on the analytical results of samples collected from underlying soil.

Subsurface chemical concentrations could, in some instances, be attributed to downward leaching of chemicals deposited at the surface. In general, in the few locations where increased subsurface chemical concentrations were detected in non-fill areas, they coincided with elevated concentrations of the same chemicals in overlying surface soil. In these areas, the concentrations decreased quickly with depth.

With the exception of PAHs, organic chemicals were only sporadically detected and at very low concentrations in the BNR Railyard.

Former Swamp/Lakebed. Most of the material encountered during drilling in the Former Swamp/Lakebed was inferred to be material placed by nongeologic processes. The inference that this material was placed by nongeologic processes was based on site history and stratigraphic relationships interpreted from observations of subsurface conditions made during drilling. Because most of this material appeared to be composed of soil, it could not be definitively classified as a "fill" material (as defined in this report).

Based on a review of aerial photographs, this area was formerly a lake. During subsurface sampling, it was possible to identify the lithologic units that corresponded to the former lake bottom. Based on the Phase II soil boring logs, the elevations corresponding to the lake bottom were contoured and the material between the lake bottom and the present ground surface has been inferred to be fill (see Appendix SB, Figure SB-21). Based on the findings of the Phase II Soil Investigation, the deepest portion of the former lake was between 12 and 17 feet below present grade in the central portion of the Former Swamp/Lakebed sampling unit.

Metal concentrations exceeding typical natural occurring concentrations were not widespread in subsurface soil in the Former Swamp/Lakebed area. PAHs were the only organic TCL analytes detected at elevated concentrations. PAHs were detected at parts per million (ppm) concentrations to a depth of 12 feet BGS in the central portion of the sampling unit based on samples collected from one boring. PAH concentrations in three other borings in this area were also slightly elevated, but concentrations decreased abruptly in samples collected below 7 feet BGS.

Leaching of metals and PAHs from soil overlying the lake bottom into soil below the lake bottom was not evident based on field observations and analytical data.

Tacoma Industrial Properties. The stratigraphy of the subsurface at TIP is characterized by a "wedge" of fill material that thickens from east to west and overlies native soil. The fill appears to extend from the eastern property boundary to the slag wall along the western property boundary. The slag wall appears to act as a retaining wall for the fill.

The fill material is composed of a slag, cinder, and sand mixture. Lead and manganese were detected in samples from this material at concentrations exceeding typical naturally occurring concentrations. Other TCL analytes were not detected at elevated concentrations.

Leaching of lead, manganese, and other selected TCL chemicals from the fill into underlying soil was not evident based on field observations and analytical results.

Airport. Fill or suspected fill materials were not encountered during the subsurface investigation of the Airport sampling unit. Elevated concentrations of TCL chemicals were only detected in subsurface soil samples collected from two locations. These boring locations were sited adjacent to the boundaries of BNR Dismantling Yard and the BNR Railyard sampling units.

One elevated lead concentration was detected at 2 feet below grade in the boring adjacent to the BNR Dismantling Yard. PAHs were detected at low concentrations in the boring adjacent to the BNR Railyard. In both cases, similar concentrations of these compounds were detected in the neighboring sampling unit. These compounds were not detected at elevated concentrations at other locations within the Airport sampling unit.

Tacoma City Light Property. The Phase II Soil Investigation at the Tacoma City Light property focused on evaluating the horizontal distribution of TCL chemicals detected in subsurface samples collected from the dry wells during the Phase I Soil Investigation.

The horizontal extent of all chemicals detected during the Phase II Soil Investigation appeared to be minimal. No chemical was detected at greater than 1.0 mg/kg at a distance of 3 feet from a dry well casing. Only in isolated cases were chemicals even detected at a distance of 1 foot from a dry well casing.

PAHs and PCBs were the organic TCL chemicals detected at the highest concentrations at Tacoma City Light property during the Phase II Soil Investigation. PAHs and PCBs were also detected at the highest concentrations at Tacoma City Light property during the Phase I Soil Investigation. Some semivolatile organic compounds were also detected, but at lesser concentrations.

Pioneer Builders Supply. Phase II borings at Pioneer Builders Supply were sited to better characterize the subsurface distribution of chemicals detected during the Phase I Soil Investigation (i.e., PCBs, semivolatile organic compounds, and PAHs).

PCBs, 1,2,4-trichlorobenzene, and 2-methylnaphthalene were the three organic compounds that were most commonly detected in the subsurface at Pioneer Builders Supply. Concentrations of these chemicals appeared to be greatest in samples collected to the west of the former tank removal excavation.

The following general conclusions were made about the subsurface soil at the STF site based on the Phase II Soil Investigation:

- Most of the elevated concentrations of TCL chemicals detected in subsurface soil samples appear to be the result of deposition of contaminated fill materials as opposed to subsurface accumulations resulting from leaching. This conclusion is supported by Phase II soil results for the Amsted property sampling unit, the southwest corner of the BNR Railyard sampling unit, and the Former Swamp/Lakebed sampling unit, which had the highest subsurface concentrations of most TCL chemicals.

- In some cases where elevated concentrations of metals were detected in surface soil, some leaching to underlying soil may have occurred. Leaching is suggested by the results for samples collected from two borings on the Amsted property sampling unit. However, analytical results for soil samples underlying fill did not exhibit evidence of leaching of metals from overlying fill material.

- Vertical and horizontal migration of TCL chemicals at dry wells at Tacoma City Light property is limited in maximum extent to about 3 feet laterally and 8 feet below the dry well casings, but is generally considerably less than these limits.

- TCL chemicals in the subsurface at Pioneer Builders Supply property appeared to increase in concentration to the west of the former tank removal excavation.

5.2.4 Unsaturated Zone Findings and Conclusions

The unsaturated zone (soil above groundwater) at STF is between 15 and 30 feet thick throughout most of the site. The thickness diminishes from east to west throughout the central portion of the site as the water table intercepts the wetland area and portions of the surface water channel, where continuously saturated sediments are present at the surface. The unsaturated zone thickness varies both laterally and seasonally as shown in Table RI-24.

TABLE RI-24

THICKNESS OF THE UNSATURATED ZONE AT THE STF SITE

Sampling Unit	Typical Thickness (feet)[a]		Annual Variation
	Maximum	Minimum	
Amsted Property/TIP	30	25	5
BNR Dismantling Yard	23	18	5
BNR Railyard (North)	27	17	10
BNR Railyard (Central)	46	29	17
BNR Railyard (South)	32	27	5
Former Swamp/Lakebed	22	13	9
Airport (at NMW-4A)	22	10	12

(a) Based on upper aquifer water level measurements.

The unsaturated zone thickness varies in response to water level fluctuations with its maximum thickness corresponding with the period of maximum seasonal water level decline (late summer) and minimum thicknesses corresponding to the highest seasonal water levels (early spring).

The unsaturated zone is composed of both naturally deposited unconsolidated sediment and fill from anthropogenic sources. Most subsurface soils are poorly graded sands and poorly graded gravels with only minor amounts of fines. Accordingly, the capillary fringe or tension-saturated zone is expected to be relatively thin throughout most of the site. Particle size distribution analyses of subsurface soil samples collected during the RI indicate that sand- and gravel-sized particles predominate those soils; generally sand and gravel constituted at least 90 percent of each sample by weight. Only unsaturated subsurface soil samples collected in the Former Swamp/Lakebed area contained high percentages of fines (i.e., up to 26 percent). Fines present in soil samples were non-plastic or of low plasticity.

Measured moisture contents for subsurface soil were generally less than 15 percent, which is consistent with the coarse-grained textures. Laboratory permeability tests of remolded subsurface soil samples yielded typical results ranging from 1×10^{-4} to 1×10^{-3} cm/sec. Calculated porosities ranged from 17 to 48 percent. Total organic carbon contents ranged from 600 mg/kg to 107,000 mg/kg.

The fill encountered onsite generally included cinders, slag, scrap metal, brick, wood, and glass. These materials are typically mixed with approximately equal amounts of soil particles. The most common fill material is a mixture of slag, cinders, and soil. Fill materials contained elevated concentrations of chemicals of concern more frequently than naturally deposited subsurface soil, which generally did not show evidence of contamination. Areas of the site in which appreciable volumes of fill are present include:

- Amsted Property. Much of the material encountered in the subsurface at the Amsted property was fill material. Fill materials ranged from 12 to 15 feet thick in some places and were present mainly to the south of the former foundry building. Many metals were detected at concentrations exceeding typical naturally occurring concentrations in samples of the fill material. Copper, lead, manganese, and zinc were the metals most commonly detected at elevated concentrations.

- BNR Railyard. Two areas of fill material were encountered in the BNR Railyard. The smaller of these two areas was encountered in the northern portion of the sampling unit. The larger area was encountered in the southwest corner of the sampling unit. Soil in the smaller area (approximately 1 acre) contained moderately elevated PCB and PAH concentrations to a maximum depth of 4 feet. Borings drilled in the southern fill area encountered about a 6-foot thickness of fill, which covered an estimated area of about 3.5 acres. Lead, copper, and PAHs were detected at elevated concentrations within this fill.

- Former Swamp/Lakebed. Most of the material encountered during drilling in the Former Swamp/Lakebed was inferred to be material placed by nongeologic processes. Much of this area was formerly a lake. Based on the Phase II soil boring logs, the lake bottom was contoured and the material between the lake bottom and the present ground surface has been inferred to be fill. The deepest portion of the former lake encountered was between 12 and 17 feet below present grade in the central portion of the Former Swamp/Lakebed sampling unit. Elevated concentrations of PAHs were detected in portions of this fill.

- TIP. The stratigraphy of the subsurface at TIP is characterized by a "wedge" of fill material that increased in thickness (to a maximum of about 10 feet) from east to west and overlies native soil. The fill appeared to extend from the eastern property boundary to the slag wall along the western property boundary. Lead and manganese were detected at elevated concentrations in samples of this material.

Elevated concentrations of PAHs were detected in subsurface soil sampled at and underlying the bottoms of the 10 dry wells at Tacoma City Light. PCBs and carbazole were also detected in samples from many of the dry wells. Elevated concentrations of 1,3-dichlorobenzene, 1,4-dichlorobenzene, chlorobenzene, benzene, and xylenes were detected in samples from DW-20, which also contained the highest levels of PCBs. Elevated concentrations of lead, chromium, arsenic, copper, and mercury were detected in various dry well samples. Elevated concentrations of most chemicals were limited to several feet in vertical and lateral extent. However, detectable organic chemical concentrations were present in a number of the lower unsaturated zone samples.

Unsaturated zone soil beneath and immediately surrounding the former tank removal excavation at Pioneer Builders Supply contained elevated concentrations of 1,2,4-trichlorobenzene, PCBs, and a complex petroleum hydrocarbon mixture. Concentration profiles were inverted in some borings (i.e., increasing concentrations with depth) in a manner consistent with those expected to result from discharges related to underground tank installations or groundwater contamination. The hydrocarbon mixture included detectable concentrations of toluene, xylenes, and ethyl benzene, as well as numerous TICs that were mostly in the carbon 8 to carbon 12 range. A lesser number of carbon 13 through carbon 20 hydrocarbon compounds was also detected. Based on the Soil Gas Survey, which was conducted in an extended area around the former tank removal excavation, significant or widespread volatile hydrocarbon contamination does not appear to be present.

The Geophysical Survey of the site using electromagnetic, magnetometer, and ground penetrating radar sensing techniques identified approximately 60 anomalies in the subsurface that were classified as potential subsurface targets. However, only two tanks were found after a confirmation investigation was conducted (excavation at anomaly sites using a backhoe).

5.3 SUBSURFACE SATURATED ZONE INVESTIGATIONS

5.3.1 Groundwater Monitoring Investigation

The primary purpose of the Phase I Groundwater Investigation was to characterize hydrogeologic conditions and groundwater quality beneath the STF site. The complete Groundwater Investigation Report is contained in Appendix GW. Specific objectives of the Groundwater Investigation were to:

- Characterize the concentration distributions of TCL analytes detected in groundwater samples collected from onsite monitoring wells during four quarters of sampling.

- Characterize background and upgradient groundwater quality.

- Obtain geologic information regarding hydrostratigraphic units beneath the STF site to assess the potential for intercommunication between the A and C aquifers (hydrostratigraphic designations according to Brown and Caldwell 1985).

- Obtain hydraulic gradient information for the upper aquifer on a monthly basis for 1 year to assess seasonal effects and the effects of pumping City of Tacoma production wells on the hydraulic gradient at the STF site.

- Evaluate groundwater vertical hydraulic gradients and changes in groundwater quality with increasing depth by installing and monitoring well clusters at two onsite locations.

- Evaluate chemical concentration data (in conjunction with data from the Phase I and Phase II Soil Investigations, Geophysical Survey, and the Soil Gas Survey) to determine the need for additional monitoring wells.

The following tasks were completed during the Phase I Groundwater Investigation:

- Installed and developed 11 new monitoring wells at the STF site, including two depth-staggered well clusters consisting of three wells per cluster (i.e., wells completed in Upper Layer A, Lower Layer A, and Layer C at both locations).

- Collected seven undisturbed soil samples from the upper aquifer during well installation to characterize physical soil properties, including vertical hydraulic conductivity, porosity, and particle size distribution.

- Measured water levels monthly in 30 groundwater monitoring wells (i.e., 29 onsite wells and 1 upgradient well) from April 1991 through March 1992. Additional monitoring was performed in late August and late March. The late-August monitoring coincided with the collection of background and upgradient samples from Tacoma Landfill wells. The late March monitoring coincided with aquifer testing that was part of the Hydraulic Characterization Investigation (Appendix HC). Measurements of water levels in upper aquifer wells in the vicinity of the Tacoma Landfill were provided by Tacoma Landfill personnel for the May, late-August, November, and February events. These measurements were incorporated into upper aquifer water level contour maps prepared for the Groundwater Investigation Report.

- Collected groundwater samples from 26 onsite monitoring wells during four quarterly sampling events: first quarter (April 1991), second quarter (July/August 1991), third quarter (October/November 1991), and fourth quarter (January 1992). Three of the monitoring wells (i.e., CBS-5A, CBS-7A, and CBS-9A) designated as being "onsite" are technically located outside the site boundary, but were included for hydrogeologic reasons based on a mutual agreement with EPA.

- Collected groundwater samples from five background monitoring wells and five upgradient monitoring wells during the second and fourth quarters.

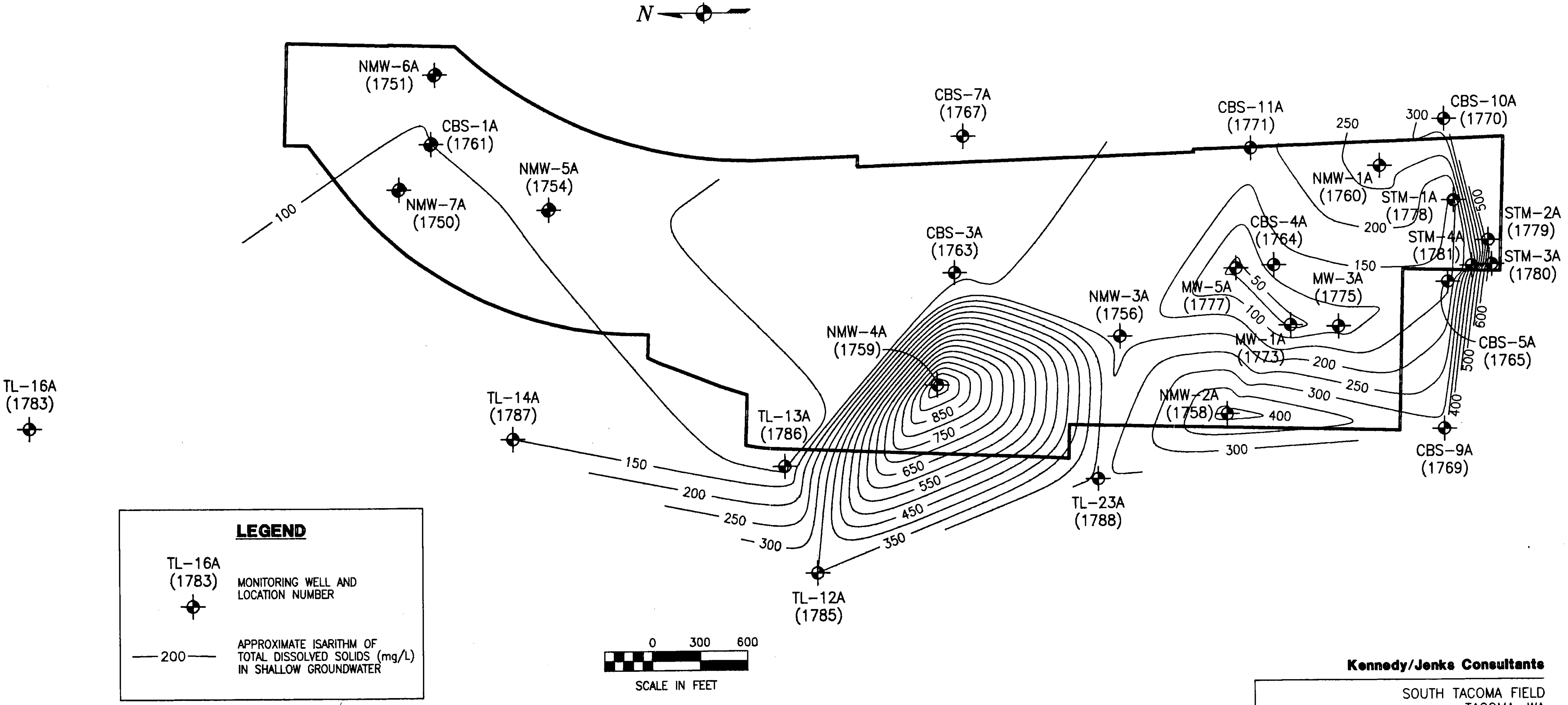
Onsite groundwater samples collected during the first and third quarters were analyzed for inorganics, PAHs, and VOCs. Onsite, background, and upgradient groundwater samples collected during the second and fourth quarters were analyzed for the full TCL suite of chemicals (i.e., inorganics, PAHs, VOCs, semivolatile organic compounds, boron, cyanide, pesticides and PCBs, TDS, TSS, and TOC). Filtered groundwater samples were collected from 12 selected wells during the third and fourth quarters and were analyzed for inorganics including boron.

Water level fluctuations of up to 17 feet were measured in the uppermost saturated zone during the RI, but sitewide annual variations of 5-10 feet were most common. Shallow groundwater quality beneath the STF shows only minimal evidence of impacts as a result of current and/or historic site activities. Current or proposed MCLs were exceeded one or more times in samples collected from 6 of the 21 onsite monitoring wells from which representative shallow groundwater samples were obtained. Eleven of 102 shallow groundwater samples (i.e., 11 percent) contained one or more chemical constituents exceeding current or proposed MCLs. Of 102 shallow groundwater samples collected during the RI, 80 were not filtered prior to analyses for inorganics and the remaining 22 were filtered. Only seven samples exceeded current or proposed MCLs for metals. Six of these samples were unfiltered samples that were analyzed for total metals concentration, and therefore, the analytical results did not differentiate metals present in/on suspended particles from dissolved metals. Only one sample that exceeded a proposed MCL (i.e., for nickel) was filtered. MCLs for one or more VOCs were exceeded in each of the four groundwater samples collected from Well NMW-1A. No significant evidence of contamination was detected in the onsite deeper saturated zone monitoring wells (NMW-3B, NMW-3C, NMW-5B, and NMW-5C).

TDS concentrations detected in samples from onsite wells ranged from 30 to 1,000 mg/L with a mean value of 246 mg/L. Fourth quarter TDS results ranged from >10 to 800 mg/L with a mean of 194 mg/L. Figures RI-5 and RI-6 show TDS contours in shallow groundwater during the second and fourth quarters. TDS variations in onsite groundwater are discussed further in Section 5.3.3.3, Groundwater Quality.

Groundwater pH values ranged from the extremes of 4.5 (NMW-4A) to 9.4 (STM-1A) with 81 percent of the measured pH values falling between 6.0 and 8.0. The remaining 19 percent of pH values were approximately evenly split between those greater than 8.0 and those less than 6.0. Figures RI-7 and RI-8 show pH contours in shallow groundwater during the second and fourth quarters. Variations in onsite groundwater pH are discussed further in Section 5.3.3.3, Groundwater Quality. Measured groundwater temperatures were generally between 10°C and 14°C.

A comparison of inorganic analyte concentrations detected in onsite wells to detected concentrations in background wells is shown in Table RI-25. Concentration of calcium, potassium, sodium, and magnesium were generally within the range of detected background concentrations and generally consistent with expected naturally occurring concentrations (Dragun 1988). Manganese concentrations were somewhat elevated in samples from several onsite wells. Both iron and manganese frequently occur at naturally high concentrations in local groundwater as result of regional geologic conditions. Samples from six wells contained elevated concentrations of iron (i.e., >3,000 mg/L) and manganese (i.e., >500 μg/L). In one well (NMW-3A), detected concentrations of iron and manganese decreased with each progressive quarter of sampling. Comparison of filtered to unfiltered sample results indicated that elevated concentrations of these metals were attributable to the presence suspended solids in the earlier sample. Another well (CBS-8A) was rejected from consideration for groundwater monitoring due to evidence of direct contamination from surface water. A third well (NMW-1A) is located at Pioneer Builders Supply. Increased formation of soluble species of manganese and iron is known to occur under reducing conditions. The



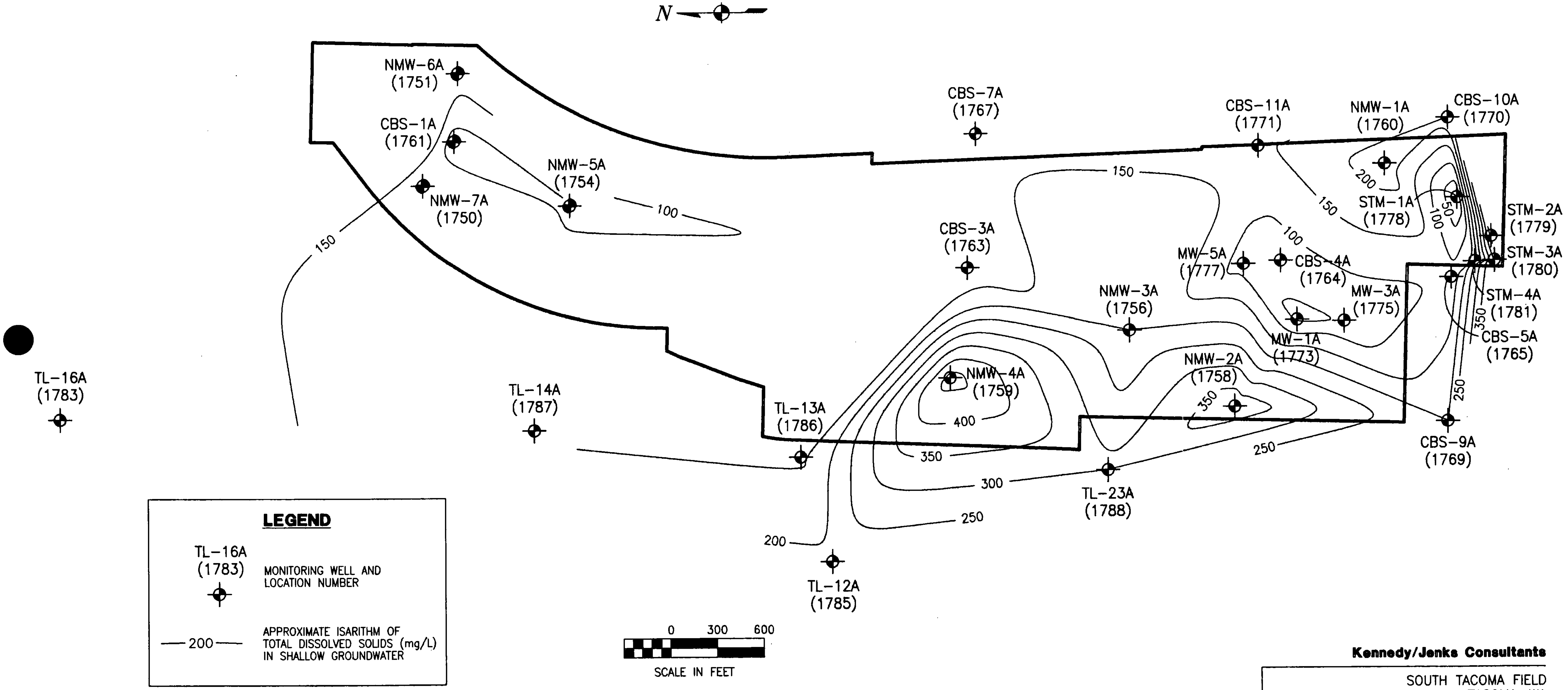
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

**SHALLOW GROUNDWATER
TDS CONCENTRATION CONTOURS
DURING JULY/AUGUST 1991**

916055.19/P2SK185

FIGURE RI-5



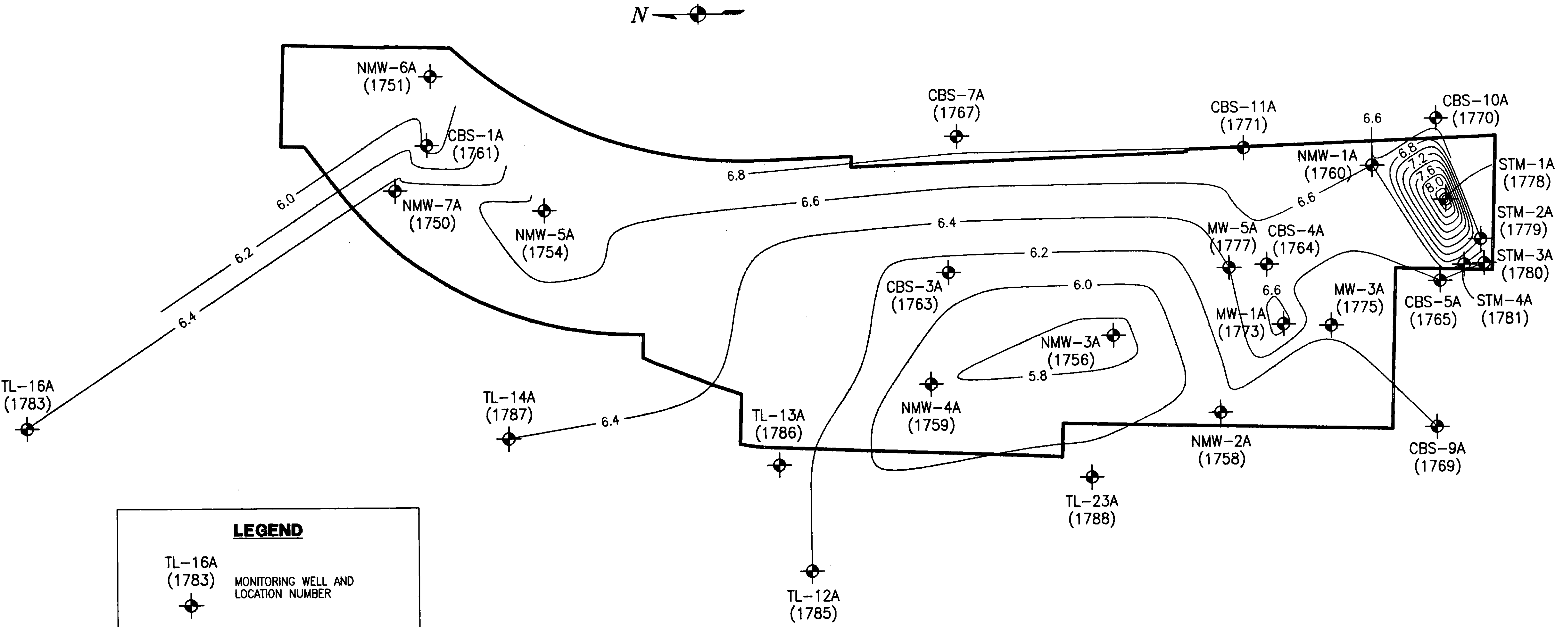
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

SHALLOW GROUNDWATER
TDS CONCENTRATION CONTOURS
DURING JANUARY 1992

916055.19/P2SK186

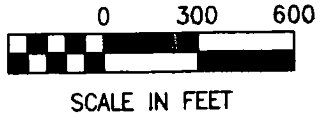
FIGURE RI-6



LEGEND

TL-16A (1783) — MONITORING WELL AND LOCATION NUMBER

—200— APPROXIMATE SHALLOW GROUNDWATER pH ISARITHM



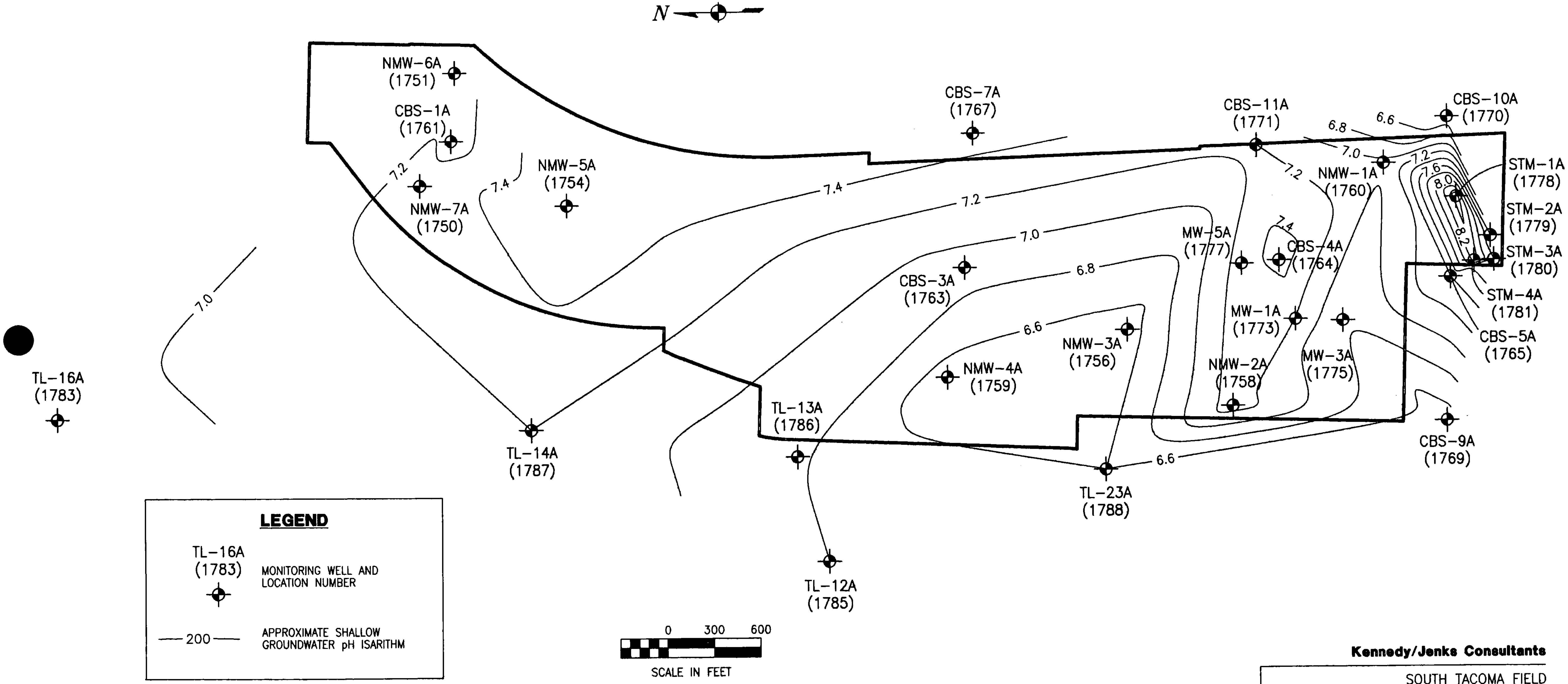
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

SHALLOW GROUNDWATER pH CONTOURS DURING JULY/AUGUST 1991

916055.19/P2SK183

FIGURE RI-7



Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

SHALLOW GROUNDWATER pH CONTOURS DURING JANUARY 1992

916055.19/P2SK184

FIGURE RI-8

presence of hydrocarbon contamination in the groundwater collected from NMW-1A suggests the possibility that microorganisms feeding on the petroleum hydrocarbons may have depleted the oxygen level in the uppermost saturated zone at this location, thereby creating reducing conditions that promote solubilization of iron and manganese. The other three wells with elevated iron and manganese are located within and adjacent to the southeast corner of the site (i.e., area of the surface water channel and/or the Former Swamp/Lakebed).

Concentrations of most other inorganics were generally within the 95% UCL of background concentrations detected in upper aquifer groundwater samples collected from wells in the northern and eastern portions of the STF site. Upper aquifer groundwater samples collected from onsite wells in the Airport and Former Swamp/Lakebed areas, the railcar cleanout area (southern end of the BNR Railyard area), and Pioneer Builders Supply contained concentrations of some inorganics that were greater than the upper bound of background concentrations. Concentrations of some inorganics detected in samples collected from upgradient wells TL-12A, TL-13A, and TL-23A were also greater than the 95% UCL of the concentrations detected in samples from background wells.

Some of the highest concentrations of inorganics (including aluminum, chromium, cobalt, copper, iron, lead, vanadium, and zinc) were detected in samples collected from offsite well CBS-10A, which is located outside the southeast corner of the site and in an area that is typically hydraulically upgradient of the site.

Concentrations of inorganics were compared to existing and proposed Federal Maximum Contaminant Levels (MCLs), Action Levels (ALs), Maximum Contaminant Level Goals (MCLGs), and Secondary Maximum Contaminant Levels (SMCLs) developed by EPA. Inorganic concentrations for samples collected from all onsite wells (except CBS-8A) that exceeded these regulatory levels are discussed below. MCLs are enforceable standards for drinking water set at levels that are protective of human health. MCLs were exceeded for the following inorganics:

- The antimony concentration detected in the unfiltered sample collected from onsite well MW-3A (located at the Amsted property) during the third quarter exceeded both of the proposed MCLs (i.e., 5 and 10 µg/L).

- The arsenic concentration detected in the unfiltered sample collected from onsite well NMW-2A during the first quarter exceeded the current MCL of 50 µg/L.

- Beryllium concentrations detected in unfiltered samples collected from onsite wells STM-3A and STM-4A during the fourth quarter exceeded the proposed MCL of 1 µg/L.

- Nickel concentrations detected in samples collected from onsite well NMW-4A exceeded the proposed MCL of 100 µg/L during the first (unfiltered), second (unfiltered), and fourth quarters.

SMCLs are nonenforceable limits intended as guidelines for use in regulating water supplies and are based on specific contaminants or water characteristics that may affect the aesthetic qualities of drinking water (i.e., color, odor, taste). SMCLs were exceeded for the following inorganics:

- Aluminum concentrations exceeded the proposed SMCL of 50 µg/L in 10 wells during the first quarter, 10 wells during the second quarter, 9 wells during the third quarter, and 4 wells during the fourth quarter. Most of the aluminum concentrations were likely caused by suspended solids, especially clay particles, in the groundwater.

- Iron concentrations exceeded the current SMCL of 300 µg/L in 15 wells during the first quarter, 9 wells during the second quarter, 13 wells during the third quarter, and 8 wells during the fourth quarter. Manganese concentrations exceeded the current SMCL of 50 µg/L in 12 wells during the first quarter, 11 wells during the second quarter, 13 wells during the third quarter, and 9 wells during the fourth quarter. As noted above, high concentrations of iron and manganese were detected in groundwater at other locations in the Puget Sound region and may be attributed to naturally occurring concentrations in groundwater (Turney 1986).

In addition to unfiltered samples required by the Work Plan (ICF 1990b), field-filtered groundwater samples were collected from 12 wells during the third and fourth quarters. The filtered samples were analyzed for total metals to allow comparisons with unfiltered samples. These comparisons were used to assess whether metals were present as dissolved constituents in groundwater or as suspended solids. Although groundwater samples were analyzed for TSS during the second and fourth quarters, the high detection limit for TSS (10 mg/L) prevented a direct comparison of TSS with metals concentrations.

The 12 wells from which samples were collected for filtered analyses were selected based on previous analytical results of metals. In general, wells were selected where previous results showed higher metals concentrations than other onsite wells.

Aluminum was the only metal consistently detected at lower concentrations in filtered samples than in unfiltered samples. This is attributed to the presence of clay minerals as suspended solids in the groundwater samples. Aluminum was not detected in any filtered groundwater samples collected during the third and fourth quarters.

In NMW-5A, NMW-3A, NMW-3B, and MW-3A, iron was not detected in filtered samples or was detected at lower concentrations in filtered than in unfiltered samples. Filtering did not make an appreciable difference in the iron concentrations detected in samples from NMW-3C, NMW-2A, NMW-4A, NMW-1A, and CBS-9A.

Manganese concentrations were generally lower in filtered samples from NMW-3A and NMW-5A compared to unfiltered samples. Manganese concentrations for samples from other wells did not vary appreciably as a result of filtering.

Other metals such as boron and calcium were present at nearly the same concentrations in filtered vs unfiltered samples during the third and fourth quarters.

Potential anthropogenic sources for the inorganics that were detected in the Airport and Former Swamp/Lakebed areas include leaching of fill material deposited in the Former Swamp/Lakebed area, infiltration of surface water from onsite and offsite sources, and offsite sources including the Tacoma Landfill and the neighboring demolition debris landfill. Potential anthropogenic sources for the inorganics detected in samples collected from the railcar cleanout area include calcium and magnesium from lime deposits from cleaning of railcars, and zinc from galvanized well casing material. The maximum detected zinc concentration of 726 μg/L in the first quarter sample from STM-2A was over one order of magnitude greater than subsequent samples and should be regarded as anomalous.

PAHs were detected in groundwater samples collected from eight onsite monitoring wells during this investigation (excluding results from CBS-8A). However, in seven of these eight wells, anthracene was the only PAH detected, and at trace concentrations that are suspected to be attributable to laboratory contamination based on the detection of anthracene in laboratory method blanks. PAHs detected in samples collected from the remaining onsite well (NMW-1A at Pioneer Builders Supply) included naphthalene, acenaphthene, fluorene, and phenanthrene. Except for naphthalene, PAH concentrations were generally low (i.e., <5 μg/L). Carcinogenic PAHs were not detected in groundwater samples collected from onsite wells during this investigation. MCLs, MCLGs, and SMCLs do not exist and have not been proposed for the PAHs detected in onsite groundwater samples collected during this investigation.

VOCs were generally not detected in upper aquifer groundwater samples from wells in the northern and extreme southern portions of the STF site. Onsite well NMW-1A at Pioneer Builders Supply contained the highest concentrations of VOCs detected during this investigation. Detectable concentrations of benzene (86-480 μg/L), toluene (51-770 μg/L), ethylbenzene (150-1,000 μg/L), and xylenes (141-2,300 μg/L) were consistently detected in samples from NMW-1A. Low concentrations of VOCs (usually less than 10 μg/L) were detected in some onsite wells in the southern portion of the site (i.e., CBS-3A, MW-1A, MW-3A, MW-5A, NMW-2A, NMW-3A, STM-3A, and STM-4A). Low concentrations of VOCs were also detected in offsite and upgradient wells TL-12A and CBS-10A and in background wells TL-16A and WCC-2. Concentrations of ethyl benzene and 1,1,2-trichloroethane in one groundwater sample collected from NMW-1A exceeded the existing MCL or proposed MCL during one quarter. Concentrations of benzene in NMW-1A exceeded the existing MCL. Concentrations of toluene, ethyl benzene, and xylene (all are normally associated with gasoline) in NMW-1A exceeded the proposed SMCLs during all four quarters.

A few non-PAH semivolatile organic compounds were detected at low concentrations in NMW-1A during the second, third, and fourth quarters and in NMW-2A during the fourth quarter. These semivolatiles were 4-methylphenol (17 μg/L), 2,4-dimethylphenol (61 μg/L), 2-methylnaphthalene (15-47 μg/L), bis(2-ethylhexyl)-phthalate (0.7-7 μg/L), and diethylphthalate (2 μg/L). Semivolatiles were detected in one offsite upgradient well (TL-12A) during the second and fourth quarters. Semivolatiles were detected in one background well during the fourth quarter. The concentration of bis(2-ethylhexyl)phthalate exceeded the proposed MCL of 4 μg/L in NMW-1A during the third quarter. Comparison of the remaining results for bis(2-ethylhexyl)phthalate were not possible because the detection limit exceeded the MCL of 4 μg/L and the MCLG of 0.

Pesticides and PCBs were not detected in groundwater samples collected from onsite, background, or upgradient wells during this investigation.

5.3.2 Hydraulic Characterization Investigation

The purpose of the Hydraulic Characterization Investigation was to evaluate selected hydraulic characteristics of subsurface water producing units at the STF site. The complete Hydraulic Characterization Report is contained in Appendix HC. The primary objectives of this investigation were to:

- Evaluate the aquifer characteristics (transmissivity, hydraulic conductivity, storativity) for three separate aquifer zones beneath the site by performing aquifer pumping tests and slug tests

- Evaluate potential inter-aquifer communication between the shallow (uppermost) groundwater zone and the lower-lying zones of saturation by monitoring water level changes induced by an aquifer test at an offsite production well

- Evaluate seasonal fluctuations in the hydraulic gradient within Layer A at the site by monitoring water levels on a monthly basis.

The following task were completed during this investigation:

- Evaluated the monthly water level measurements for 30 monitoring wells, which were monitored for 12 consecutive months as part of the Groundwater Investigation

- Conducted two aquifer pumping tests in shallow onsite wells

- Conducted slug tests at 16 wells across the site

- Monitored water levels in onsite wells during the performance of an aquifer test at an offsite production well.

Five hydrostratigraphic layers have been identified at the STF site and are composed of members of the five geologic units listed in Table RI-26 (Brown and Caldwell 1985). The hydrostratigraphic layers, the sequence in which they were encountered during the RI, and their correlations to lithologic units identified in central Pierce County are summarized in Table RI-26. Further discussion of hydrostratigraphy is presented in Section 3.6

TABLE RI-26

SUMMARY OF HYDROSTRATIGRAPHIC LAYERS

Hydrostratigraphic Layer	Unit Designation	Unit Thickness (ft)[a]	Soil Description
Upper Layer A	Vashon Drift (Colvos Sand Member)	62-101	Poorly graded sand with silt and gravel.
Layer A_1	Discovery Nonglacial Unit Narrows Glacial Unit	0-33 6-12.5	Clay, silt and sand. Silt.
Lower Layer A	Narrows Glacial Unit	59-67.5	Gravel.
Layer B	Kitsap Formation	2-15	Silt and clay.
Layer C	Flett Creek Glacial Unit	100[b]	Cobbles and gravel.

(a) Unit thicknesses are based on field observations made during the STF Phase I Groundwater Investigation, Kennedy/Jenks Consultants (1992a).

(b) Layer C was penetrated approximately 25 feet during the STF Phase I Groundwater Investigation.

Results of the hydraulic characterization are summarized below.

5.3.2.1 Water Level Monitoring. Available information indicates that the STF site lies in the vicinity of a regional groundwater mound of the uppermost aquifer that is oblong in shape and oriented from north to south (Griffin et al. 1962; Brown and Caldwell 1985). The axis of the mound forms a regional groundwater divide and the presumed direction of groundwater flow is east on the east side of the mound and west on the west side of the mound. The mound is likely caused by convergence of groundwater flow from north and south of the South Tacoma Channel and significant recharge of surface water at the site. In the central portions of the mound, the direction of the hydraulic gradient is toward the north to northeast.

The results of water level monitoring during the STF RI are consistent with the groundwater regime described in the available literature.

Results of monthly water level monitoring at the STF site, over a 1-year period, indicate that the predominant direction of the hydraulic gradient in Upper Layer A, and presumed direction of shallow groundwater flow, is toward the north to northwest. The magnitude of the hydraulic gradient fluctuates both spatially and seasonally from 0.0004 to 0.001 ft/ft in the central portion of the site during non-pumping conditions. Spatial variations that have been observed include a steep dip in the hydraulic gradient in the southwestern portion of the site that trends to the southwest and a small groundwater mound in the vicinity of the Amsted property. The cause of the mound is unknown. Water level monitoring indicates that the hydraulic gradient in Layer C is also toward the northwest at the STF site.

Pumping of shallow groundwater (Upper Layer A) by municipal wells to the east of the site has a significant impact on the direction of groundwater flow at the STF site. During the summer months, a cone of depression extends from the pumping wells to beyond the western property boundary of the site. As a result of pumping, a seasonal reversal of the hydraulic gradient occurs on the eastern side of the Tacoma Landfill investigation area.

There is a net downward vertical gradient from Upper Layer A to Lower Layer A. The head differential between these two zones of saturation ranged from a minimum of 0.51 feet at Well Cluster NMW-3 in the wet season to maximum of 39.39 feet in Well Cluster NMW-5 during the dry season. A net downward vertical gradient exists between Lower Layer A and Layer C. This head differential ranged from 0.27 feet in Well Cluster NMW-3 during the wet season to 27.87 feet in Well Cluster NMW-5 during the dry season. The exaggerated head differences during the summer months is a result of pumping of municipal wells in the vicinity of the site.

5.3.2.2 Aquifer Pumping Tests and Slug Tests. The results of the two aquifer pumping tests performed in Upper Layer A indicate that transmissivity values range from 67,000 gpd/ft to 71,000 gpd/ft (corresponding hydraulic conductivity values range from 1,100 to 1,200 gpd/ft^2) at Wells NMW-4A and NMW-3A, respectively. The specific yield for the Upper Layer A ranged from 0.001 to 0.036 depending on which analysis method was used. The Newman (unconfined) (1975) solution method matched conditions of the aquifer test the best; however, resulted in anomalously low specific yield values. More accurate specific yield values (0.034 to 0.036) were obtained using the Cooper-Jacob (1946) solution method. The estimated seepage (horizontal groundwater flow) velocity ranged from 60 ft/yr to 150 ft/yr.

Slug tests conducted during this investigation indicate that transmissivity values are one to two orders of magnitude less than those values calculated through performance of aquifer tests. The anomalously low transmissivity values calculated through slug tests may be attributed to the high hydraulic conductivity of the formation and the possibility that slug tests may only test the hydraulic characteristics of the well filter pack.

5.3.2.3 Inter-Aquifer Communication. Statistical analyses of monthly groundwater level monitoring data were inconclusive in identifying areas of enhanced leakage from Upper Layer A to the lower-lying zones. Qualitative evaluation of water level monitoring hydrographs shows that significant head fluctuations occur in Lower Layer A (Wells NMW-3B and NMW-5B) during seasonal groundwater removal in Layer C, indicating communication between the two zones of saturation. Based on qualitative evaluation, it appears that communication between the two zones is greater in the south at Well NMW-3C, and less in the northern portion of the site at Well NMW-5C. This corresponds with lithologic conditions that indicate Layer B is approximately 2 feet thick at Well NMW-3C and 15 feet thick at Well NMW-5C. Hydrographs also indicate little head fluctuation between Upper Layer A and Lower Layer A, indicating limited, if any, communication between the two zones of saturation. Lithologic information indicates that Layer A_1 was approximately 37 feet thick at Well Cluster NMW-3 and 6 feet thick at Well Cluster NMW-5. Although quantification of the vertical conductivity of Layer A_1 was not possible with available information, lithologic information and the water level monitoring data suggest that this unit may act as an effective confining layer between Upper Layer A and the underlying relatively permeable zones.

Analysis of aquifer test data from Well TAC 1A (located approximately 1 mile southeast of the site) indicate leakage from Lower Layer A to Layer C in the vicinity of Well Clusters NMW-3 and TAC 89.5. Estimates of vertical conductivity for Layer B at these two locations ranged from 1.34×10^{-3} ft/day to 4.44×10^{-4} ft/day, respectively. These conductivity values are approximately 6 to 7 orders of magnitude lower than conductivity values calculated for Layer C. Test results for Well Cluster NMW-5 were influenced from operation of heat pump wells at Tacoma Public Utilities and cannot be used to estimate possible leakage in the northern portion of the STF site.

5.3.2.4 Groundwater Recharge. Onsite recharge to Upper Layer A is from percolation of precipitation and surface water runon. Using a reported annual precipitation of 37.06 inches and an evaportranspiration rate of 21 inches per year (Brown and Caldwell 1985), approximately 114,000,000 gallons of water might percolate to groundwater from precipitation. Based on the estimated size of the drainage basin, net surface water runon from offsite sources was estimated at approximately 85,000,000 gallons per year (Kennedy/Jenks Consultants 1992c). Using a rough estimate of 60 percent evaportranspiration, an estimated 34,000,000 gallons of surface water runon might percolate through the vadose zone and eventually recharge groundwater annually. Therefore, total recharge to shallow groundwater from surface water runon and precipitation is estimated at approximately 148,000,000 gallons annually. It should be noted that this is an approximated recharge value.

Approximately 2.02 billion gallons of water are held in storage in interstitial spaces of the porous media of the Upper Layer A. This calculation is based on the following assumptions:

- Site area is approximately 262 acres
- Upper Layer A has an average saturated thickness of 65 feet
- Average effective porosity is 36.5 percent.

The estimated volume of annual recharge (approximately 148 million gallons) amounts to less than 8 percent of the volume of water held in storage in Upper Layer A.

5.3.3 Saturated Zone Findings and Conclusions

The water quality and hydraulic characteristics of saturated zones below the STF site have been characterized through installation, water quality and water level monitoring, and testing of monitoring wells. The substantive findings and conclusions of these activities are summarized below.

5.3.3.1 <u>Stratigraphic Conditions</u>. The stratigraphic conditions identified below the STF site during drilling activities are consistent with the reported regional stratigraphic conditions. As a result, lithologic conditions encountered beneath the STF site appear to be the same as those identified to the west below the Tacoma Landfill and to the east in the wellfield used by Tacoma Public Utilities.

Three aquifer zones and two confining layers were identified as part of subsurface investigative activities. These hydrostratigraphic units include:

- Upper Layer A (aquifer)

- Layer A_1 (confining layer)

- Lower Layer A (aquifer)

- Layer B (confining layer)

- Layer C (aquifer).

The aquifer zones identified below the STF site include Upper Layer A, Lower Layer A, and Layer C. These units are typically characterized as coarse-grained units composed of cobbles, gravel, and/or sand with little or no fine-grained particles. The aquifer zones have been assigned relatively high hydraulic conductivity values ranging from approximately 300 to 3,000 gpd/ft^2 (Brown and Caldwell 1985). The confining layers include Layer A_1 and Layer B which are typically composed of silt and clay-sized particles. Aquifer testing activities performed during the RI confirm the reported range of hydraulic conductivity values for the aquifer zones and indicate that the confining layer (Layer B) between Lower Layer A and Layer C may have a hydraulic conductivity values that is up to 6 orders of magnitude lower that the overlying and underlying aquifer zones.

The lateral continuity (throughout the site) of each of the aquifer zones and confining layers that have been identified at STF cannot be confirmed on the basis of available information. Available information indicates that Layer A_1 is not laterally continuous to the east of the STF site (Brown and Caldwell 1985). In this area, Upper Layer A and Lower Layer A form a single aquifer zone. Layer A_1 was observed to be significantly thinner (approximately 6 feet thick) in the northern portion of the site at Well NMW-5C than was observed in the southern portion of the site at Well NMW-3C where Layer A_1 was observed to be approximately 37 feet thick. Regionally, Layer B has been observed at thickness of over 100 feet, however, below the STF site Layer B was observed to range in thickness from 2 to 15 feet.

5.3.3.2 Groundwater Flow Regime. The regional groundwater system of the uppermost aquifer in the vicinity of the STF site is dominated by the prevailing lithologic and recharge conditions of the area. The STF site is located within a geomorphic structure known as the South Tacoma Channel. The structure is representative of a outwash channel created during the Vashon Glaciation. As a result, sediments within the South Tacoma Channel have a higher hydraulic conductivity than the surrounding sediments (Griffin et al. 1962). Because groundwater moves in the direction of least resistance through a formation, it is assumed that groundwater will flow more readily through the South Tacoma Channel than it will perpendicular to the South Tacoma Channel.

Groundwater recharge also plays a significant role in the understanding of the regional flow regime in the vicinity of the STF site. The area to the south of the South Tacoma Channel dominates recharge of the South Tacoma Channel. As a result the, predominant direction of the hydraulic gradient south of the STF site is to the north to northwest. Groundwater recharge north of the South Tacoma Channel has also been observed. The hydraulic gradient in this area is to the south. These two recharge sources in the South Tacoma Channel converge in the vicinity of the STF site. As a result of convergence of groundwater flow and due to significant surface water recharge, a groundwater mound is formed beneath the STF site. The groundwater mound has north-south orientation parallel to the South Tacoma Channel. The assumed direction of groundwater flow to the east of the mound is to the east and the assumed direction of groundwater flow to the west of the mound is to the west. The north-south axis of the STF site is generally indicative of the divide between flow to the east and flow to the west. This divide changes seasonally due to varying recharge conditions and as a result of groundwater pumping to the east of the STF site. The presumed direction of groundwater flow within the groundwater mound is to the north-northwest in the direction of the hydraulic gradient. Estimated horizontal groundwater flow velocities for Upper Layer A ranged from 60 ft/yr to 150 ft/yr.

Variations in the hydraulic gradient at the site are caused primarily by groundwater pumping from water supply wells to the east of the site by Tacoma Public Utilities. These water supply wells are completed in both Upper Layer A and in Layer C. Pumping of Upper Layer A water supply wells results in a cone of depression that extends across the STF site and into the Tacoma Landfill study area. During pumping, the hydraulic gradient of the uppermost aquifer at the site changes from northwest to east toward the water supply wells.

Seasonal fluctuations in water level elevations of Upper Layer A occurred throughout the site. Water levels are typically at their lowest in August and September and at their highest in March and April. Yearly water level fluctuations in Upper Layer A were observed to vary by as little as 3 feet at CBS-9A to as much as 17 feet at CBS-3A.

Water level information obtained during the RI indicates that there is a net downward gradient between each of the three aquifer zones. During the summer months when the potentiometric surface of Layer C is at its lowest, the head differential between aquifer formations is the greatest. Water levels of Lower Layer A follow the drop in head observed in Layer C and the head fluctuations were similar in magnitude. Upper Layer A does not exhibit this same response.

Through performance of aquifer tests and water level monitoring during the RI, there appears to be leakage from Lower Layer A through the confining layer (Layer B) to Layer C. The amount of leakage through Layer B cannot be accurately estimated. However, because there is approximately six orders of magnitude difference between the conductivity of aquifer zones (i.e., Lower Layer A and Layer C) and the intervening confining layer (Layer B), the leakage rate is expected to be low. Results of the aquifer tests and the water level measurements also indicate little or no leakage from Upper Layer A to Lower Layer A. Therefore, Layer A_1 is expected to act as an effective confining layer at the STF site to inhibit vertical movement of shallow groundwater and soluble contaminants, if any, to lower lying aquifer zones.

5.3.3.3 Groundwater Quality. As indicated above, three aquifer zones have been investigated as part of the RI. Investigation of groundwater quality focused on the uppermost aquifer zone (i.e., Upper Layer A) with sampling of 26 monitoring wells. However, groundwater occurring in lower-lying aquifer zones (Lower Layer A and Layer C) were also investigated to a lesser extent with the installation and sampling of two onsite wells installed in each of these zones. Chemical constituents and parameters included in the analyses of groundwater samples and the frequency of these analyses are summarized in Section 5.3.1.

Based on available information collected during the RI, only localized areas of shallow groundwater exhibit variations in chemical quality that suggest possible impacts resulting from current and/or historical site activities. No significant evidence of contamination was detected in the onsite deeper saturated zone monitoring wells (NMW-3B, NMW-3C, NMW-5B, and NMW-5C). This conclusion is supported by the following observations:

- With the possible exception of the former tank removal excavation at Pioneer Builders Supply, established chemical plumes in shallow groundwater were not detected and concentrations of chemical analytes detected in background samples were generally comparable to concentrations detected in onsite groundwater samples.

- Relatively low levels of TDS detected in groundwater throughout most of the site. Areas with slightly elevated TDS concentration in groundwater were the extreme southern portion of the site, and the wetlands and the Former Swamp/Lakebed areas.

- pH measurements were near neutral for groundwater throughout most of the site. Slightly acidic pHs were detected in shallow groundwater in the wetlands and Former Swamp/Lakebed areas. Elevated pHs were typical of groundwater samples collected in the extreme south end of the BNR Railyard.

These general observation and exceptions to them are discussed below.

The distribution of chemical constituents detected in groundwater is reported in Appendix GW. Groundwater analytical results for VOCs, semivolatile organic compounds, inorganics, pesticides/PCBs, boron, and cyanide do not indicate the presence of a sitewide plume or appreciable regional impact to groundwater. Four localized areas of the site where appreciable variations in shallow groundwater chemical quality were detected are summarized below.

The first area is the Pioneer Builders Supply property where the concentrations of ethyl benzene, 1,1,2-trichloroethane, and benzene were detected at concentrations above the MCLs. The source of chemicals in groundwater at this location may be soil contamination attributed to a release(s) from the former USTs that have been removed from this area. Analytical results for groundwater samples at this location also indicate the presence of low levels of PAHs and elevated iron and manganese. Iron and manganese are likely a result of reduced subsurface conditions caused by the presence of petroleum hydrocarbons.

The second and third areas include contiguous portions of the Airport and Former Swamp/Lakebed areas, and the former railcar cleanout area in the south end of the BNR Railyard. Concentrations of some inorganic constituents (primarily iron and manganese) in these areas were detected at levels exceeding the 95% UCL of background concentrations. Although the reason for elevated metal concentrations is unclear, naturally high concentrations of these metals occur locally as a result of surrounding geologic conditions. A study performed in the vicinity of the Tacoma Landfill indicated that iron and manganese concentrations in the study area were generally above available EPA drinking water standards (Lum and Turney 1985). Other factors that may lead to elevated metal concentrations in the Former Swamp/ Lakebed and Airport areas include 1) enhanced leaching of metals due to weak organic acids produced by decaying organic matter in nearby wetlands areas, 2) infiltration of dissolved contaminants from surface water runon, and 3) the presence of laterally extensive layers of fill materials placed in the Former Swamp/

Lakebed areas. An additional source of these metals may be the Tacoma Landfill to the west of the site where concentrations of metals exceeding background have been detected in groundwater. pH conditions in soil in the former railcar cleanout area also cause a local variation in water quality as discussed below.

The fourth area includes the Amsted property where a relatively small volume of (low miscibility) heavy fuel oil was encountered floating on the surface of the water table. The hydrocarbon contamination in this area is being investigated under a separate Consent Order with EPA (Region 10).

TDS concentrations of site groundwater ranged from 30 to 1,000 mg/L with a mean value of 246 mg/L. TDS provides a general indication of the water quality. Elevated TDS concentrations may indicate areas where soluble contaminants are being continuously released. For example, TDS concentrations of up to 42,000 mg/L have been reported in sanitary landfill leachates (EPA 1978). The TDS of natural groundwater typically ranges from 0 to 1,000 mg/L (Freeze and Cherry 1979).

As a general rule, TDS concentrations in shallow onsite groundwater are equal to or less than the TDS detected in background wells in the vicinity of the site. Contour maps of the site indicate TDS values in groundwater of Upper Layer A were generally below 200 mg/L. Three areas exist where TDS values were in excess of 200 mg/L. These include Pioneer Builders Supply, the Airport area and adjacent Former Swamp/Lakebed, and the railcar cleanout area. These areas coincide with the areas discussed above where concentrations of metals above background levels have been detected.

Hydrogen ion concentration (pH) provides another means to evaluate general groundwater quality at the site. Most groundwater across the United States have pH values that range from approximately 6.0 to 8.5 (Hem 1989). Values of pH in groundwater at the STF site ranged from 4.5 to 9.4. Eighty-one (81) percent of the measured pH values were between 6.0 and 8.0. The lowest pH values were typically detected in the vicinity of the Former Swamp/Lakebed. In these areas, it is believed that weak organic acids (e.g., humic and fulvic acids) formed through the degradation of organic material in the wetlands areas may be the source of these low pH values. The highest pH values were typically detected in the vicinity of the railcar cleanout area where lime was found at the ground surface and is believed to be the cause of the high pH values detected in groundwater samples collected from this portion of the site.

In summary, groundwater below the STF site is generally of good quality. Historical site use resulting in the presence of elevated metals and PAH concentrations in surface soil do not appear to have an appreciable or widespread impact on groundwater quality at the site. Four areas have been identified with discernible chemical impact to groundwater. At two of these areas (Pioneer Builders Supply and the Amsted property), chemical impacts appeared to be very localized and there was no indication of a extensive chemical plume. At the Airport and Former Swamp/Lakebed areas, metals (primarily iron and manganese) concentrations exceeded background levels. The presence of fill in the Former Swamp/Lakebed area and the subsurface environmental condition associated with the perennial wetlands may contribute to the availability and dissolution of metals, respectively, in the shallow groundwater in these areas. However, available information suggests that elevated concentrations of iron and manganese also may occur naturally in groundwater in the vicinity of the STF site (Van Denburgh and Santos 1965; Turney 1986).

TABLE RI-25

COMPARISON OF INORGANIC ANALYTE CONCENTRATIONS DETECTED IN ONSITE WELLS TO NATURALLY OCCURRING CONCENTRATIONS IN GROUNDWATER AND CONCENTRATIONS DETECTED IN BACKGROUND WELLS

Analyte	Range of Concentrations in Onsite Wells (µg/L)	Naturally Occurring Concentrations in Groundwater (µg/L)(a)	Range of Concentrations in Background Wells (µg/L)(b)
Al	<16.0 - 5,940	<5.0 - 1,000	<16.0 - 10,500
Sb	<11.0 - 50.7	<100(c)	<11.0 - <20.0
As	<1.0 - 50.9	<1.0 - 30 (4,000)	<1.0 - 9.0
Ba	<2.0 - 500	10 - 500	<2.0 - 159
Be	<1.0 - <2.3(d)	<10	<1.0
B	20.2 - 1,940	20 - 1,000 (5,000)	<19.0 - 184
Cd	<1.0 - <3.0	<1.0	<1.0 - <4.6
Ca	3,470 - 109,000	1,000 - 150,000	9,490 - 78,300
Cr	<3.3 - 9.9	<1.0 - 5.0	<5.0 - 41.1
Co	<3.0 - 218	<10	<3.0 - 16.1
Cu	<1.0 - 19.7(d)	<1.0 - 30	<1.0 - 112
Fe	<11.0 - 31,000	10 - 10,000	13.6 - 28,800
Pb	<0.7 - 58.9	<15	<1.0 - 33.4
Mg	1,300 - 93,800	1,000 - 50,000	6,440 - 48,300
Mn	<1.0 - 5,200	<1.0 - 1,000	<1.0 - 896
Hg	<0.1 - <0.4	<1.0	<0.2
Ni	<6.7 - 1,950	<10 - 50	<8.0 - <44.0
K	<643 - 6,940	1,000 - 10,000	1,080 - 8,280
Se	<1.0 - 26.8(d)	<1.0 - 10	<1.0 - <30.0
Ag	<3.0 - 10.6	<5.0	<4.0 - <6.0
Na	3,500 - 234,000	500 - 120,000	5,190 - 514,000
Tl	<1.0 - <7.5	<100(c)	<1.0 - 2.2
V	<3.3 - 30.5	<1.0 - 10	<4.0 - 36.5
Zn	<2.0 - 726	<10 - 2,000	<2.0 - 170

(a) Dragun (1988). Numbers in parentheses are extreme values of naturally occurring elements.
(b) Includes second and fourth quarters of background well sampling.
(c) Freeze and Cherry (1979).
(d) For some analytical results, U qualifier indicates that U value exceeded maximum value shown. Upper limit of Be values was <2.6. Upper limit of Cr values was <41.1 for background and <21.5 for onsite. Upper limit of Cu values was <21.0. Upper limit of Se values was <30.0.

6.0 CHEMICAL FATE
AND TRANSPORT

6.0 CHEMICAL FATE AND TRANSPORT

This section describes the fate and transport of chemicals of concern at the STF site. In general, chemical fate refers to the ultimate disposition of the chemical of concern and to the movement and/or transport processes that cause the chemical to reach this disposition. For example, the fate of a hydrocarbon compound may be its transformation (mineralization) to carbon dioxide and water through bio-oxidation. In the case of some inorganic chemicals (elements) that merely move through cycles within the environment, the concept of ultimate disposition is less important than relative mobility. Under some circumstances, identifying an element's fate may mean identifying the point in the element's cycle in which the its residence time at an identified location is sufficiently long for it to be regarded as stationary (immobile) for practical purposes.

Transport mechanisms are defined as those physical or chemical mechanisms that result in the movement of a chemical of concern from one location to another within environmental media (soil, water, or air). Examples of physical transport include movement of suspended soil particles containing adsorbed chemicals through soil pores, surface water, or air. Other examples involve mechanisms such as chemical dissolution and leaching from soil, and subsequent movement of the mobile chemical species in groundwater. The chemicals of concern addressed in this RI Report are those chemicals present in soil or water at the site that have been identified by EPA as warranting further evaluation using a risk-based screening methodology (EPA 1992a,b,c).

Section 6.1 presents the chemicals of concern identified by EPA along with their physical and chemical properties followed by a general evaluation of factors affecting chemical movement and transformation in the environment. Due to the variety of chemicals of concern identified at STF and complexity of the factors potentially affecting their fate and transport, the general evaluation presented in

Section 6.1 contains considerable detail. Processes affecting the mobility and fate of both organic and inorganic chemicals are discussed. All of the processes discussed occur at the site to varying degrees, however, some are much more important than others.

Section 6.2 examines possible routes of chemical migration at the STF site, and considers the various factors affecting chemical fate and mobility in terms of their relative importance. The potential routes of migration evaluated are:

1. Erosion and surface water migration pathway

2. Air migration pathway

3. Unsaturated zone migration pathway

4. Saturated zone migration pathway.

In general, it is concluded that the chemical migration along these pathways is likely to be very limited due to the nature of the physical environment at the site and the chemicals present. The potential for offsite movement or redistribution of soil and sediment particles by surface water or wind erosion is minimal. While leaching of chemicals of concern may induce some vertical migration in the unsaturated zone, a number of different mechanisms serve to either retard or effectively immobilize many chemicals in the unsaturated soil. Groundwater movement in the saturated zone might induce lateral migration of chemicals of concern, however, significant vertical groundwater flow does not appear to be present. As with the unsaturated zone, a number of mechanisms serve to impede the movement of all but the most mobile chemicals (e.g., VOCs) in groundwater. The complexity and dynamics of the mechanisms governing chemical fate and transport in the uppermost saturated zone beneath the site make accurate quantitative modeling of these mechanisms and prediction of the resultant effects on groundwater quality impossible. However, existing groundwater quality data for onsite wells provide a useful indication of the cumulative effects of the mechanisms on groundwater quality given that the chemicals of concern have likely been resident in onsite soil and sediment for many years. Existing shallow groundwater data for the STF site show little evidence of degradation by industrial chemicals detected in site soils. VOCs exceed MCLs in samples from monitoring well NMW-1A (Pioneer Builders Supply) and one sample collected from NMW-4A (Airport area) contained a dissolved nickel concentration that was slightly over twice the proposed MCL.

Finally, Section 6.3 presents the evaluation of migration potential for chemicals of concern along those pathways that have been identified in preceding section as being potentially significant in terms of chemical transport. The evaluation includes consideration of:

1. The potential movement rate and chemical composition of water percolating through the unsaturated zone (soil solutions) and into the saturated zone

2. The potential capacity of unsaturated soil to retain metals through cation exchange

3. The estimated migration rates for organic chemicals of concern in the subsurface

4. The potential effects of the chemicals of concern present in surface water runon and sediment on the onsite surface water channel area.

By comparing calculated ionic species concentrations in a soil solution (based on soil solubility equilibrium data) with data from batch extraction tests (namely MWEP and TCLP) performed on samples of contaminated STF soil, it was concluded that soil mechanisms other than thermodynamic solubilities alone control the ultimate concentration of soluble chemical species in onsite soil solutions.

A sitewide comparison of estimated leachable metal cation amounts to the cation exchange capacity (CEC) of the unsaturated zone was performed. Based on this comparison, subsurface soil throughout the majority of the site contains many times the capacity theoretically required to retain (by cation exchange reactions) the metals leached from surface and near-surface soil.

Estimated migration rates for VOCs and semivolatile organics in the STF subsurface are considerably greater than those estimated for the higher molecular weight organics. This is consistent with the known behavior of all these chemicals in soil/water systems and the fact that they were detected locally in groundwater during the RI. The potential dissolution and movement rates of PCBs and PAHs in soil and sediment at the site were concluded to be negligible.

Finally, the evaluation of metals loading from runon to the onsite surface water channel led to the conclusion that such loading does not appear to represent a significant potential impact to the sediment in the channel area. When the average annual concentration increase due to runon over the volume of sediment theoretically subject to loading is considered, the effects on metals concentrations are relatively small.

6.1 CHEMICAL CHARACTERISTICS AND ENVIRONMENTAL BEHAVIOR

This subsection identifies the chemicals of concern, the physical/chemical properties, and their general characteristics with respect to environmental mobility and fate.

6.1.1 Chemicals of Concern Present at the STF Site

Chemicals detected in environmental samples collected from the STF site originated from many sources as described in Section 2.2.

Because of the variety of activities conducted at the site that could have resulted in the release of chemicals into the environment, the scope of the RI included extensive environmental and laboratory analyses of samples by methods capable of detecting a broad spectrum of possible chemicals of concern. Selected analytical methods provided the capability of detecting previously identified and suspected chemical contaminants, as well as a wide variety of other possible chemicals of concern. Based on the findings of the RI field investigations, EPA selected a number of chemicals of concern for surface soil, groundwater, and air using a risk-based screening methodology. The union of these chemicals of concern are categorized as inorganics or organics and are presented in Table RI-27.

6.1.2 Chemical Properties

Certain chemical properties strongly influence the fate and mobility of a chemical in soil, surface water, and groundwater. Data on selected properties are critical for understanding or estimating water chemistry, which in turn, may explain the presence or absence of chemicals at onsite and downgradient areas. Consideration of fate and mobility properties is also essential for predicting behavior of chemicals at a site during or after remediation activities.

This section provides information regarding selected chemical properties that are important to chemical fate and mobility. Selected properties for each of the chemicals of concern are provided in Tables RI-28 and RI-29. An explanation of these properties is briefly discussed below. Because of the variety of possible forms in which metals may occur in the environment and the lack of information regarding the speciation of individual metals at the STF site, the chemical properties presented in Table RI-28 are for the metals of concern in their elemental forms.

6.1.2.1 Chemical Identification and Molecular Weight. Each chemical of concern is identified by its name and, for organics, empirical formula in Table RI-29. A molecular or atomic weight (g/mole) of the chemical is also listed in Table RI-29.

TABLE RI-27

CHEMICALS OF CONCERN FOR THE STF SITE[a]

Inorganics	Organics
Aluminum	Chloroform
Antimony	Tetrachloroethene
Arsenic	1,1,2-Trichloroethane
Beryllium	Benzene
Boron	Toluene
Cadmium	Ethylbenzene
Chromium	Xylenes
Cobalt	2,4-Dimethylphenol
Copper	Hexanone
Lead	2-Methylnaphthalene
Manganese	Naphthalene
Mercury	Carcinogenic PAHs
Nickel	- Benzo(a)anthracene
Selenium	- Benzo(b)fluoranthene
Silver	- Benzo(k)fluoranthene
Vanadium	- Benzo(a)pyrene
Zinc	- Chrysene
	- Dibenzo(a,h)anthracene
	- Indeno(1,2,3-cd)pyrene
	PCBs

(a) Union of chemicals of concern for surface soil, groundwater, and air (EPA 1992a,b,c).

TABLE RI-28

PHYSICAL AND CHEMICAL PROPERTIES OF INORGANIC CHEMICALS OF CONCERN FOR THE STF SITE

Chemical	Molecular Weight (g/mol)	Specific Gravity(a,b) (Unitless)	Melting Point(a) (Celsius)	Boiling Point(a) (Celsius)	Water Solubility(c) (mg/L)	Vapor Pressure(c) (mmHg)	Henry's Law Constant (c) (Unitless)
Aluminum (Al)	26.98	2.702	660.4	2,467	(d)	(e)	(e)
Antimony (Sb)	121.75	6.684 (25 C.)	630.5	1,750	(d)	(e)	(e)
Arsenic (As)	74.92	5.727 (14 C.)	817 (28 atm.)	613	(d)	(e)	(e)
Beryllium (Be)	9.01	1.85	1,278	2,970 5 mm.)	(d)	(e)	(e)
Boron (B)	10.81	2.34-2.47	2,300	2,550	(d)	(e)	(e)
Cadmium (Cd)	112.41	8.642	320.9	765	(d)	(e)	(e)
Chromium (Cr)	52.00	7.2	1,857	2,672	(d)	(e)	(e)
Cobalt (Co)	58.93	8.9	1,495	2,870	(d)	(e)	(e)
Copper (Cu)	63.55	8.92	1,083	2,567	(d)	(e)	(e)
Lead (Pb)	207.19	11.34	327.5	1,740	(d)	(e)	(e)
Manganese (Mn)	54.94	7.2	1,422	1,962	(d)	(e)	(e)
Mercury (Hg)	200.59	13.59	-38.9	356.6	0.03	0.0013	0.47
Nickel (Ni)	58.71	8.9	1,455	2,730	(d)	(e)	(e)
Selenium (Se)	78.96	4.26-4.81	60-217	685	(d)	(e)	(e)
Silver (Ag)	107.87	10.5	961.9	2,212	(d)	(e)	(e)
Vanadium (V)	50.94	5.96	1,890	3,380	(d)	(e)	(e)
Zinc (Zn)	65.38	7.14	419.6	907	(d)	(e)	(e)

(a) CRC (1981).
(b) All values taken at 20°C.
(c) Strumm and Morgan (1981); all values taken at 25°C.
(d) The solubility of the metal is dependent on environmental conditions and which species are present.
(e) Value is insignificant.

TABLE RI-29

PHYSICAL AND CHEMICAL PROPERTIES OF ORGANIC CHEMICALS OF CONCERN FOR THE SOUTH TACOMA FIELD SITE

Chemical	Empirical Formula	Molecular Weight (g/mol)	Specific Gravity[a] (Unitless)	Melting Point[a] (Celsius)	Boiling Point[a] (Celsius)	Water Solubility[b,c] (mg/L)	Vapor Pressure[b,c] (mmHg)	Henry's Law Constant[b,c] (atm-m3/mol)	K_{oc}[b,c,d] (mL/g)
Volatile Organics									
Benzene	C6H6	78	0.8786	5.5	80.1	1,750	9.52E+01	5.59E-03	83
Ethylbenzene	C8H10	106	0.867	-94.97	136.2	152	7.0E+00	6.43E-03	1,100
Toluene	C7H8	92	0.867	-95.1	110.8	535	2.81E+01	6.37E-03	300
m-Xylene	C8H10	106	0.864	-48/-53	139	130	1.0E+01	6.9E-03[a]	758[a,e]
o-Xylene	C8H10	106	0.88	-25	144.4	175	1.0E+01	4.9E-03[a]	283[a,e]
p-Xylene	C8H10	106	0.86	13	138.4	198	1.0E+01	7.0E-03[a]	677[a,e]
Total Xylenes	C8H10	106	NA[f]	NA	NA	198	1.0E+01	7.04E-03	240
Chloroform	CHC13	119.4	1.489	-64	62	8,200	1.51E+02	2.87E-03	31
Hexanone	C6H12O	100.2	0.8017	-85/-80	116/119	19,000[a]	6.0E+00[a]	NA	12[e,g]
Tetrachloroethylene	C2C14	165.8	1.626	-22.7	121.4	150	1.78E+01	2.59E-02	364
1,1,2-Trichloroethane	C2H3C13	133.4	1.44	-35/-36.7	113.7	4,500	3.0E+01	1.17E-03	56
Semivolatile Organics									
2,4-Dimethylphenol	C8H10O	122	1.036	26	211.5	6,200[h]	9.8E-02[h]	6.3E-07[h]	81.5-283[e,i]
2-Methylnaphthalene	C11H10	142	0.994	34	241-242	25.8[i]	6.81E-02[i]	NA	3,560[e,i]
Naphthalene	C10H8	128	1.152	80.2	217.9	30[a]	1.0E+00[a,j]	4.30E-04	1,240[h,k]
Carcinogenic PAHs									
- Benzo(a)anthracene	C18H12	228	NA	158	435[l]	0.0057	2.20E-08	1.16E-06	1,380,000
- Benzo(b)fluoranthene	C20H12	252	NA	167	NA	0.014	5.00E-07	1.19E-05	550,000
- Benzo(k)fluoranthene	C20H12	252	NA	217	480[l]	0.0043	5.10E-07	3.94E-05	550,000
- Benzo(a)pyrene	C20H12	252	NA	179	311	0.0012	5.60E-09	1.55E-06	550,000
- Chrysene	C18H12	228	1.274	254	488	0.0018	6.30E-09	1.05E-06	200,000
- Dibenzo(a,h)anthracene	C22H14	278	NA	266-267	524	0.0005	1.00E-10	7.33E-08	3,300,000
- Indeno(1,2,3-cd)pyrene	C22H12	276	NA	160	536	0.00053	1.00E-10	6.86E-08	1,600,000
Polychlorinated Biphenyls	NA	NA	NA	NA	NA	0.031	7.70E-05	1.07E-03	530,000
Aroclor 1248	C12H6C14	291.8	1.41[m]	NA	340-375[m]	0.054[n]	4.94E-04[n]	1.30E-01[n]	758,000[m]
Aroclor 1254	C12H5C15	326.3	1.50[m]	NA	365-390[m]	0.012[n]	7.71E-05[n]	9.00E-02[n]	1,520,000[m]
Arcolor 1260	C12H4C16	360.7	1.58[m]	NA	385-420[m]	0.0027[n]	4.05E-05[n]	2.00E-01[n]	3,030,000[m]

(a) Verschuren (1983).
(b) EPA (1986b).
(c) Values taken at 20°C, unless otherwise noted.
(d) K_{oc} is the organic carbon normalized soil/water partition coefficient.
(e) Calculated from K_{ow} values using the formula; $K_{oc}=0.48\ K_{ow}$; (Hassett et al. 1980).
(f) NA = Not available or not applicable.
(g) Toxicological profile for 2-hexanone (ATSDR 1990b).
(h) Howard (1989); solubility and vapor pressure measured at 25°C and Henry's Law Constant measured at 8°C.
(i) National Library of Medicine, Hazardous Substance Databank, U.S. Department of Health and Human Service; vapor pressure measured at 25°C.
(j) Solubility measured at 53°C.
(k) Calculated from K_{ow} values using the formula, $K_{oc}=0.62$ Kow (Karickhoff et al. 1979; Rao and Davidson 1980).
(l) CRC (1981).
(m) Toxicological profile for selected PCBs (ATSDR 1987c).
(n) Strumm and Morgan (1981); values measured at 25°C.

The molecular or atomic weight is necessary for conversion of units, such as mg/kg or mg/L to molar units.

6.1.2.2 Specific Gravity. The specific gravity for each compound is listed in Table RI-29. Values are unitless and are reported for 20°C, unless otherwise noted.

6.1.2.3 Melting Point and Boiling Point. The melting point and boiling point of each compound/element are listed where available. The values are given in degrees Celsius. Boiling point data are reported for the chemical's behavior at 1 atmosphere unless otherwise noted.

6.1.2.4 Water Solubility. Water solubility values are reported in ppm (mg/L) for a temperature of 20°C, unless otherwise noted. Water solubility is the maximum concentration of a compound/element than can be dissolved in pure water at a specific temperature and pH. Water solubility values are also useful as general measures of the relative hydrophobicities of chemicals and an indication of when free-phase or liquid-phase product may be present (e.g., chemical concentrations in water approaching or exceeding their solubilities).

6.1.2.5 Vapor Pressure. Vapor pressures are reported unless they are considered insignificant, as in the case of most metals. Units for vapor pressure are in mm/Hg, and are reported for 20°C, unless otherwise noted. Vapor pressure is useful in evaluating the potential for releases to air from solid and liquid-phase sources.

6.1.2.6 Henry's Law Constant. Henry's Law constants reported are calculated from the ratio of vapor pressure and water solubility, with the result reported in units of atm. m^3/ mole. The constants are useful in evaluating the potential for releases to air from chemicals of concern in aqueous solutions.

6.1.2.7 Organic Carbon Normalized Soil/Water Partition Coefficient, K_{oc}. The soil/water partition coefficient, normalized for organic carbon fraction is reported in mL/g for each compound when available. K_{oc} is a measure of the sorption potential of the chemical on soil. Where K_{oc} was not reported in the literature, it was calculated from the K_{ow} value using the following formula based on correlations found by Hassett et al. (1980).

$K_{oc} = 0.48\ K_{ow}$ (for volatile organics)

or

$K_{oc} = 0.62\ K_{ow}$ (for PAHs).

The basis for these calculations has been reported by Karickhoff et al. (1979), Rao and Davidson (1980), and Mabey et al. (1982).

6.1.3 General Evaluation of Chemical Movement, Persistence, and Transformation in the Environment

This section discusses the movement and transformation of chemicals in soil/water systems. The reservoir for most of the chemicals of concern detected at the STF site is soil and sediment (soil). The total mass of chemicals of concern contained in surface water and groundwater, as indicated by the chemical concentrations detected in these media, is insignificant when compared with the mass contained in soil and sediment. In addition, the transient nature of water moving through the surface water channel and shallow aquifer make the RI data for water quality in these media only useful to the extent that they indicate possible soil/water interactions at the time of the RI. Although movement of minor amounts of chemicals from the site into the air through wind erosion of soil particles and volatization can occur, the potential airborne modes of chemical transport were determined to be insignificant (see Preliminary Dispersion Modeling Report, Appendix DM) and, therefore, are not the focus of this section. Accordingly, this section focuses on chemical mobility and fate in soil/water systems.

The movement and transformations of chemicals in soil/water systems are functions of potentially complex and competing chemical, physical, and biological processes. Reliable conclusions or predictions regarding the behavior of a chemical in any specific environment (soil or water system) require that the actual experience in the field (i.e., monitoring data) be understood and related to the fundamental principles and theories of chemical reactivity and transport in the environment.

The behavior of a chemical in a soil or water system can be regarded as a function of environmental variables and chemical properties. The environmental variables are characteristic of the site-specific environment and can include pH, temperature, redox conditions, microorganism populations and types, and soil constituents. Such characteristics often vary even within a small area in vertical or lateral directions, and, therefore, are appropriately considered "variables" in an environmental assessment. Thus, assessments of chemical behavior in a large area, such as those presented in Section 6.3, must implicitly assume an average or other assigned value for each of several environmental variables (e.g., a conservative value that overestimates mobility or transformation rates can be used as a tool for evaluation in an exposure assessment).

In contrast to the environmental variables, some characteristics of a chemical are functions of the chemical itself (e.g., structure or reactivity) and can be practically invariant under environmental conditions. Some of those properties, which include vapor pressure, water solubility, and the fundamental equilibrium and partitioning constants are discussed in Section 6.1.2. Such properties can often be directly measured in the laboratory under controlled conditions, and then used with environmental variables to estimate chemical behavior in a specific environment.

As a background to discussions on chemical fate and mobility at the STF site, it is important to recognize that onsite soil is a heterogeneous porous material, with soil particulate matter typically occupying from 60 to 70 percent of a volume of soil. The remaining volume of soil is occupied by "soil air" and/or "soil water." Soil above the water table (in the unsaturated or vadose zone) may contain differing amounts of soil air and soil water depending on its specific retention and on water sources that provide infiltrating water (rainfall or surface discharges). Below the water table, the soil is saturated with water (air-filled pores do not exist to any appreciable degree); this saturated soil zone is the region that is the source of groundwater. Some authors prefer the term "subsurface water" to describe both soil water and groundwater, but because the term groundwater has already been used extensively throughout the RI, the use of the two separate terms (soil water and groundwater) to describe subsurface water has been retained in the following discussion. The discussion below deals with how chemicals behave in the soil and soil water system; except for unique situations, subsurface chemical movement and chemical reactions in the solid phase of soil are less important as a major pathway for chemical movement or transformation than are waterborne routes.

6.1.3.1 Chemical Transport. The transport of a chemical in soil is governed in part by the chemical form in which it is present. Metals may be found in the environment in their elemental forms, as free (uncomplexed) ions, or in inner or outer sphere complexes (Turner et al. 1981). At temperatures normally found at ground surface and in the shallow subsurface most elemental metals are solids. With the exception of mercury, subsurface migration of metals as elemental liquids or gases is not an important transport mechanism. Some organometallic compounds have significant vapor pressures and tendencies to partition into the gas phase under natural conditions and gas-phase transport mechanisms may be significant. These metals compounds are more appropriately regarded as organic compounds for chemical transport modelling purposes. Movement of soil water (groundwater) containing metals is the major mechanism accounting for subsurface transport of metals. Soil water may contain dissolved metals ions and complexes, and/or suspended precipitates or soil particles coated with sorbed metals.

Organic chemicals or mixtures may be present as free phase (pure solids or liquids) gas (vapor) phase, stationary phase (adsorbed to or absorbed by solids), or dissolved phase (in aqueous or organic solutions). The potential for movement of an organic chemical between any two points in soil is a function of concentration, temperature, and/or pressure (liquid and gas) gradients, which drive the vapor and liquid-phase movement. For instance, the vapor and liquid phases of VOCs may move simultaneously and independently due to the vapor-pressure gradients in the soil, until the net transport of the VOCs reaches a steady-state condition (i.e., concentration distribution stabilizes). Also, the rate of volatilization of VOCs from subsurface soil to air is controlled by the rate of convection and diffusion through the soil layer. Each of these processes can be described by a linear rate law, stating that the flux is proportional to the moving force. For convection, also called mass flow, the moving force consists of a gradient of total gas pressure, and results in the entire mass of air moving from a zone of higher pressure to one of lower pressure. For diffusion, the moving force is a gradient of partial pressure (or concentration) of the VOCs.

The movement of chemicals (inorganic and organic) in the saturated zone also occurs in response to concentration, temperature, and pressure gradients. Movement of dissolved chemicals (solutes) in coordination with groundwater flow, the most important potential transport mechanism at the site, is the best studied chemical movement mechanism in the saturated zone. Movement of non-aqueous phase liquids (NAPLs) and suspended sediment particles as well as movement of solutes along concentration and thermal gradients can be important chemical transport mechanisms, but are not as well understood (National Research Council 1990).

The mechanisms governing solute transport are advection, dispersion, and chemical reactions. Advection is the process by which solutes are transported by the bulk motion of flowing groundwater. Advection can carry nonreactive solutes at an average rate equal to the linear velocity of the groundwater. Dispersion is the spreading of constituents over an area larger than would be predicted from advection alone. There are two components to dispersion: mechanical dispersion and molecular diffusion. Mechanical dispersion is a spreading caused by the tortuous flow of groundwater containing a solute through the porous media. Molecular diffusion is the spreading of solutes along concentration gradients due to the thermal-kinetic energy of the solute particles. Chemical reactions are processes such as radioactive decay, biodegradation, precipitation, and sorption. Such reactions can impede the movement of chemicals in groundwater.

Groundwater movement through an aquifer is typically regarded as the single-most important saturated zone phenomenon governing chemical transport. The variables controlling the movement of water through an aquifer are the hydraulic conductivity of the porous media, potentiometric head, water losses (sinks) from and additions (sources) to the aquifer, storage capacity of the porous media, and the time period being considered. The spatial distribution of the values for the controlling parameters throughout the groundwater system being modeled and their temporal variations are also important variables.

6.1.3.2 Mobility of Chemicals in Soil/Water Systems. The rate of movement of a chemical through a soil/water system is dependent on the properties of both the chemical and the system itself. Because soil/water systems have heterogeneous characters that varies with location and time, the properties of these systems are considered to be environmental variables. By contrast, many properties of a chemical are intrinsic to the structure of the chemical, and can be essentially invariant under most naturally occurring environmental conditions.

6.1.3.2.1 Organics Mobility. A basic principle for understanding and predicting the mobility of a chemical in a soil/water system is that the chemical will distribute itself between the stationary soil (particulate) phase and the mobile aqueous phase. Chemicals that are distributed (or partitioned) predominantly in the aqueous phase will move more readily with groundwater, while chemicals that preferentially adhere to the stationary soil particles will be retarded in the movement with groundwater. It is also important to recognize that although partitioning to soil can provide a significant resistance to chemical movement in groundwater, the partitioning process will not result in a chemical being totally immobile in groundwater. The discussion below presents the quantitative basis for estimating chemical mobility relative to the rate of groundwater movement.

In this discussion of the partitioning of chemicals, soil particles are referred to as "soil" and soil water and groundwater are referred to as "water." If an organic chemical is present at low concentrations in water and soil, the chemical concentrations in soil and in water at equilibrium (C_s and C_w, respectively) are often related by the simple expression:

$$K_d = \frac{C_s}{C_w} \qquad (1)$$

where K_d is called the soil/water partition coefficient of the chemical (Karickhoff 1984; Podoll and Mabey 1984).

The important feature of equation (1) is that the ratio C_s/C_w is constant for a small amount of chemical in a given soil/water system. However, large amounts of chemical in the water or soil may change their respective properties that affect partitioning. A more accurate form of equation (1) is the Freundlich equation:

$$K_d = \frac{C_s}{C_w} \exp(1/n) \qquad (2)$$

where the (1/n) term is an empirical parameter indicative of any non-linear behavior of the sorption process, as may occur at high concentrations of chemicals in soil. At the low concentrations (i.e, <10 ppm) of chemicals, 1/n is often assumed to be unity and equation (1) is deemed adequate (Podoll and Mabey 1984).

Several mechanisms (i.e., specific types of chemical interactions with soil) can potentially contribute to an observed K_d value at a site. The importance of each mechanism is determined, in part, by the soil properties. One important mechanism involves the amount of organic carbon (or organic materials) in soil. Increasing amounts of natural organic materials (e.g., humic acids or fulvic acids) increase the capacity of the soil to sorb non-polar organic chemicals. Research and numerous laboratory and field studies have shown that, in many soil/water systems, K_d is related to the fraction of organic carbon in soil, f_{oc}, and a property of the chemical, K_{oc}, as shown below:

$$K_d = K_{oc} f_{oc} = \frac{C_s}{C_w} \qquad (3)$$

Thus, a knowledge of f_{oc} for soils of interest and the K_{oc} value for a chemical allows for calculation of C_s/C_w. If information on C_s is available, calculation of C_w is possible. K_{oc} is referred to as an organic carbon-normalized soil partition coefficient and is experimentally determined from measured K_d and f_{oc} data for chemical/soil systems.

Other mechanisms that contribute to the observed sorption of chemicals to soil include partitioning of chemicals between water and mineral soil surfaces in which the surface area and surface activity of the soil particles influence the partitioning coefficient. For example, clays show greater sorptive properties than do sands, in part, because of the larger surface areas of the clay materials compared to sands. Unfortunately, the quantitative understanding that exists for partitioning of organic chemicals between water and mineral surfaces is not as well developed as it is for the K_{oc}-f_{oc} relationship, but such sorption processes are the subject of current research efforts.

The estimated values of K_d can be used to evaluate the movement of chemicals through saturated soil or in unsaturated soil (as in leaching through vadose zone soil). The mathematical expression for estimating the velocity of chemical movement, V_c, in groundwater with a flow velocity, V_w, is given by the expression:

$$V_c = V_w \left(1+\frac{\rho_b}{n} K_d\right)^{-1} \tag{4}$$

or

$$V_c = V_w \left(1+\frac{\rho_b}{n}K_{oc}\, f_{oc}\right)^{-1} \tag{5}$$

where n is the soil porosity, and ρ_b is the bulk mass density of the soil/water system (Freeze and Cherry 1979). This equation defines the relative velocity of chemical movement according to the movement of center of mass of a chemical moving in a pulse. It is important to recognize that the shape of the pulse itself (as defined by chemical concentration profile) around the center of mass will be determined by more complex dispersive processes in the groundwater environment.

Equation (5) shows that the velocity of a chemical's movement through a groundwater system is a function of both environmental variables (V_w, ρ_b, n, f_{oc}) and of a chemical property (K_{oc}), and that the mobilities of chemicals at a site can be evaluated from their K_{oc} values. It must also be recognized that these equations apply strictly to organic chemicals, but that K_d values for an inorganic chemical could also be used if only the transport of the species for which the K_d was determined is of interest.

6.1.3.2.2 Inorganics Mobility. The mobility of inorganics (including metals) in soil and groundwater is often more difficult to understand and predict than organics. This is because some elements can be present in one or several oxidation states, and each state exhibits its own chemistry in interacting with soil particulates, soil organics, and other inorganic constituents (Tessler et al.

1979). The formation of these different forms is referred to as speciation. Depending on the speciation of the inorganic components, the element of concern may be found to have various degrees of mobility in a particular environment (Dowdy and Volk 1983). Metals, metalloids, and selenium are the inorganic chemicals of concern at the STF site. Some of the principles governing the mobility of metals in soil/water systems are discussed below.

As noted previously, metals in natural waters, including soil water and groundwater, are present either as free (uncomplexed) ions or as various complexes formed with both inorganic and organic ligands. Two types of soluble metals complexes are formed between metals and complexant ligands.

- Outer sphere complexes (or ion pairs) consist of relatively weak electrostatic associations formed between a hydrated ion and complexant ligand, one or both of which retain a hydration shell.

- Inner sphere complexes consist of electrostatically strong metal-complexant ligand associations in which a covalent bond is formed between the metal and complexant ligand.

Both types of metal complexes may be electrically charged (positive or negative) or neutral. Diagrams that plot aqueous solution redox potential (Eh) vs pH delineate the stable metal species present under given Eh-pH conditions. Such diagrams are a convenient means of displaying stability relationships where equilibrium redox reactions are involved. Unfortunately, departures from equilibrium conditions are common in natural soil/water systems.

A large number of complexant ligands and metals occur in natural waters, including soil water and groundwater. Many complexant ligands are conjugate bases of weak acids, and the extent to which complexation occurs depends on the pH of the water as well as the relative amounts of metals and ligands. The hydroxide (or OH^-) ion is the most important inorganic ligand in natural waters.

Transition metals, rare earth elements, and some Group III elements hydrolyze in water to form hydroxo-complexes. Chloride (Cl^-) and carbonate ($CO^{2-}{}_3$) are also important inorganic ligands in natural waters (Evans 1989).

Specific interactions of metals with organic ligands are not as well understood as are those involving inorganic ligands. Complexant organic ligands of importance include simple aliphatic and aromatic acids (e.g., citric, oxalic, gallic acids) as well as more structurally complex acids such as those contained within soluble humic and fulvic acid fractions (Evans 1989).

The formation of complexed metals species is of interest from a chemical mobility standpoint in that the form in which a metal occurs affects its solubility as well as its affinity for electrically charged soil particles. The movement of a metal through soil/water systems can be viewed as the product of competing forces; those forces serving to move the metal and those forces serving to retard its movement or retain it in a given location. In general, the moving forces are those that promote dissolution of a metal as a soluble species in migrating water (although movement of suspended fine-grained sediment is important in surface water and in some subsurface water systems). Movement of metals-coated sediment particles in a surface water system is governed primarily by erosion and sedimentation processes that occur in response to the energy imparted to the sediment particles by moving water. Chemical forces competing to retain metals in stationary soil and sediment are those that promote the loss of the metal from aqueous phase to a solid phase. This process is termed sorption and it involves three main processes:

- Precipitation. The development of a solid phase that incorporates the metal into a primitive molecular unit (a complex) that repeats itself in three dimensions.

- Adsorption. The accumulation of the metal species at the interface between the aqueous solution phase and the solid adsorbent without the development of a three-dimensional molecular arrangement (i.e., monolayer of adsorbed species).

- Absorption. The diffusion of an aqueous metal species into a solid phase (Corey 1981; Sposito 1984).

Under suitable soil conditions, metals added to the soil will precipitate as secondary minerals. The oxides, oxyhydroxides, hydroxides, and carbonates are the most important of these precipitates, with phosphates, silicates, and sulfide generally being of lesser importance (Evans 1989). The extent to which dissolution or precipitation of a given mineral will occur can be described by its solubility product, K_{so}, the product of the activity of its constituent ions in solution.

$$Me_{\ell} L_{m_{(s)}} \leftrightarrow \ell Me^{m+} + mL^{\ell-} \; ; \; K_{so} \qquad (6)$$

at equilibrium,

$$K_{so} = \frac{\{Me^{m+}\}^{\ell} \, \{L^{\ell-}\}^{m}}{\{Me_{\ell} L_{m_{(s)}}\}} \qquad (7)$$

where Me^{m+} is the metal ion, $L^{-\ell}$ is the anionic ligand, and $Me_{\ell}L_{m_{(s)}}$ is the solid precipitate.

Assuming that the activity of a solid phase is unity, a simplified representation is:

$$K_{so} = \{Me^{m+}\}^{\ell} \, \{L^{\ell-}\}^{m} \qquad (8)$$

Precipitation reactions may be important metals retention mechanisms in soil at the STF site. Aluminum, copper, cadmium, iron, and zinc all commonly form hydroxide precipitates in soil. Barium, cadmium, lead, iron, and zinc might be expected to precipitate as carbonates (Evans 1989).

Adsorption reactions involving the formation of either inner sphere or outer sphere complexes with the surfaces of both mineral and organic matter are important mechanisms of metals retention in soil. Adsorption is generally differentiated from precipitation by the formation of a monolayer of adsorbed species on a soil surface as opposed to a three-dimensional coating. The distinction between adsorption and precipitation is less clear when a continuum exists between an adsorbed layer on a surface and a precipitated overlying coating (Sposito 1985). Three types of adsorption are of particular importance to the retention of metals in soil/water systems:

- Non-specific adsorption to soil particles
- Specific adsorption at mineral surfaces
- Adsorption by organic matter.

Non-specific adsorption (cation exchange reactions) at a soil particle surface involves the formation of a weak association between a metal ion and a soil particle surface in response to electrostatic or coulombic forces of attraction. Such bonding is referred to as non-specific because adsorbed cations may be readily exchanged with other cations that similarly form only outer sphere complexes with the soil surface. The attraction of positively charged cations in solution to negatively charged soil particles is a particularly important retention mechanism in soil containing appreciable amounts of phyllosilicate clay minerals micas). These clay mineral surfaces retain a negative charge regardless of variations in soil pH and are accordingly referred to as constant charge surfaces. Particle surfaces composed of oxide and (oxy) hydroxide minerals as well as certain functional groups within humic substances also provide cation exchange sites. However, their surface charges are pH-dependent and are referred to as variable charge surfaces.

In addition to the sign and the strength of the electrical charges developed on the surfaces of soil particles, the total surface area available for adsorption is an important variable in determining the cation exchange capacity (CEC) of a soil. CEC is measured in the laboratory and is reported in milliequivalents of exchange capacity per 100 grams of soil (meq/100 g). In evaluating a given soil's capacity to retain metals, measured values from 5 to 15 meq/100 g are customarily regarded as medium CECs. Values of greater than 15 meq/100 g are regarded as high CECs, while values of less than 5 meq/100 g are considered to be low (EPA 1977).

The CEC in any particular soil is affected by the kind and quantity of clay mineral and organic matter, and the pH of the soil/water solution. Among common clays, the CEC is usually higher for montmorillonite, followed by illite, and then by kaolinite. CECs are also affected by physical factors, such as soil texture (smaller particles have higher CECs).

The CEC in soil increases with increasing soil pH, and decreases with decreasing pH.

At the exchangeable sites in the soil surfaces, the "major cations" (Ca, Mg, K, and Na) are usually present in higher concentrations than any of the trace metals. Consequently, trace metals cannot successfully compete for the cation exchange sites that are dominated by the major cations (Wiklander 1974; Fuller 1977). As a result, the removal of trace metals from soil-water interfaces by cation exchange is usually insignificant when compared to other mechanisms (Murrmann and Koutz 1972).

In nature, sorption, solid-liquid complexation, and ion exchange processes are difficult to distinguish from one another. Although ion exchange mechanisms can be distinguished by the initial and subsequent cation/anion concentrations, these three mechanisms are usually grouped together as if they were one mechanism.

Ion exchange is one of the most important mechanisms for controlling the migration of the major cations. Ion exchange is a reversible chemical reaction that follows the law of mass action and is restricted by the number of available exchange sites on the mineral and the strength of the bonding of the exchangeable ions to the mineral surface.

According to Rose (1966), the clay soil selectivity for common soil cations is:

- Al > Ba > Ca > Mg > K > Na > Li

Specific adsorption of mineral surfaces involves the formation of covalent bonds between the adsorbed species and the mineral surface, so that the adsorbed species are not readily displaced. Many metallic cations are capable of forming inner sphere complexes with charged mineral surfaces through ligand exchange processes. Larger alkali metal ions can also be specifically adsorbed without ligand exchange onto some clay mineral surfaces. Specific adsorption complexes occur most readily on oxide and hydroxide surfaces.

Specific adsorption is common on both constant and variable charge surfaces. On variable charge surfaces, this type of adsorption is particularly important for metals that hydrolyze in water, including most of the transition and rare earth elements as well as other metal ions such as Hg^{2+} and Pb^{2+} (Barrow 1987). These adsorption reactions often occur between hydroxo-metal complexes and the negatively charged surfaces of aluminum, manganese, and iron oxides, hydroxides, and oxyhydroxides when surface -OH or $-OH_2^+$ groups on the surfaces are replaced by the adsorbing ligand. In general, important specific adsorption reactions involving metals are strongly pH-dependent (Evans 1989). It has been proposed that hydrous oxides of iron and manganese provide the principal control on the fixation of metals in soil and freshwater sediment (Vuceta and Morgan 1978).

Adsorption of metals by organic matter in soil involves the formation of both inner sphere and outer sphere (cation exchange) complexes with organic surfaces as well as precipitation reactions. Chelation, or the bonding of more than one linkage between a metal cation and each associated complexant organic ligand, is an important type of inner sphere complex formed between metals and organic matter. Because of the wide variety of naturally occurring organic chemicals present in soil, only a limited number of specific complexation reactions have been isolated and studied (Vuceta and Morgan 1978). Metals retention by various humic and fulvic acid fractions isolated from soil has been the subject of extensive study. However, many have concluded that it is difficult to differentiate the importance of complexation reactions relative to other retention mechanisms (Evans 1989). The complexity of humic materials has led to the more frequent use of macroscopic evaluation tools, such as CEC measurements, to approximate the importance of organic matter as a soil retention mechanism at specific sites.

Metals retention by soil in soil/water systems has been studied extensively in terms of the pH conditions occurring in the system. Adsorption of cationic metals (e.g., Pb^{2+}, Cd^{2+}, Zn^{2+}, Cu^{2+}, Hg^{2+}, Cr^{3+}) generally increases as the pH of the system increases. Conversely, adsorption of heavy metals (e.g., Cr^{6+}, As^{3-}, Se^{4-}) in the anionic form generally decreases as the pH of the system increases (California DHS 1990). This behavior is largely due to the binding of metals to soil by cationic exchange and other mechanisms, and by precipitation of metals in the carbonate, oxide, and hydroxide forms as discussed above. Evaluation of mobility in terms of pH-governed mechanisms is based on the concept that the major concentration of a metal is present in an immobile state, and that a very low concentration of the metal does exist in the mobile phase as different species.

Ionic organic materials present in soil or groundwater also can affect the mobility of metals because they compete with soil or other soil constituents to complex the metal. If the organic-metal complex itself partitions strongly to soil solids, another route for metal immobilization obviously exists. However, if the organic-metal complex is partitioned predominately to the aqueous phase, the metal is "mobilized."

A large number of metals and complexant ligands are present in soil/water (solution). The tendency for a given complexation reaction to occur can be evaluated by examining the formation constant for the complex. While laboratory analyses for metals typically provide results for total metals content and not for particular species, simple systems can sometimes be modeled to determine the concentration distributions of various species present based on their formation constants. Unfortunately, complicated systems such as those found at the STF site do not lend themselves to modeling because of the vast array of possible organic and inorganic ligands present.

The foregoing discussion is applicable to both groundwater environments, where water flow through soil pores may be continuous, as well as to the unsaturated zone, where a major problem in estimating chemical mobility is evaluating the discontinuous water flow through the soil profile.

6.1.3.3 Fate of Chemicals in Soil/Water Systems. A number of different reaction processes may occur in unsaturated soil or groundwater systems that transform chemicals into new chemicals (or products). Such processes include photolysis, reduction, oxidation, hydrolysis, and hydration. Biotransformation, the enzyme-catalyzed transformation of chemicals mainly by microbes, can also be very important in soil/water system. The rate of each process that transforms a chemical (or generates a product) depends both on the inherent reactivity of a chemical toward the process (e.g., hydrolysis or oxidation) and the environmental variables that affect or influence the transformation reaction (variables may include pH, water, oxygen, type and population of microorganisms, and major and minor nutrients). For some chemicals in some environments, several processes may compete to transform a chemical.

Unfortunately, the heterogeneous character of the soil/water system and the complex interrelationships between the environmental variables themselves prevent an accurate prediction of what processes or reaction rates will occur for a chemical at a given site. However, the geochemical and microbial factors that control the production and levels of some important environmental variables have been studied in laboratory and field experiments. This information, together with a knowledge of the reactivity of chemicals, can be used to explain why some transformations have occurred, or to qualitatively predict what reactions will (or will not) occur at a given site (Mabey 1984).

As an example of the complexity of the transformation processes that can occur in the subsurface environment, the following scenario is a possible interpretation of the groundwater quality monitoring data from the upper aquifer well (NMW-1A) located at Pioneer Builders Supply. A zone of dissolved petroleum hydrocarbons (e.g., benzene, toluene, ethylbenzene, xylenes, and naphthalene) in groundwater also contains a low concentration of 1,1,2-trichloroethane. This groundwater zone is present in sediments that contain naturally occurring coatings of iron and manganese precipitates. The upper aquifer may normally be oxic (oxygen-containing) but the presence of the lighter hydrocarbons has changed the oxic nature of the soil/water system as the microbial populations in the system oxidize the hydrocarbons to organic acids and eventually CO_2.

$$\textit{hydrocarbons} + O_2 \rightarrow \textit{organic acids}, CO_2 \qquad (9)$$

Consumption of oxygen in the subsurface soil system can result in anoxic (or anaerobic) conditions. It has been established that 1,1,2-trichloroethane can be chemically or microbially transformed in anoxic environments with reductive dehalogenation proceeding to produce 1,1-dichloroethene and vinyl chloride (ATSDR 1988).

$$1,1,2\text{-}TCA \xrightarrow[conditions]{anoxic} 1,1\text{-}dichloroethene,\ vinyl\ chloride \qquad (10)$$

The generation of anoxic conditions and organic acids by the biotransformation of hydrocarbons will also result in heavy metals (M) being mobilized in groundwater by several mechanisms. One mechanism is the acidification of soil to below pH 6.5 by the acid biotransformation products; the production of low molecular weight organic acids also can shift the metal equilibria in soil/water systems to produce higher concentrations of the more mobile organic acid-metal complexes. Heavy metals will also be released into groundwater because insoluble ferric oxide/hydroxide or manganese oxide/hydroxide species in soil will be reduced to soluble Fe^{2+} and Mn^{2+} species. The binding of heavy metals to the oxide/hydroxide/oxyhydroxide constituents is one important mechanism for immobilization of metals.

$$\overset{\underline{\text{MOBILE}}}{\text{(soil/organic-Me)}} + \text{(low molecular weight acids)} \rightarrow \overset{\underline{\text{MOBILE}}}{\text{(Me-low molecular weight acid complexes)}} \qquad (11)$$

$$\overset{\underline{\text{IMMOBILE}}}{(Fe^{3+}\text{ oxide/hydroxide, }Mn^{2+}\text{ oxide/oxyhydroxide-Me complexes})} \xrightarrow[\text{conditions}]{\text{reducing}} \overset{\underline{\text{MOBILE}}}{(\text{soluble }Fe^{2+}, Mn^{2+})} + \overset{\underline{\text{POTENTIALLY MOBILE}}}{\text{(Me)}} \qquad (12)$$

The elevated manganese and iron concentrations detected in filtered groundwater samples collected from NMW-1A at Pioneer Builders Supply suggest that such reduction reactions may be occurring. The multiple interrelationships for constituents (natural and anthropogenic) in soil/water systems and their implications for the transport and transformation of chemicals in these systems necessitate consideration of the possible fates of chemicals of concern in the RI process.

6.2 POTENTIAL ROUTES OF MIGRATION

This section describes the routes that chemicals of concern could be transported from the STF site soil and sediment to potential human exposure points. As noted earlier, the soil and sediment present on the STF site contain the majority of chemicals of concern and are regarded as the potential source area from which chemical transport is of greatest importance. Chemical concentrations in onsite vegetation (blackberries) were investigated during the RI and found to not be a significant potential source of chemical exposure. Accordingly, the following discussion focuses on potential chemical migration through soil/sediment and from soil/sediment to other environmental media.

6.2.1 Erosion and Surface Water Migration Pathway

Chemical migration via the surface water pathway can occur mainly by entrainment of solid-phase chemicals or chemical-coated soil particles, or by dissolution of chemicals in moving surface water. Floating organic-phase liquids or microemulsions may also be moved by surface water flow. However, onsite chemical concentrations do not appear to be sufficient to produce these phenomena. Erosion can displace chemical solids or soil particles on the land in response to water or wind action. Conversely, deposition can reduce mobility of soil particles or chemical solids in response to the action of wind and water.

deposition. Erosion of STF surface soil by wind action is addressed in Section 6.2.2 (Air Migration Pathway).

Human activity such as driving, digging, or walking across the site can loosen soil particles from exposed soil surfaces and subject them to entrainment in moving air and/or water. "Tracking" of contaminated soil and dust by humans, animals, and vehicles can also move contaminants away from areas where they were deposited. The potential for mass movement of soil is minimal on the STF site. Two areas where the slope of the land surface could be regarded as sufficiently steep to be subject to landslides or mass wasting are 1) bluffs along the western margin of the site, and 2) the fill wall along part of Madison Street (adjacent to TIP). The natural bluffs consist of soil that has not been exposed to the chemicals of concern that some other onsite soils have been and these are heavily vegetated. Accordingly, erosion from this area is not of concern from a chemical migration standpoint. The fill wall along Madison Street is composed of well-indurated slag material that is not particularly susceptible to slides or slumping. Accordingly, chemical dissolution, and surface soil and sediment erosion by water are the principal chemical migration routes of concern at the STF site.

Two types of water-induced erosion, sheet erosion and channel erosion, can transport soil and chemical particles over land. In general, there was no evidence that either of these soil erosional processes are occurring to any appreciable degree at the STF site. The most important factors controlling erosion are rainfall regime (amount and rate), vegetal cover, soil type, and land slope. Precipitation that does not infiltrate starts flowing down slopes as sheet flow, which may transport the windblown and raindrop dislodged particles. As more flow accumulates, rivulets are formed in non-cohesive soil, and the flow ceases to be sheet flow. If appreciable sheet flow occurred over non-cohesive soil, the evidence of such runoff would usually be clearly observable.

With the exception of a few paved areas, the potential for appreciable sheet flow does not appear to exist at the STF site. Such flow was not observed during

With the exception of a few paved areas, the potential for appreciable sheet flow does not appear to exist at the STF site. Such flow was not observed during rainfall events and there was no physical evidence at the site (e.g., presence of rivulet). Factors that tend to minimize the potential for sheet flow are:

- Typical storm events in the Tacoma area tend to be of low intensity.
- The majority of the site (i.e., 75 percent of the unpaved site area) is covered by vegetation; estimated infiltration capacity is relatively high.
- The slope of the ground surface over more than 90 percent of the site is 3 percent or less.
- Land adjacent to the drainage channels is predominantly flat except in the areas described above (i.e., western bluff and slag wall along Madison Street).

In channels, water carries sediment as suspended solids and as bed load. The sediment can be introduced from upstream channel reaches and from the sheet flow and rivulets that enter from lands adjacent to the channel, or the channel can generate sediment from the banks and the bottom of the channel itself. Significant bed erosion can undercut banks and cause landslides to develop. The resulting landslide would generate soil mass that could become part of the sediment load. No significant slumping or landsliding of soil adjacent to the surface water channel was observed.

The drainage channel begins in Reach A at the end of the 60-inch storm drain outfall identified as Location 2500. A 24-inch storm drain outfall, Location 2501, also discharges in Reach A. Stormwater enters the drainage channel from these two stormwater pipes and from the adjacent land and steep banks adjacent to the site on the west. The channel appears to have a flat natural gradient and has vegetation in all onsite reaches.

There are indications that culverts drain two of the cross-channel embankments, but their sizes are unknown. Water has been observed to backup and be retained behind the embankments that divide the reaches. All of the embankments are known to have been overtopped during the 12 months of the RI study, but none of them show evidence of erosion from the overflow. The effective lengths of the embankments are long, and the top widths are all in excess of 12 feet. Embankment heights are all less than 10 feet. Between 5 and 10 acre feet of storage is available upstream of each of the embankments.

As observed during runoff events, stormwater rises behind the embankment until it is overtopped. The lack of damage from known overtopping of the embankments indicates that the flows are shallow and have low velocities, and that there is little danger of the embankment being washed out by a flood event. If the embankment were to wash out, bed load and suspended solid transportation could be significant. When overtopping does occur, the stormwater returns to the drainage channel immediately downstream.

Eddies and bubbling observed during runoff events indicate that culverts drain the embankments between Reaches A and B, and between Reaches C and D. It is not known if a culvert exists under the embankment between Reaches B and C. Large culverts would be visible, and because no culverts have actually been observed at any of the embankments, it is probable that the capacities of embankment culverts are substantially smaller than the flows contributed by the two storm sewers.

As long as the embankments remain in place, there is potential for transporting only small amounts of suspended sediment into Reach D. There is substantial physical evidence in Reaches A, B, and C to support this conclusion.

- There is little evidence of recent sediment deposits in any of the reaches. This also supports the hypothesis that there is little sediment loading contributed by sheet flow.

- There are no zones of active bank scour.

- The channel bed is stable and does not appear to have any recent movement.

- It is probable that most sediment is introduced to the site through the two storm drain outfalls, which are located upstream of Reach D (i.e., at the beginning of the onsite channel in Reach A).

Stormwater flows offsite through Reach D in a 72-inch culvert under 56th Street. The maximum measured discharge from Reach D was 6.36 cubic feet per second (cfs) in the preceding 12-month period. The channel is small and overgrown through Reach D, with an artificial embankment on the left (east) bank and a natural bank on the right (west) bank. Small trees and heavy plants grow within the flow area of the well-vegetated channel. Flow velocity through the area is likely less than 2 feet per second. There is no evidence of active bed or bank erosion, or any evidence of significant deposition. Sediment leaving Reach D is limited to small suspended sediment that is passed through or over the embankment between Reaches C and D.

The main conclusion is that the sediment masses leaving the site are small, and less than the amount of sediment that is brought onto the STF site through the two storm sewers. Additional conclusions include:

- Most surface water, either entering the site or generated onsite as sheet flow, is percolated into the groundwater or lost to evapotranspiration before reaching the onsite channel.

- The majority of stormwater that reaches the drainage channel is detained behind three embankments that cross the channel. Behind these embankments, and along the eastern stream bank, there is no evidence of bank or bed erosion, or large volumes of accumulated sediment.

- The channel in Reach D is overgrown and has a high ambient resistance to flow. Like the other reaches, there is no evidence of bank or bed erosion, or large volumes of accumulated sediment.

The onsite surface water system is relatively complex with respect to the potential geochemical processes that affect surface water quality. Possible sources of dissolved metals and PAHs (the primary chemicals of concern) potentially affecting onsite surface water quality may be runon and contaminated sediment that have deposited onsite. Therefore, principal factors affecting onsite surface water quality are 1) the chemical quality of runon, and 2) appreciable changes in the onsite surface water environment that will influence the mobility and transport of previously deposited contaminants through processes such as dissolution and/or resuspension.

As discussed above, overland transport of surface soil from other areas of the STF site does not appear to be a significant mechanism for migration of metals and PAHs into the surface water channel. Sediment containing metals and PAHs may serve as a source of chemicals for dissolution into surface water. The highest concentrations of metals and PAHs appear to be present in sediment in upstream reaches (Reaches A and B), with the highest concentrations of PAHs being present near the storm drain outfalls. Metals and PAH are likely to be well bound to sediment and will not be readily displaced in the absence of appreciable changes in runon quality (e.g., lower pH).

Surface water was only observed flowing from the site during periods of heavy and/or prolonged precipitation. Based on these observations and the water balance calculations made as part of this RI, it was concluded that the onsite surface water channel serves as a recharge zone for the shallow aquifer in the area. The effect of this recharge on shallow groundwater quality is further discussed in Section 6.2.4.

Mass loading estimates (made as part of the analysis of data gathered during this RI) suggest that a significant proportion of the metals and PAHs discharged from offsite sources into the onsite surface water channel are retained onsite. The implications of chemical loading of the surface water channel sediment are examined in Section 6.3. The quality of runoff from the site was consistent with or better than runon quality throughout the RI, suggesting that the overall function of the onsite surface water channel is one of settling, absorbing, and otherwise retaining much of the contaminant load discharged to it from offsite, upstream sources.

6.2.2 Air Migration Pathway

The chemicals of concern identified in surface soil can potentially migrate within and off the STF site via the air pathway. However, based on results of dispersion modeling (see Section 5.1.2), this potential was demonstrated to be low. Any activity conducted onsite that generates fugitive dust provides a potential mechanism for transporting particle bound chemicals in the air. Depending on the particle size and the local meteorology, the suspended particle will be transported downwind from the source area and eventually deposited by removal at the surface or by wet deposition processes. Potential suspension of dust at STF would primarily occur either as the result of wind erosion or from a mechanical disturbance. The remainder of this section discusses air migration pathways at the STF site and the relevant factors that either influence or inhibit such transport.

6.2.2.1 Wind Suspension. The chemicals of concern can potentially be entrained, dispersed, and eventually deposited via wind sediment transport from the exposed surfaces within the STF site. Once entrained, a particle may move by creeping along the surface (particle diameters greater 500 μm); bouncing (termed "saltation," particle diameters ranging from 70 to 500 μm); or in suspension. Long-term suspension occurs when the wind velocity is much larger than the settling velocity of the entrained particle and is typically associated with particles less than about 20 μm. Wind erosion of the soil on the STF site, which contains a wide range of grain sizes, would be subject to all modes of particle transport.

The nature of wind-suspended transport is controlled both by the characteristics of the airflow near the ground and the physical properties of the source material. Climatology conducive to wind erosion could be described by a large probability of high wind events, high ambient temperatures, and the absence of precipitation or snow cover. A source material receptive to wind suspension is characterized by low moisture or other cohesive properties, low particle density, a large fraction of aggregates less than 1 mm, unlimited fetch, and the absence of vegetation cover or organic residue.

As described in Section 5.1.2 (Air Dispersion Modeling Investigation), climatic conditions at the STF site are not conducive to windblown dust. High wind events at the site are relatively uncommon due to the regional meteorology of Puget Sound. High wind events are also typically associated with precipitation or occurred during periods of the RI when source conditions were moist. The presence of local terrain features, trees, and buildings in the proximity of the STF also shelter the site from high winds reducing the potential for erosion.

Source conditions within the STF site also tend to inhibit wind suspension. The majority of the site was characterized by stable vegetation, pavement, or covered by buildings. The exposed areas present on the site were found to contain a large fraction of pebbles, rocks, and other debris, which all act to protect the finer material. Finally, the grain size analyses of surface soil indicated that most of the elevated concentrations of the chemicals of concern were located in soil with low to moderate potential erodibilities.

During the preliminary dispersion modeling, windblown suspension of inhalable material from STF was evaluated (see Section 5.1.2). Wind suspension of the chemicals of concern at the STF site was found to be relatively insignificant when predicted air concentrations were compared to health-conservative criteria.

6.2.2.2 Mechanical Suspension. Air migration of contaminants from the STF site could potentially occur when dust is mechanically generated by either handing the source material or when exposed surfaces are disturbed by vehicular traffic. When a vehicle crosses an exposed surface or travels on an unpaved roadway, dust is generated by the wheels of the vehicle and by the wake of the vehicle. The amount of particulate matter emitted is a function of the grain size of the source material, vehicle speed, vehicle weight, number of wheels, and the moisture of the surface. This mechanical activity also tends to destabilize the exposed source area and contribute to the susceptibility of the surface to wind suspension.

Vehicular traffic on paved roads also suspends previously deposited material. Emissions factors commonly employed to predict resuspended dust from paved surfaces are primarily dependent on the amount of fine material or silt loading on the roadway.

Under existing conditions at STF, the primary mechanical means for suspension of the chemicals of concern involve vehicular traffic associated with the industries on the southern portion of the site. A secondary source of lesser significance is occasional vehicular traffic on the small unpaved roads on other portions of the site that have limited access. However, the number of vehicles involved was relatively small and air emissions from such sources were found to be relatively minor during the preliminary dispersion modeling.

Materials handling of contaminated surface or subsurface soil associated with remedial actions or other future activities at the STF site would also constitute a potential means for particle-bound chemicals migrating offsite. Fugitive dust generated during material handling is dependent on the nature of the handling operation (e.g., equipment used), number of times the material is handled, meteorology, and physical properties of the source material. Materials handling emissions are usually a function of the grain size of the source material, moisture content, and the local wind speed.

6.2.3 Unsaturated Zone Migration Pathway

As discussed in Section 6.1.3.1, there are several transport mechanisms that can cause the migration of chemicals to occur in the unsaturated or vadose zone. In the following section, the more important of these mechanisms are considered:

- Leaching. The dissolution and subsequent movement of dissolved chemical species by percolating water.
- Eluviation. The movement of soil or chemical particles in suspension through the unsaturated zone.
- Plant Uptake. The uptake of chemicals by plant roots and incorporation of the chemicals into plant tissue.
- Volatilization or Gas Phase Diffusion. The partitioning or evolution of a chemical solid, liquid, or aqueous (dissolved) phase into the gas phase, and subsequent movement through soil gas and/or loss to the atmosphere by diffusion.

These mechanisms occur simultaneously and their actions are interrelated.

6.2.3.1 Leaching. Evaluation of the potential for and significance of leaching as a mechanism for transport of dissolved chemicals through the unsaturated zone is complicated by a number of conditions that exist at STF. A number of well-established methods exist for evaluating the potential movement rates of organic chemicals, and such an evaluation has been performed. The results are presented in Section 6.3.

Evaluation of metals-bearing solution formation and movement is more complex. The migration and attenuation of metals in solution in soil are affected by the following variables:

- Diffusion and dispersion

- Precipitation/dissolution (solubility)

- Adsorption/desorption

- Complexation

- Ion exchange

- Soil redox potential.

The soil properties affecting metals mobility and attenuation are soil texture (clay content), hydrous oxide content (Fe, Mn, Al), type and content of organic matter, particle size distribution, CEC, and soil pH. Descriptions of how these soil properties affect migration and attenuation mechanisms, and thus the relative mobility of metals in solution are provided below.

6.2.3.1.1 Diffusion and Dispersion. Diffusion and dispersion of a chemical through the soil are physical factors affecting a chemical's mobility. Molecular diffusion is caused by the concentration gradient of chemicals that can develop in the soil, causing the migration of chemicals from regions of higher concentrations to lower concentrations. Diffusion effects increase the migration of soluble species in the soil when very low infiltration rates are present. This phenomenon is discussed in Section 6.3.2.4. Hydrodynamic dispersion is the result of variations in pore velocities within the soil. In general, soil with small pore sizes can attenuate the migration of soluble contaminants better than soil with large pore sizes (EPA 1978).

6.2.3.1.2 Precipitation/Dissolution. Precipitation/dissolution (solubility equilibria) reactions occurring in the underlying soil can help attenuate metals migration with soil solutions. Lead, copper, and zinc ions can form carbonates and oxides in relatively oxidizing soil/water environments, and sulfide solids in relatively reducing environments when soluble sulfide is present. The attenuation effects of precipitation/dissolution of metals is more significant at neutral or higher pH values. At lower pH levels (such as in those expected in some STF surface soil), other effects such as adsorption will usually be the dominant attenuation mechanism.

6.2.3.1.3 Adsorption/Desorption. Sorption (adsorption or desorption) is the most common mechanism associated with trace metals migration in soil. Under oxidizing or low pH conditions, adsorption can usually regulate the concentration of metals well below the level controlled by precipitation.

Because of the relatively rapid rate of adsorption processes in comparison to precipitation reactions, adsorption mechanisms may affect the concentration of a constituent even if that constituent exhibits a low thermodynamic solubility in the soil solution, in equilibrium with its controlling mineral solid.

Some of the most important adsorption mechanisms in soil are those associated with iron and manganese hydrous oxides (Jenne 1968). Jenne (1968) suggested that hydrous oxides are the main controlling factor in the environmental fixation of trace metals. This theory is supported by findings that manganese and iron oxide contents are highly correlated with the quantity of trace metals in soil (Korte 1975). Iron and manganese are both relatively abundant in STF surface soil in areas where elevated concentrations of other metals are present and are expected to increase fixation of these other metals.

Clay minerals, hydrated aluminum oxides, and soil-organic solids may also adsorb metals of concern from the soil solution. Inorganic chemical cations adsorb strongly to hydrous metal oxides, namely iron and aluminum oxides.

As in the case of precipitation reactions, sorption processes are strongly dependent on pH (Stumm and Morgan 1981).

In general, cations exhibit adsorption proportional to dissolved concentration only at low adsorbate concentrations.

6.2.3.1.4 Complexation. Complex formation may affect attenuation and migration of soil solution constituents in two ways. If the complex formation occurs with a ligand in the solution phase, it can greatly increase the contaminant concentration in the solution. Conversely, if the complex formation occurs between the soluble contaminant and ligands immobilized in the solid phase, especially as with organic chelates, the level of contaminants in the solution can be decreased (Schnitzer 1971).

Because soil contains a variety of organic compounds and complexes, the net attenuation effects by complexation is difficult, if not impossible, to evaluate with any degree of certainty.

6.2.3.1.5 Ion Exchange. Most of the ion exchange effects in soil systems originate from the exchange sites on layered silicate clays and organic matter. The layered aluminosilicate secondary materials in soil hold a permanent negative charge. The total capacity of soil to exchange cations is called the cation exchange capacity (CEC).

6.2.3.1.6 Soil Redox Potential. As previously discussed, the soil redox potential affects the oxidation state of many soil constituents, making them either more soluble or less soluble in the soil solution.

Based on a knowledge of the site geology and the types and concentrations of metals in the unsaturated soil, it is possible to develop a conceptual model of metals leaching in the unsaturated zone and use it to evaluate the subsurface processes actually occurring at STF. While the complexity of reaction dynamics in the attainment of chemical equilibria is beyond the scope of this simplified model, the model provides a useful tool for conceptualizing metals transport phenomena in the unsaturated zone.

In most areas of the site where elevated metals concentrations are present in soil, the elevated metals zone consists of the upper few inches or feet of soil. This zone of elevated metals (elevated zone) is underlain by soil material that was largely unaffected by the initial deposition of metal-bearing materials at the site. There are several fill areas where deeper deposition of metal-bearing materials occurred and it is recognized that the elevated zone is thicker in these areas.

Underlying the elevated zone is a zone of native soil material that can be referred to as the retention zone as it has a certain capacity to retard and retain metals leached from the elevated zone. This retention capacity is dependent on critical subsurface conditions (e.g., Eh and pH) remaining relatively constant. When metal-bearing materials were initially introduced into the soil, the total metal masses in each of these materials contained varying proportions of potentially leachable metals. The degree to which the leachable metals have been removed and transported downward may vary in different areas of the site. In some areas, leaching of metals from the elevated zone may have occurred, and sorption or precipitation of these metals may have retained them in soil several feet below the uppermost 2-3 feet of soil. A significant portion of the leachable metals may have already been removed from the elevated zone in these areas. In other areas, much of the mass of metals available for leaching may still be present in the elevated zone. In any case, some quantity of leachable metals remains in the elevated zone.

The amounts of leachable metals present are a function of metallic species present, soil mineral composition, texture, pH, and oxidation-reduction potential. The rate at which leaching will occur is a function of reaction kinetics as well as infiltration rates and the frequency of percolation events. Because the kinetic rate expressions for leaching are extremely difficult to write from purely theoretical considerations, the best data available are those obtained experimentally from the batch leaching tests conducted as part of the Phase II Soil Investigation.

The boundary between the elevated zone and retention zone is not clearly defined, but is instead, defined by a transitional area; the same mechanisms that serve to retain metals in the retention zone are also at work in the elevated zone. Leaching of metals from the elevated zone or eventually from the retention zone represents the exceedence of the capacity of that zone to immobilize metals under existing conditions.

As metals are leached from the elevated zone (or deeper zones), they migrate with the percolating soil water until they are precipitated, adsorbed, absorbed, or until the percolating water itself is immobilized within the soil matrix. As the capacity of each sequentially deeper soil zone to retain metals is depleted and consumed, metals are transported progressively deeper by percolating water. Presumably, the metals available for leaching in the elevated zone are also being simultaneously depleted. Eventually, essentially all leachable metals have been removed from the elevated zone as well as underlying zones, which have been enriched with metals by soil wetting fringes (percolating waters) containing metals.

If capacity is adequate in the retention zone, metals will not be transported into the saturated zone in detectable quantities or at detectable concentrations. If capacity is not adequate, migration of metals into the saturated zone will occur with each saturated zone recharge event. Accurate calculation of the time required for migration into the saturated zone to occur is not possible given the complexity of natural geologic setting. Instead, it is more practical to compare estimated retention capacity to leachable metals quantities. In addition to leaching of metals in the saturated zone from exceedence of retention capacity, rapid water movement through the unsaturated zone could cause such migration to occur. If water movement through the unsaturated zone occurs relatively rapidly, as it may in some of the onsite soils with relatively high hydraulic conductivities, the contact time between percolating water and sorbent media (retention zone soil) may not be sufficient for retention reactions to occur, thus limiting retention and allowing some dissolved (leached) metals to pass into the saturated zone as percolating water recharges the saturated zone.

There is no clear indication that leaching of metals from the unsaturated zone into the underlying groundwater is occurring to any appreciable degree at STF based on the analytical results for filtered groundwater samples collected from the uppermost saturated zone. If water containing metals at appreciable concentrations is percolating through the unsaturated zone and recharging groundwater, it is possible that groundwater quality is unimpacted as a result of a combination of attenuation or dilution in the saturated zone. Metal concentrations leached in sequential batch tests using MWEP were generally quite low (see summary of results in Tables SB-181 through SB-184, Appendix SB). In samples from the Amsted property, copper, lead, and zinc were present at the highest initial concentration and formed the highest concentrations in leaching test extracts. Relatively low concentrations (i.e., less than 1 mg/L) of aluminum, copper, lead, nickel, and zinc were contained in MWEP leaching test extracts for samples from the BNR Dismantling Yard. The potential migration of metals and other chemicals of concern through the unsaturated zone is further evaluated in Section 6.3.

6.2.3.2 Eluviation. Eluviation and leaching are both mechanisms by which chemicals may be moved downward through the unsaturated zone in response to the action of percolating water. Eluviation, or the movement of particles through the unsaturated zone, may be important to chemical movement, but probably only in the uppermost few feet of onsite soil. One result of soil forming processes, which are ongoing in most areas of STF, is the development of distinct layers or horizons of varying depths in the relatively young glaciofluvial sediment or regolith at the top of the unsaturated zone. The unconsolidated uppermost soil layer which is composed of humus and mineral particles, is the zone of eluviation (removal). Materials can be moved down from this layer either in chemical solution or suspension. Underlying the zone of eluviation is a more compact layer in which much of the material carried down from the upper layer is deposited. This layer is the zone of illuviation (accumulation). Relatively insoluble metal particles or particles containing absorbed or adsorbed chemicals could, hypothetically, be moved downward through the unsaturated zone by eluviation. Suspended soil particles in solutions generally range in size from 0.001 to 8 microns. The removal of constituents by soil filtering (straining) is applicable to a wide range of particle sizes, and not exclusively to larger particles (Lu 1985). Even a small depth of soil can remove large quantities of particulate material (Mang et al. 1978).

Field observations and logs from borings drilled throughout the site indicate that, with the exception of the Former Swamp/Lakebed area, unsaturated soil and soil materials containing observable fines are typically confined to depths of 2 feet or less. Based on particle size distribution tests of surface and subsurface soil throughout the site, fines are generally less than 15 percent in surface soils and less than 5 percent in subsurface soils. Clays and other colloidal materials exhibit the greatest tendency for movement by eluvial processes. Hydrometer testing of surface soil indicates that clays are absent. Logs of subsurface soil samples show that clays are largely absent from onsite areas, except for a portion of the Former Swamp/Lakebed area. These and other findings of the RI with respect to chemical concentration distributions in the subsurface at STF indicate that eluviation will not likely have a significant impact on the movement of chemicals of concern in the unsaturated zone at the site.

6.2.3.3 Plant Uptake. Removal of metals from shallow vadose zone soil can occur through plant uptake. Metal cations present in soil water may be absorbed by roots and incorporated into both aboveground and belowground plant tissue.

Only 16 of the 90 (or more) elements that plants contain are actually essential to their growth. These essential elements are carbon, hydrogen, oxygen, phosphorus, potassium, nitrogen, sulfur, calcium, iron, magnesium, boron, manganese, copper, zinc, molybdenum, and chlorine (Donahue et al. 1977). Excessive uptake of a number of these essential elements can be detrimental to plants. Other non-essential metals such as cadmium, chromium, lead, mercury, and nickel may also be absorbed by plant. The phytotoxicity of zinc, copper, and nickel are well documented and, in the case of crop plants, toxic effects are caused by uptake before their concentrations in plant tissue can reach levels that pose problems to human or animal health. The majority of crop plants do not accumulate lead (EPA 1983).

The relative solubility of most heavy metals in most soil water is low and, as a result, their potential for uptake by plants is typically low. Soil CEC (i.e., defined as the amount of exchangeable cations per unit weight of soil measured in milliequivalents per 100 grams of soil) is used to relate total metal additions to a soil's ability to minimize metal uptake by plants. The CEC of a soil is a measure of the net negative charge associated with both clay minerals and organic matter. CECs measured for shallow soil (i.e., 2 feet deep) at STF are relatively high, ranging from 17 to 80 meq/100 g. CEC is a valuable measurement of a soil's ability to retain metals. This is acknowledged by EPA in guidance for developing soil amendment programs where design loading rates are developed for municipal sludges containing heavy metals. Greater heavy metal application rates are typically allowable in soil with higher CECs (i.e., greater than 15 meq/100 g) (EPA 1983).

A soil pH of 6.5 or greater minimizes the uptake of heavy metals by crop plants (EPA 1983). All but one of 22 measured soil pHs at STF were greater than 6.5. The average pH was 7.7 for all soil tested and 7.5 for soil collected at 2 feet BGS. In the case of most of the grasses present onsite, metals uptake may result in cyclic movement of small quantities of metals vertically in shallow soil. For example, metals accumulate aboveground in the living grass plant, the plant dies and decays, and the metals are returned to the soil. The potential uptake of metals by blackberry plants and incorporation into their fruit was studied by sampling, washing, and analyzing blackberries for metals of concern. The findings of the investigation do not indicate that accumulation of metals in blackberries is occurring (see Appendix BB).

Research has shown that PAHs can be present in detectable concentrations in vegetable and fruits grown in PAH-contaminated soil near high traffic areas (Wang and Meresz 1982). However, considering low soil concentrations and low water solubilities of the probable carcinogenic PAH detected at STF, plant uptake is not expected to be significant in terms of chemical transport. Several studies have shown that essentially no plant uptake of PCBs occurs (EPA 1983).

6.2.3.4 Diffusion. Aqueous- and gas-phase diffusion of chemicals are closely related and neither appears to be a significant chemical transport mechanism in the STF unsaturated zone. Conditions under which gas-phase diffusion might play an important role in chemical transport (e.g., concentrated areas of VOCs in the subsurface) generally are not present at STF. Hydrocarbon contamination adjacent to the former tank removal excavation at Pioneer Builders Supply has apparently weathered, and, based on the results of soil gas sampling, is not evolving appreciable concentrations of VOCs into surrounding soil gas. Biologically mediated formation of organometalloid forms of arsenic (i.e., methylation to produce volatile methyl arsines) can lead to migration and/or loss of vapor-phase arsenic to the atmosphere. Volatilization of mercury could, similarly, lead to migration atmospheric losses. Biotransformation and gas-phase diffusion of heavy metals in the unsaturated zone are probably unimportant in terms of mechanism for movement or removal of appreciable metal masses.

Aqueous-phase diffusion of dissolved chemical constituents in relatively immobile soil water coating soil particles in the unsaturated zone is a possible pathway for chemical movement in the unsaturated zone. Movement of chemicals by this mechanism would be expected to be limited by relatively slow diffusion rates (e.g., several orders of magnitude slower than gas-phase diffusion of VOCs) and weak concentration gradients in soil water. Accordingly, this is not regarded as an important unsaturated zone transport mechanism.

6.2.4 Saturated Zone Migration Pathway

Transport of chemicals of concern in the saturated zone is a function of several physical and chemical processes. The dominant processes that contribute to the movement of a chemical through the saturated zone can be separated into two categories. Those that influence the physical transport of the chemical through the saturated formation and those that effect the fate of the chemical during transport. These dominant processes are identified below:

- Transport Processes
    - Advection. Advection is the bulk movement of water caused by differences in the temperature, density, or pressure.
    - Molecular Diffusion. The molecules of a contaminant solute are in a constant state of motion due to their kinetic energy. This movement causes the contaminant to move in non-preferential directions.
    - Mechanical Dispersion. Mechanical dispersion is the spreading and mixing of a contaminant solute through mechanical mixing as the solute moves the interstitial spaces of the porous media.

- Fate Processes
    - Sorption. Sorption refers to the partitioning of the contaminant media molecules as solute passes through a solid media.
    - Biochemical Transformation. Biochemical transformation refers to the formation of daughter products through processes such as hydrolysis, biodegradation, oxidation, reduction, precipitation, and volatilization.

As with chemical movement through the vadose zone, the processes of groundwater chemical movement occur simultaneously and their actions are interrelated. Depending on several site-specific conditions including the solute composition and the nature of the aquifer, some of these processes may be dominant over the others.

The following conceptual model of contaminant transport in the saturated zone begins with a discussion of transport processes. These are the processes that are responsible for the movement of groundwater and contaminant solute through the saturated formation. This discussion is followed by a summary of fate processes which describe transformation and volume reduction of solute during transport. The conceptual model is based on the assumption that inorganic and organic chemicals of concern have been carried to the saturated zone (Upper Layer A) by any of a number of means including percolation of surface water.

As a discussed above, advection is the principal process for movement of groundwater through the formation. The process occurs as a result of pressure gradients in the formation (EPA 1989). Groundwater will typically flow from high pressure to low pressure, which is usually in the direction of the hydraulic gradient. As the groundwater moves, it transports the dissolved contaminant (solute) with it. This process is typically responsible for horizontal movement of the contaminant in the aquifer. However, depending on the aquifer, there may be vertical gradients that effect the vertical movement of groundwater as well. At the STF site, the primary direction of the hydraulic gradient is to the north to northwest. This general flow gradient may be altered by groundwater pumping, which occurs to the east of the STF site, and variations in seasonal recharge (refer to Appendix HC for more detail).

Advective forces may also effect the vertical movement of non-aqueous phase liquid (NAPL) contaminants through density differences. For example, if the NAPL is more dense than the surrounding groundwater, advection will cause the NAPL to sink in the formation as it moves horizontally. The investigative results from the RI do not suggest the presence of dense NAPLs in groundwater at the site. Groundwater may also move vertically in the uppermost saturated zone in response to vertically hydraulic gradients induced by leakage through an underlying confining layer. Based on calculations made during performance of the Hydraulic Characterization Investigation, there appears to be little tendency for groundwater to move vertically through confining layer separating Upper Layer A from Lower Layer A.

The second transport process identified above is the molecule diffusion of contaminant molecules. This process is also referred to Brownian motion and results from molecular vibration. Molecular diffusion is an isotropic process that occurs in the absence of advection and causes gradual mixing of the solute with the surrounding groundwater. A typical example of molecular diffusion is the gradual spreading of a dye (solute) in a quiescent bowl of water. With increasing time, the dye will eventually achieve equilibrium in the bowl and the water will be of an uniform color. In this way, molecular diffusion is responsible for movement of a chemical from areas of high concentration to areas of lower concentration. Areas of the saturated zone in which diffusion may play a significant role in chemical movement at STF include the petroleum hydrocarbon plume in groundwater at Pioneer Builders Supply, and the wetlands/surface water channel.

The third transport process identified above is mechanical dispersion. As groundwater moves through a formation, numerous bifurcations, velocity variations and intricate meandering of flow through the complex pore structure cause contaminant spreading in the transverse and longitudinal directions. On a micro-scale, this mechanical dispersion is caused by the following conditions:

- As the groundwater flows through the individual pore spaces of the soil particles, it experiences frictional forces at the boundaries of the pores. This results in zero velocity at the soil particle and accelerated velocities in the pore spaces.

- The tortuous path that groundwater takes as it moves through the soil particles results in splitting and deflection of the stream flow.

Mechanical dispersion is an anisotropic process and occurs only where there is bulk movement of the groundwater. In the absence of advection, mechanical dispersion would not occur. Given the coarse-grained texture of the aquifer materials at the STF site, mechanical dispersion is expected to be less effective in mixing of a solute than it would be in a aquifer composed of predominantly fine-grained soil particles.

These latter two processes have the tendency of increasing the transport rate of a chemical solute over that caused by advection alone.

Similar to the retention zone discussed above in Section 6.2.3.1, several processes affect the fate of a chemical as it moves through the porous media of an aquifer. The most important processes include sorption and transformation. These processes typically tend to retard the rate of contaminant movement, reduce the volume of contaminant, and/or transform the contaminant.

The uppermost saturated zone at STF, Upper Layer A, contains and transmits the groundwater into which chemical releases from the site's surface and unsaturated zone are most likely to occur.

The uppermost saturated zone at STF can be regarded as characterized by two distinct settings:

- The uppermost saturated zone overlain by an appreciable thickness of unsaturated soil

- The uppermost saturated zone beneath and immediately adjacent to the surface water channel and associated wetlands.

Percolating water, which may contain chemicals of concern, can enter the uppermost saturated zone through essentially constant recharge in portions of the wetlands/surface water channel or through periodic recharge "events" that occur as wetting fringes migrating through the unsaturated zone reach the water table. As discussed extensively in Sections 6.2.3 and 6.3, the unsaturated zone has the capacity to retain chemicals of concern by various mechanisms as they percolate through the unsaturated zone.

The same retention mechanisms are available to retain chemicals as they migrate through perennially saturated sediment in and near the wetlands/surface water channel. However, many environmental conditions that affect chemical movement differ substantially in this area from the rest of the site. The conditions are summarized below.

- Offsite Chemical and Sediment Loading. Unlike other areas of the site, chemicals and sediment from offsite sources continue to be deposited in the wetlands/surface water channel area. To a large extent, much of this deposited chemical mass may already be relatively immobile in that it is sorbed to suspended sediment. Compounds, such as surfactants, that affect the mobility of chemicals of concern may also be deposited to the onsite surface water channel through runon.

- Organic Matter Formation. The biological activity in the wetlands and along other portions of the onsite channel continue to create new organic matter that is assimilated into the sediment in this area. This constant replenishment and building of the organic matter content in the area's sediment forms a substrate that is important in regulating chemical fate and mobility.

- Organic Acid Formation. Organic acids, including humic and fulvic acids, are formed in natural stream environments as vegetal matter decays. The addition of organic acids to the soil water system in the wetlands/surface water channel area plays an important role in regulating chemical fate and mobility immediately underlying saturated zone. These acids may act as complexant ligands that may reduce or increase the solubilities of metals species. In addition, they serve to lower the pH of groundwater in this area, as shown in Figures RI-7 and RI-8.

- Oxygen Depletion. The presence of standing water over large areas and the decay of underlying organic matter through biological activity tends to consume available oxygen in the uppermost saturated zone in the wetlands/surface water channel area. The resulting reducing environment in the uppermost aquifer is evidenced by the presence of dissolved iron and manganese concentrations in shallow groundwater samples collected from the southwest portion of the site, which are higher than most detected elsewhere onsite. This reducing zone can be significant locally to the mobility of certain metals. Some metals become more soluble in reducing solutions, and dissolution of ferric hydroxides and manganese oxides will release metals sorbed to these solids.

The complexity and dynamics of the mechanisms governing chemical fate and transport in the uppermost saturated zone beneath the wetlands/surface water channel area make accurate quantitative modeling of these mechanisms and prediction of the resultant effects on groundwater quality impossible. However, existing groundwater quality data for wells sited in this area provide a useful indication of the cumulative effects of the mechanisms on groundwater quality given that appreciable concentrations of chemicals of concern have likely been resident in the area's sediment for many years. The effects of further chemical loading to sediment in this area are further evaluated in Section 6.3.4. As discussed in Section 6.1.3.3, biochemical transformation processes may affect the fate of organic chemicals in the saturated zone onsite.

Biochemical transformation includes a variety of chemical reactions (e.g., hydrolysis, biodegradation, oxidation, reduction, precipitation, and volatilization). Because mass is neither created or destroyed, these transformations result in the formation of daughter products of organic compounds. Based on analytical results of groundwater samples, two areas of the STF site have been identified where biochemical transformation may be important to organic chemical transformation and degradation (i.e., Pioneer Builders Supply property and the Amsted property).

6.3 EVALUATION OF CHEMICAL MIGRATION POTENTIAL

This section presents the evaluation of chemical migration potential along those pathways that have been identified in preceding sections as being potentially significant in terms of chemical transport. The evaluation includes consideration of 1) the potential movement rate and chemical composition of water percolating through the unsaturated zone (soil solutions) and into the saturated zone; 2) the potential capacity of unsaturated soil to retain metals through cation exchange; 3) the estimated migration rates for organic chemicals of concern in the subsurface; and 4) the potential effects of the chemicals of concern present in surface water runon and sediment in the onsite wetlands/surface water channel area.

6.3.1 Inorganic Chemical Quality of Soil Water and Groundwater Recharge

The following evaluation was performed to examine the theoretical inorganic chemical composition of soil water at a hypothetical location on the Amsted property or BNR Dismantling Yard, and to quantitatively evaluate the attenuative mechanisms that would influence the chemical composition of that soil water as it percolates through the unsaturated zone and eventually reaches groundwater.

The volume of water that percolates through unsaturated soil, V_{WP}, at the STF site is dependent on several factors. In general, the volume of water percolating, its rate of movement, and its chemical composition are generated by the following conditions:

- Availability of water
- Site surface conditions
- Chemical loading and characteristics at the site

- Subsurface soil conditions.

Factors affecting the availability of water include direct precipitation, surface run-on, groundwater intrusion, and irrigation. Of these, only direct precipitation and surface runon apply to the site. Groundwater intrusion is not a factor in the STF site areas considered in this evaluation because the contaminated soil layer is above the groundwater table.

Direct precipitation represents the primary source controlling water availability at the soil surface. The effect of surface runon in this case is comparatively smaller and can be ignored for the purposes of estimating leachate volumes generated. The amount of surface runon is expected to be very small because of the vegetative cover that exists at the site and its surrounding areas, and because surface slopes in the areas adjacent to the site are less than 2 percent.

Some water accumulated at the site surface due to direct precipitation is lost through evapotranspiration. The balance infiltrates through the site surface or leaves the site as surface runoff. The breakdown of available water distribution among infiltration, surface runoff, and evapotranspiration is largely dependent on location-specific surface conditions (e.g., vegetation, cover material characteristics, land topography) and underlying soil properties (e.g., permeability, compaction, moisture content). The quantitative determination of this breakdown at the site is very complex. For simplification, this analysis assumes that all water accumulated at the site surface infiltrates through the site surface (surface runoff and evapotranspiration losses are assumed to be negligible).

6.3.1.1 Precipitation. As discussed previously, precipitation will be the main contributor to V_{WP}. Precipitation includes rainfall and snowfall. Rainfall induces more direct and rapid percolation than snowfall (Caffrey and Ham 1974; Fenn et al. 1975; and Dass et al. 1977).

Storm characteristics affecting percolation rates are amount, intensity, frequency, and duration (Chow 1964). In general, rainfall amounts can be estimated based on existing precipitation records applicable to the site. The average annual precipitation for the site area is 37.06 inches/year. Rainfall intensity, frequency, and duration are harder to estimate accurately. For the sake of analysis, the effects of rainfall intensity and duration are considered assuming conditions equivalent to the 100-year storm event occurring at the site. The rainfall value for a 24-hour, 100-year storm for the site is approximately 4 inches.

6.3.1.2 Average Linear Velocities of Percolating Water. Estimation of the average liner velocity is used to evaluate the contact time that could occur between the percolating water and the contaminated (elevated zone) soil at the site. The calculated contact time can be used to estimate whether equilibrium conditions can be expected to occur.

Hydraulic conductivities for the metals-bearing surface soil layer (elevated zone) throughout the site have been determined to vary between $1\text{x}10^{-6}$ and $1.5\text{x}10^{-4}$ cm/sec, depending on the localized soil composition. Using sample-specific porosity data, the average linear velocity of water that infiltrates the ground surface and percolates through the elevated zone would range from $2.8\text{x}10^{-6}$ to $1.6\text{x}10^{-3}$ cm/sec. With the exception of several subsurface samples from Tacoma City Light property and the Former Swamp/Lakebed area, measured subsurface hydraulic conductivities were consistently greater than $1\text{x}10^{-4}$. These sample data in conjunction with recorded lithologic conditions indicate that deeper subsurface percolation rates will exceed those occurring in the elevated zone over the majority of the site. Accordingly, it can be concluded that the rate of percolating water movement through the elevated zone at the site will be the controlling rate that governs contact time in that zone. We therefore assumed an average linear velocity range of $2.8\text{x}10^{-6}$ cm/sec (0.095 inches/day) to $1.6\text{x}10^{-3}$ cm/sec (54 inches/day) to estimate contact times between the contaminated soil layer and the water traveling through the soil at the site.

6.3.1.3 Soil Water Composition. Significant research efforts have been spent in attempts to predict the composition of leachates (soil water) that are generated in soils. However, the accurate prediction of soil water compositions for a given site remains a complex and difficult, if not impossible, effort. Despite this fact, some general conservative assumptions can be made regarding the maximum metal concentrations that can be expected to be present in a soil solution based on soil chemistry and ionic solubility equilibria alone. (Additional factors affecting soil solution composition are discussed later.) Equilibrium solubility data for inorganic constituents in the aqueous (water) phase of soils have been developed empirically over the years. The basis for estimating inorganic concentrations in the water phase of soils at equilibrium along with other information on chemical equilibria of inorganic constituents in soils can be found in the literature (Lindsay 1979). This information was used to estimate maximum inorganic concentrations that can be expected in the soil water.

6.3.1.4 Summary of Factors Affecting Soil Solution Composition. In general, the solubility of soil constituents is affected by a variety of physical, chemical, and biological activities occurring within the soil.

Physical factors that affect leachate composition include rainfall properties and residence time of the water through the contaminated soil layer. The most important rainfall property is the rainfall pH, which affects the pH of the soil. For purposes of simplification, a rainfall pH of 5 is assumed for this evaluation. Residence time of the water in contact with the soil depends on the thickness of the soil zone under consideration and water infiltration rates. In general, longer residence times allow soluble chemical constituents to approach equilibrium concentrations. Thus, concentrated soil solutions would be expected when residence times are long, whereas dilute solutions would be expected when residence times are short. This pattern has been verified for soil as well as solid wastes under actual field conditions (Lu et al. 1985). For the range of calculated average linear velocities of 0.095 to 54 inches/day (under saturated flow conditions) and a contaminated soil depth of 6 inches, the residence time is calculated to be between about 2.7 hours and 63 days. A residence time of 63 days may be enough for some chemical constituents in the soil to reach their ionic equilibria with their corresponding mineral phases, but is not enough for other constituents. However, it should be noted that the attainment of concentration equilibria in actual soil solutions are much more likely than these saturated flux residence times imply, because considerably longer residence times may be expected for some recharge water once the specific retention of the elevated zone is reached following a precipitation event.

Chemical and biological factors that affect the chemical composition of the soil solutions are pH, redox potential, adsorption and complexation mechanisms, precipitation/dissolution mechanisms (ionic solubility), temperature, biological mechanisms, and ion exchange. These factors are discussed in some detail in Section 6.1.3.2.

The pH of the soil solution influences chemical processes (precipitation, dissolution, redox reactions, and sorption). Acidic pH conditions tend to increase the solubilization of trace metal constituents and decreases the sorptive capacity of soil.

The redox potential will affect the oxidation state of many soil constituents, making them either more soluble or less soluble in the soil solution.

Adsorption and complexation are probably the most important processes influencing the attenuation or mobility of trace metal constituents in soil. Under oxidizing conditions, adsorption can regulate the concentration of a constituent well below the level controlled by ionic equilibria/precipitation effects. In complexation, metal cations combine with non-metallic compounds called ligands by means of coordinated-covalent bonds. In general, complexation acts to increase the concentration of metals above their normal expected solubilities in soil solution. Conversely, complexation of metals could also enhance the adsorption of metals by the solid phases of a soil, depending on the specific metal, the ligand type, and mineral composition of the soil. The net effect of adsorption and complexation mechanisms on soil solution composition is difficult to quantify because of the complex and heterogeneous nature of soil systems.

The ionic equilibrium relationships that exist between soluble ions in the soil solution and the minerals present in the solid phase of the soil establish how inorganic constituents partition themselves between the solid and liquid phases. Soils contain numerous minerals. These minerals impose limits on the chemical composition of the soil solution. If the soil solution becomes supersaturated with respect to any mineral, the mineral can precipitate until equilibrium is attained. If the soil solution becomes undersaturated with respect to any mineral present in the soil solids phase, that mineral can dissolve until equilibrium is attained.

Temperature plays a role in controlling the solubility of many chemical constituents and their reaction rates, as well as controlling biological activity.

Biological processes affect the ionic equilibria in soil solutions through immobilization of chemical constituents by biological assimilation, formation and decomposition of organic-inorganic complexes, control of redox potential, and through control of CO_2 and O_2 levels in the soil. Through these processes the constituents in soil solutions can be mobilized, complexed, precipitated, or sorbed.

The ion exchange capacity of a soil can also affect the level of chemical constituents found in the soil solution. The ability of the soil to immobilize soluble ions depends on the availability of exchange sites within the soil, the specific ion type, contact time, the diffusion characteristics of the soil/water system.

6.3.1.5 Calculation of Soil Solution Composition. To conservatively estimate soil solution composition at the STF site, the general characteristics of a contaminated soil area at the site and its interaction with the infiltrating water have been assumed. Based on these soil and water characteristics, an analysis and estimation of the concentrations for the major cationic species of concern under equilibrium conditions was performed on a specific cation basis to arrive at the rough estimation of soil solution composition. This evaluation conservatively assumes that sufficient contact time is available for the dissolution of solid phase metallic minerals to proceed to equilibrium.

6.3.1.5.1 Contaminated Soil and Infiltrating Water Characteristics. Soil with elevated metals concentrations at the STF site had pH values ranging from 6 to 8. These pH values are consistent with those exhibited by typical soils, which range from 3.5 to 9.0. Because the pH of the water infiltrating through the soil is assumed to be 5, the pH of the soil solution (i.e., the liquid phase that completely envelops the solid phase in a soil matrix) is generally expected to vary between 5 and 8, depending on amount of water infiltrated, carbonic acid concentrations in the soil solution, and dissolution and precipitation of minerals within the soil matrix as a result of soluble ion removal that occurs during the infiltration process. To establish ionic concentrations at equilibrium, assumption of a system pH is required. A conservative soil pH solution of 5 is used as the basis for calculating soluble ion concentrations in this analysis.

As previously discussed, the soil solution is affected by a range of biological and chemical adsorption mechanisms, but its composition is ultimately controlled by the mineral phases present in the soil (Lindsay 1979). However, the rates of dissolution and precipitation of soil minerals are so slow for some constituents that true equilibrium is not attained. An ion's tendency to remain in solution is influenced by the concentration of that ionic species in the soil solution, and the ability of solid phases in the soil to replenish that species as it is depleted from solution.

The concentrations of common metals (e.g., Al, Fe, Ca, Mg) detected in soil samples from the STF site are generally within the typical ranges detected in most native soils. Cu, Zn, Pb, Cd, and Mn concentrations are substantially elevated in some STF surface soils. Na, K, and Ca levels in the STF soils are relatively low in comparison to typical levels found in native soils. The low Na, K, and Ca contents observed lead to the assumption that the STF soil can be characterized as being a soil composed mostly of unsubstituted aluminosilicates, with some portion of the aluminosilicates being present as Mg aluminosilicates (montmorillonite). Soils contain many different aluminosilicate minerals (Dixon and Weed 1977). The presence of appreciable concentrations of Fe in soil indicates that iron minerals (such as iron oxides and hydroxides) are also present in significant amounts in the soil.

For this evaluation, it is also assumed that reducing conditions prevail in the elevated zones (as defined in Section 6.2.3.1) based on the fact that the contaminated soil typically is covered by vegetation and is the soil layer located at the surface. Living organisms within the contaminated soil and the vegetation cover above decrease O_2 levels and increase CO_2 concentrations in the soil. These biological processes have reducing effects on the soil matrix.

Rainfall adds water that dilutes the soil solution. The excess water may drain from the soil profile and carry with it salts and other dissolved constituents. Although dilution of the soil solution by this mechanism will tend to prevent the saturation of the soil solution under equilibrium conditions, the calculation of ionic concentrations presented herein will be based on the assumption that saturation (equilibrium) conditions are attained. This permits the calculation of conservative ionic levels in the soil solution based on the assumption that precipitation/dissolution mechanisms control the soil solution composition.

Discussion and calculation of the predicted concentrations of a specific ion in the soil solution based on ionic equilibria are presented in the following paragraphs.

6.3.1.5.2 Aluminum. During the infiltration of water, aluminum is released from primary minerals and precipitated in the form of a secondary mineral, largely as aluminosilicates. Following the aluminosilicates, gibbsite [gamma-$Al(OH)_3$] is the next most common Al hydroxide mineral found in soils. Both aluminosilicates and gibbsite limit the activity (concentration) of Al^{3+} in the soil solution. Because the equilibrium concentration of Al^{3+} with respect to aluminosilicate minerals is lower than that with respect to gibbsite, it is conservatively assumed that the concentration of Al^{3+} in the soil solution is controlled by the gibbsite solubility line. The concentration of Al^{3+} is empirically given by:

$$\log Al^{3+} = 8.04 - 3\,pH$$

For the assumed soil solution pH of 5, the expected Al^{3+} concentration is predicted to be 1.1×10^{-7} moles/liter (M), or 0.003 mg/L.

Other aluminum minerals that might be present in the STF soil in smaller amounts (such as sulfates) are too soluble to persist in soils. As can be seen by the relationship, the total aluminum concentration in soil solution is pH-dependent and is unaffected by the soil redox potential. It should be noted, however, that Al^{3+} can form complexes that can increase the total soluble Al in the soil solution.

6.3.1.5.3 Silica. The solubility of silica in terms of undissociated silicic acid (H_4SiO_4, or "soluble silica") is expected to range from 0.0001 M (9.6 mg/L) to 0.00182 M (175 mg/L). The concentration of soluble silica in soil is largely unaffected by pH. However, equilibrium concentrations are difficult to attain because soluble silica tend to be adsorbed in the surface of soils. The dissociation of soluble silica to form silicate ions is very small. This dissociation is insignificant at pH 7 and below. In the normal pH range of soils, only soluble silica dominates the major silicate species present in the soil solution.

6.3.1.5.4 Aluminosilicates. Aluminosilicates comprise a major portion of the mineral fraction of soils. Primary aluminosilicates in soil are relatively unstable and dissolve slowly. Some of the products recombine to produce secondary soil minerals such as kaolinite [$Al_2Si_2O_5(OH)_4$] that are more stable in soils. All of the sodium aluminosilicates minerals are unstable in soils and will disappear with weathering because kaolinite and pyrophylite [$Al_2Si_4O_{10}(OH)_2$] aluminosilicates are more stable. Sodium aluminosilicates do not appear to be a major STF soil component due to the low levels of Na measured. Over time, Na is expected to leach from the soil matrix. The same is true for potassium and potassium aluminosilicates, especially at pH 5 and above. The decrease in pH below 7 favors the dissolution of calcium aluminosilicates leading to precipitation of kaolinite instead. Ca^{2+} ions are also expected to be depleted from the soils by leaching over time.

6.3.1.5.5 Carbonates. Carbonate reactions are among the most important occurring in soils. Plant roots and other organisms in soils continually produce CO_2 which lowers soil pH. The partial pressure of CO_2 in shallow soil gas is expected to be slightly higher than in atmospheric air because of root and organism respiration. In flooded soils, the CO_2 level is much higher because diffusion of the gas through water is much slower than through air. CO_2 levels in flooded soils can range from 0.01 to 0.3 atm. At pH levels below 5.8, no carbonates are formed in the soil solution, with negligible amounts of carbonates being present in soil at pH values below 7. At these pH levels, only bicarbonates and dissolved carbonic acid are present. The level of dissolved carbonic acid is approximately $1x10^{-5}$ M, and of bicarbonate is about $1x10^{-5}$ M and below with decreasing pH. The concentration of carbonates in acidic soils is expected to be quite low, and thus the existence and stability of carbonates at pH 5.8 and below is very low.

6.3.1.5.6 Calcium. Calcium levels are variable in soils. Ca content in soil solutions is largely controlled by the availability of parent material and rainfall. All calcium aluminosilicates are unstable in acidic soils and can be expected to eventually dissolve. The reference concentration of Ca ions in acid and neutral soil solutions is estimated at about 0.0032 M (130 mg/L). In such soil solutions, soluble Ca ions are largely buffered by exchangeable calcium because of the high selectivity that soils (especially aluminosilicate and other clay minerals) have for calcium ions. As exchangeable bases are depleted from soils, the pH drops causing H^+ and Al^{3+} to enter the exchange sites displacing Ca^{2+} and other cations. This displacement helps to maintain fairly constant levels of soluble Ca^{2+} over a wide range of pH. In acidic soils, the formation of calcium complexes does not affect total soluble calcium concentrations significantly and therefore, their effects can be ignored. Redox relationships in soil do not affect calcium concentrations in soil solution. Calcium concentrations in shallow groundwater at the STF site typically ranged from 10 to 100 mg/L.

6.3.1.5.7 Magnesium. Below pH 7.5 most Mg minerals are too soluble to persist in soils. Because of this, Mg depletion in acidic soils can be expected. The equilibrium solubility of Mg ions in the STF soil solution, buffered by exchangeable Mg, is estimated at 0.001 M (24 mg/L).

6.3.1.5.8 Sodium and Potassium. The low quantities of Na and K present in the STF contaminated soil are expected to be depleted over time. Na and K are present in the soil matrix as adsorbed exchangeable cations in the soil. The concentration of Na in soil solution in equilibrium with exchangeable Na (or soil-Na) adsorbed in typical soils is about 0.001 M (23 mg/L). This level of Na is the approximate level found in well-drained soils. Approximately the same level has been determined for soluble K (0.001 M or 39 mg/L). Sodium concentrations detected in shallow groundwater at the STF site were roughly consistent with the calculated equilibrium concentration. Potassium concentrations in groundwater were significantly lower than the calculated equilibrium concentration, suggesting that onsite soils are generally potassium-deficient.

6.3.1.5.9 Manganese. Manganese exists in soils either as Mn(II), Mn(III), or Mn(IV). Mn forms hydrated oxides with mixed valency states. Mn solubility in soils is affected by pH, redox potential, and complexation. Common minerals of Mn include oxides, carbonates, silicates, and sulfates. The most stable Mn mineral under well-oxidized conditions is pyrolusite (MnO_2). Estimation of the Mn concentration in the soil solution is difficult due to its dependence on several factors. However, a Mn solubility as high as 0.1 M (5,500 mg/L) in the soil solution is estimated for typical soils containing 10 percent moisture by weight.

6.3.1.5.10 Zinc. The solubility of Zn^{2+} in the soil solution increases with decreasing solution pH. The solubilities of all zinc minerals increases 100-fold for each unit decrease in pH. Other minerals seem to play a role in controlling equilibrium Zn ion levels in soil, although the actual relationships continue to be studied. Carbonates, hydroxides, and oxides of zinc are too soluble to persist in soils. The specific minerals controlling the activity of soluble Zn in soil solutions are not known. Soluble Zn equilibrium is probably controlled by exchangeable Zn present in the soil matrix. At pH 7.7 and below, the predominant Zn species present in solution is the Zn^{2+} ion. Formation of the zinc-hydroxyl complex ($ZnOH^+$) is more prevalent above this pH value of 7.7. Zinc ion can also form complexes with sulfate ion to form the $ZnSO_4$ complex. Formation of this complex increases the solubility and mobility of Zn^{2+} in soils. The reference solubility equation for zinc in the soil solution was developed empirically (Lindsay 1979). The relationship is:

$$\log Zn^{2+} = 5.8 - 2\,pH$$

At a pH of 5, the resulting zinc concentration in soil solution is 6.3×10^{-5} M (4 mg/L).

6.3.1.5.11 Copper. The minerals governing the solubility of Cu^{2+} in soils are not known. However, its solubility is known to be primarily controlled by pH.

As with zinc, a reference solubility equation for Cu was developed empirically. The relationship is:

$$\log Cu^{2+} = 2.8 - 2\,pH$$

At a pH of 5, the equilibrium Cu^{2+} concentration in soil solution is expected to be 6.3×10^{-8} M (0.004 mg/L).

Cu^{2+} is the predominant ion below a pH value of 6.9, while the complex $Cu(OH)_2$ is the major solution species above that pH. Bicarbonate can also complex with copper ion under near-neutral pH conditions and when high CO_2 concentrations are present in the soil. Both organic and inorganic complexes of copper are normally present in soil solutions, both of which contribute to the concentration of soluble copper in the solutions above the equilibrium concentration as calculated above. When complexing agents are absent or only present in low concentrations, Cu (II) is expected to be substantially removed from solution by adsorption. Higher concentrations of complexing agents (particularly organic ligands and surfaces) can result in partial or total release of the adsorbed copper into solution as complexed copper, depending on the surface/organic ligand ratio (Vuceta and Morgan 1978).

6.3.1.5.12 Lead. Lead(II) oxide (PbO) forms are very soluble minerals in soil, even at pH 8 or above. Cerrusite ($PbCO_3$) is the most stable Pb mineral in soil with pH values above 6 because CO_2 levels in soils are generally higher than those of the atmosphere. However, lead carbonates are very soluble in soil matrices. Anglesite ($PbSO_4$) is the most stable form of Pb at pH 6 and below, although just as with carbonates, sulfates are very soluble in soil matrices. Other Pb minerals such as silicates, chlorides, and oxides of lead are also too soluble to be important in soils.

Below pH 8, only Pb^{2+} and the $Pb(OH)^+$ complex contribute significantly to total lead in solution. This is true even for contaminated soils where Pb^{2+} may approach 0.001 M. An average soluble Pb concentration of $3.2\text{x}10^{-9}$ M (0.0007 mg/L) at equilibrium is estimated for soil solutions with pH values ranging from 5.5 to 7.5 where hydroxyapatite and chloropyromorphite control phosphate and lead activities. The actual level of total soluble lead in the soil solution is nevertheless expected to be higher due to the formation of Pb complexes. The value depicted above could also be higher because trivalent cations such as Al and Fe depress phosphate ion concentrations, thus increasing Pb^{2+} solubility.

6.3.1.5.13 Iron. The solubility of trivalent iron in soil solutions is largely governed by its thermodynamic equilibrium with ferric oxide and hydroxide minerals present in the soil matrix. The ferric ion solubility in typical soils is correlated to pH in the following equation:

$$\log Fe^{3+} = 2.7 - 3\,pH$$

Assuming a soil solution pH of 5, the equilibrium Fe^{3+} concentration found in soils is approximately $5\text{x}10^{-13}$ M ($2.8\text{x}10^{-8}$ mg/L). Although ferric ions are known to form several complexes in soil with chloride, nitrate, sulfate, and phosphate anions, none of them are particularly significant in soils. Instead, ferric ions tend to hydrolyze with water to form soluble $Fe(OH)_3$, $Fe(OH)_2{}^+$, and $Fe(OH)^{2+}$ ions in much higher quantities than Fe^{3+} ion alone. In the pH range of soils, these hydrolysis species are more abundant than free Fe^{3+}, thereby increasing the total iron concentration in solution. At a pH of about 5, the combined concentration of all predominant hydrolyzed ferric species plus free Fe^{3+} result in a calculated total soluble iron concentration of about $6\text{x}10^{-4}$ mg/L as iron.

It should be noted that iron concentrations found in a soil solution are attributable not only to the ferric ion and its hydrolyzed forms, but to the ferrous ion and its hydrolyzed forms. The relative ratio between the ferric ion and the ferrous ion is primarily affected by the redox potential in the soil. Ferrous ions are expected to predominate in reducing environments such as in this soil where biological processes occur. The equilibrium solubility of the ferrous ion alone is higher than those for the various ferric ions, at pH values near 5. The estimated Fe^{2+} concentration found at this pH in the soil solution assuming slight reducing conditions is in the order of 1.5×10^{-6} M (0.084 mg/L).

Based on the foregoing discussion, the ferrous ion is expected to contribute the most to the total soluble iron levels in the soil solution.

6.3.1.6 Comparison of Thermodynamic Equilibrium Data With Leachate Tests. Leachability tests were conducted on samples of contaminated soil obtained from the site at four different locations. The tests were conducted by running a 1-L volume of deionized water per extraction run through a 10 gm soil sample. Four sequential extractions were conducted per soil sample. Each extraction was carried out according to the Monofilled Waste Extraction Procedure (MWEP). The analytical results for the four soil samples tested are shown in Tables SB-181 through SB-184 of Appendix SB.

In addition to the MWEP extraction tests, a TCLP extraction test was also performed on each of the four soil samples used for the MWEP test. The results are shown in Table SB-186 of Appendix SB.

The resulting metal concentrations in the extracts obtained from either the MWEP or TCLP tests were consistently higher than those predicted based on the thermodynamic equilibrium data for soils. These results might suggest that the effect of ion complexation and other soil mechanisms play a larger role in controlling the resulting extract composition, than do thermodynamic equilibrium relationships in the soil. In addition, it should be noted that the predicted equilibrium solution concentrations are based on the solubilities of metallic metals commonly found in soil. The speciations in which individual metals are actually present in onsite soil are not known.

Results of the MWEP and TCLP tests may suggest that metals concentrations present in the leaching test extracts are artificially elevated in response to the presence of complexing agents, which were liberated into solution (during the testing procedures) in quantities that would not be expected under natural circumstances. The leachability tests used (MWEP and TCLP) sacrifice accurate prediction of leachate constituent intensity (concentration) in the interest of providing conservative estimates of total leachable constituent masses (EPA 1978a; EPA 1979a; and Houle and Long 1980).

Based on the leaching results, it can be concluded that the prediction of the soil solution composition for the STF soils cannot be based on chemical equilibria data alone. In light of the equilibria concentrations predicted on the basis of thermodynamic considerations, it appears that TCLP extract results can reasonably be used to represent maximum credible soil solution concentrations. The TCLP leaching test is designed to simulate the effects of highly aggressive precipitation (acid rain) on the generation of leachate from a solid waste mixture. The leachate produced and its composition, therefore, provide an indication of highest contaminant metal concentrations that should be expected in the leached solution.

6.3.1.7 Conclusions. Based on the discussions presented above, the following conclusions and recommendations can be made:

- The movement of water through the unsaturated zone at the site is affected by several site and atmospheric conditions. Among these, rainfall (precipitation) and site surface conditions are the most important factors affecting the volume of water that percolates through the unsaturated zone at the STF site.

- The composition of the soil solutions that would be formed at the STF site is very difficult to predict due to the complex mechanisms present in soil systems. Comparison of calculated ionic species in a soil solution (based on soil solubility equilibrium data) with data from batch extraction tests (namely MWEP and TCLP) performed on soil samples from the STF site indicate that soil mechanisms other than thermodynamic solubilities alone influence the ultimate concentration of soluble chemical species in the soil solution. Quantitative prediction of the effect of these soil mechanisms, however, cannot be made.

- Attenuation and immobilization of metals of concern will occur when percolating soil solutions reach the underlying soil layers. One of the major attenuation factors will undoubtedly be adsorption.

6.3.2 Sitewide Cation Exchange Capacity Evaluation

A simple model was developed to compare the theoretical cation exchange capacity in the unsaturated zone (retention zone as defined in Section 6.2.3.1) with conservatively estimated cation quantities that might leach from the overlying surface soil (elevated zone). Conservative assumptions regarding metals leachability and sorption were made to model a "worst-case" situation. This evaluation used site-specific data on CECs for subsurface soil and metals leachability from surface soil.

As noted previously, neither the TCLP nor the MWEP testing performed on surface soil samples from the site were designed to accurately predict leachate constituents concentrations. Instead, they are batch test procedures that were designed to simulate "worst-case" conditions and provide conservative estimates of leachable contaminant masses.

The TCLP extraction procedure was generally developed to predict contaminant leachabilities in landfills where industrial solid wastes have been co-disposed with municipal wastes. Results of TCLP tests are used for comparison to regulatory levels established under the Resource Conservation and Recovery Act (RCRA). The TCLP was not intended to simulate in situ leachability of metals-bearing soils. Specific limitations of the TCLP test in relation to surface soil leachability at STF are:

- TCLP uses an excessively acidic leaching solution. For materials with a pH value greater than 5, the leaching solution is specified to have a pH equal to 2.9. Surface soils at the site are not generally expected to be exposed to such a low pH leaching conditions.

- Grinding and milling are employed during sample preparation to decrease sample particle size. This preparation step may expose additional soil surface area to the leaching solution that would not be exposed for leaching under actual in situ conditions.

The MWEP was developed to predict the time-dependent, mass leaching behavior of a homogeneous single-component industrial waste that has been landfilled (e.g., fly ash, electroplating sludge). Limitations of the MWEP data for use in predicting metals leachability from surface soil at the site include:

- Soils at the STF site are a complex, multi-component system. These soils also were found to have very heterogeneous compositions and concentration distributions.

- The MWEP testing performed on STF soil samples simulated a maximum of 3.8 years of leaching under saturated conditions.

As noted previously, batchwise leaching of soil employs mechanical agitation that may liberate complexing agents into solution that might not be available under natural conditions. This is consistent with the test objectives of TCLP and MWEP, which include use of test conditions that yield conservative results.

The objective of the CEC evaluation was to compare the non-specific adsorptive capacity of subsurface soils at the site to "worst-case" leachable metals as predicted by TCLP testing. The TCLP leaching data were used on the basis that they represent the maximum cation masses that could reasonably be expected to leach from the elevated zone.

The following sections state the specific assumptions used by the CEC evaluation model. These assumptions are divided into three categories: general assumptions, leachability assumptions, and retention assumptions. A sample model calculation is also presented. Finally, the results and conclusions of the evaluation are discussed.

6.3.2.1 General Assumptions:. The general assumptions regarding the overall site conditions and applicability of this evaluation were:

- Only insignificant quantities of leachable metals will be added to the site in the future. Specifically, it is assumed that any fill materials placed on the site will not be contaminated and that normal weathering of the existing geologic materials occurs.

- Soil pH, redox conditions, and hydraulic conductivities will remain fairly constant across the site.

- Adequate contact time is available between percolating water and the surrounding soils for cation exchange reactions to occur. This may not be true during heavy recharge events, however, reduced contact times under such conditions would also be expected to result in lower metals concentrations in percolating water.

- Historic leaching from the contaminated surface soil would be expected to much higher than current leaching. Therefore, some of the CEC that is theoretically available in subsurface soils has already been spent.

6.3.2.2 Leachability Assumptions. To facilitate modeling, it is necessary to make several assumption regarding the metals being leached and their behavior at the site. These assumptions primarily deal with selecting which metals leach to an appreciable degree and predicting their leachabilities based on available data. The following assumptions regarding the elevated zone or source of leachable metals were made:

- Cu, Mn, Pb, Zn, Ca, Mg, K, and Na will be the most important metals leached from onsite surface soils in terms of loading subsurface cation exchange sites. This is indicated by the results of both the TCLP and MWEP leaching tests, which were performed during the Phase II Soil Investigation. While other metals did leach from onsite surface soils during testing, concentrations and total leached masses of these metals were typically two to three orders of magnitude less than for copper, manganese, lead, and zinc. Al, Sb, and Ni leached significantly in some cases, but as discussed later, other conservative assumptions were included to compensate for the decision not to include all metals that were detected in the leaching test extracts in the model.

  Ca, Mg, K, and Na were also considered of importance because they may be sorbed preferentially by soil and affect the number of sorption sites available for other metals.

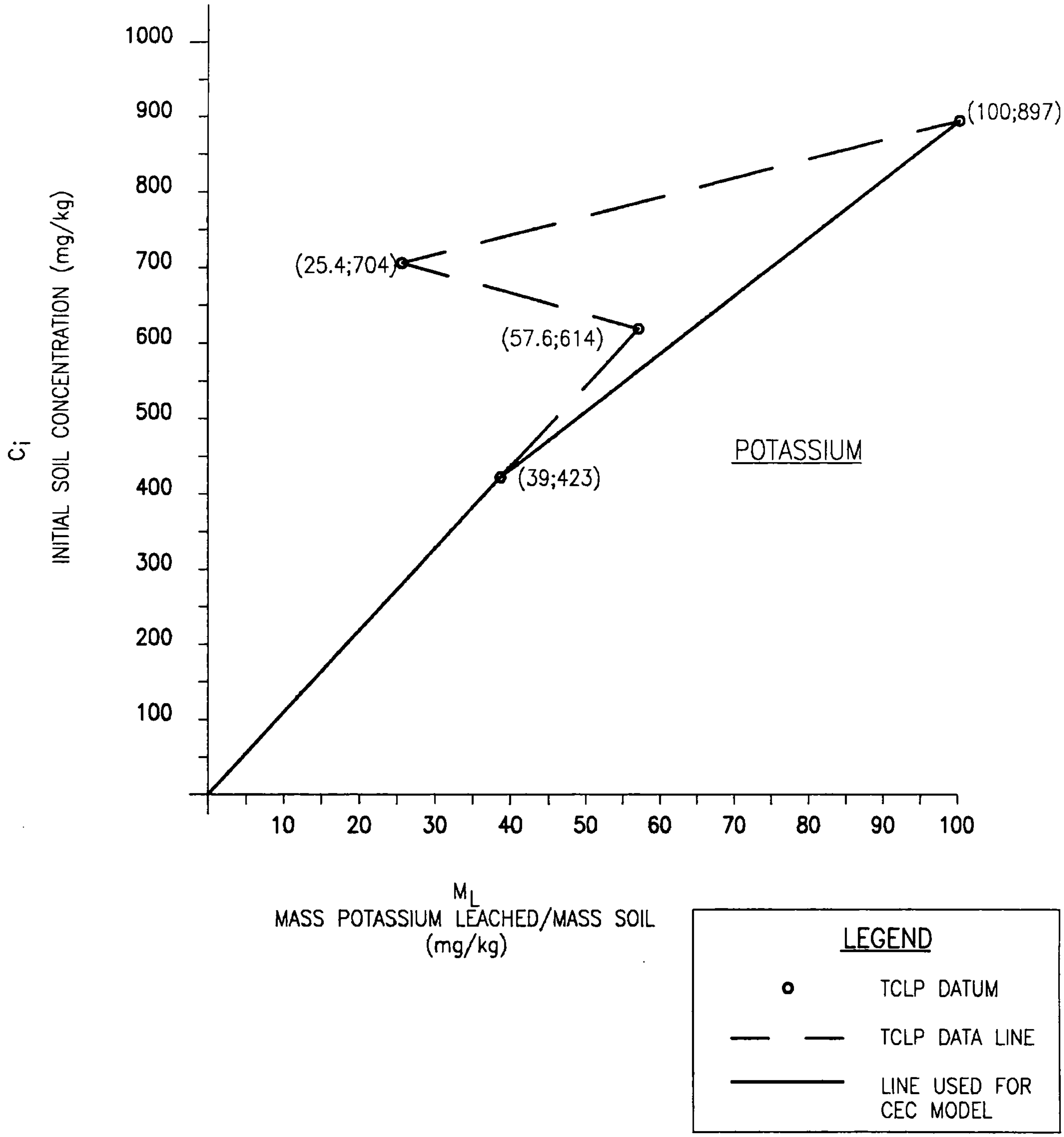
- The relationships for predicting the mass of a metal leached per-unit weight of surface soil on the basis of the metal's total concentration in that soil are based on TCLP leaching data. TCLP leachability testing was performed on four soil samples. These samples were selected to be representative of a wide range of surface soil lead concentration. Fairly wide concentration ranges for Cu, Zn, and (to a lesser degree) Mn were also represented.

Due to the sample preparation method for TCLP extractions, sodium data were not available. It was conservatively assumed that all sodium detected in surface soil would leach.

The masses of metals leached from a specific sample were calculated from the TCLP extract using the test procedure dilution ratio or 20 to 1 (liquid to solid). Initial soil concentrations vs TCLP leached masses of metals per kilogram of soil were plotted on a linear scale. A linear relationship was assumed between adjacent data points.

Linear functions with negative slopes (i.e., decreasing leachability with increasing initial soil concentration) were not used. Two linear relationships (i.e., for different ranges of initial concentrations) were selected for Cu, Pb, Mn, Zn, Ca, Mg, and K. Equations were written for these relationships that predict a value that either equals or exceeds the actual leachable mass associated with an initial sample concentration. The plots and linear equations used in predicting leached metals masses are presented in Figures RI-9 through RI-12.

- The source zone for leaching of metals (i.e., the elevated zone) is assumed to be the upper foot of soil across the site. It was assumed that the metal concentration detected in a sample from a grid square during the Phase I Soil Investigation is uniformly present throughout the entire area of a given grid square in the soil to a depth of 1 foot. Based on the total volume of soil in the upper foot of a grid and the relationship discussed above (for relating total metals concentrations in soil to mass of metal leached per kilogram of soil), a total leachable mass for each metal was calculated for each grid square.



C_i: $\geq$ 423 mg/kg; $M_L = \frac{C_i}{7.6} - 16.6$

C_i: < 423 mg/kg; $M_L = \frac{C_i}{11.1}$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

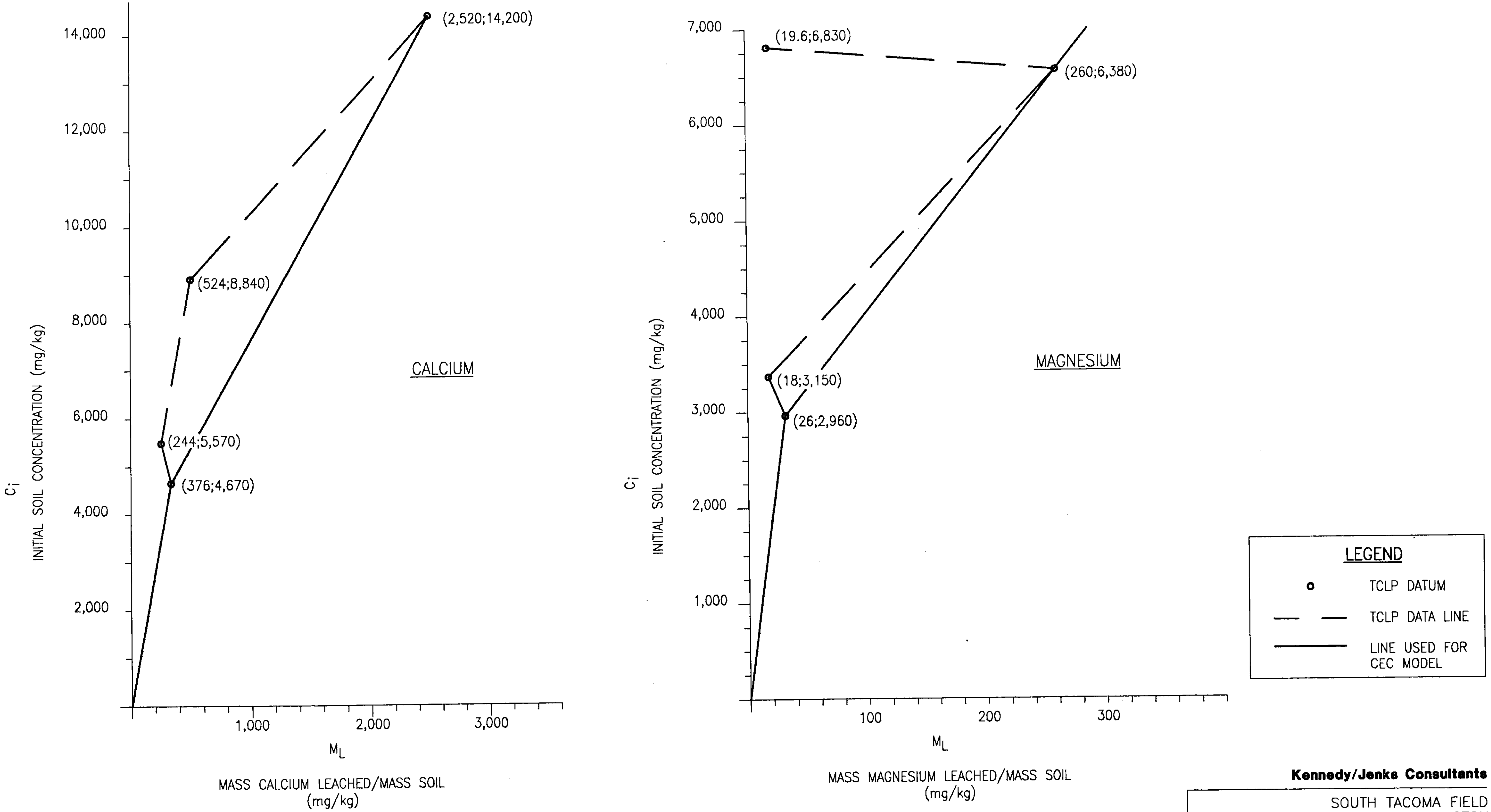
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WASHINGTON

RELATIONSHIP OF INITIAL SOIL CONCENTRATIONS TO TCLP LEACHABLE MASSES FOR POTASSIUM

916055.19/P2SK182

FIGURE RI-9



C_i: $\geq$ 4,670 mg/kg; $M_L = \frac{C_i}{4.44} - 678$

C_i: 0 to <4,670 mg/kg; $M_L = \frac{C_i}{12.4}$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

C_i: $\geq$ 2,960 mg/kg; $M_L = \frac{C_i}{14.6} - 176$

C_i = 0 to <2960 mg/kg; $M_L = \frac{C_i}{114}$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

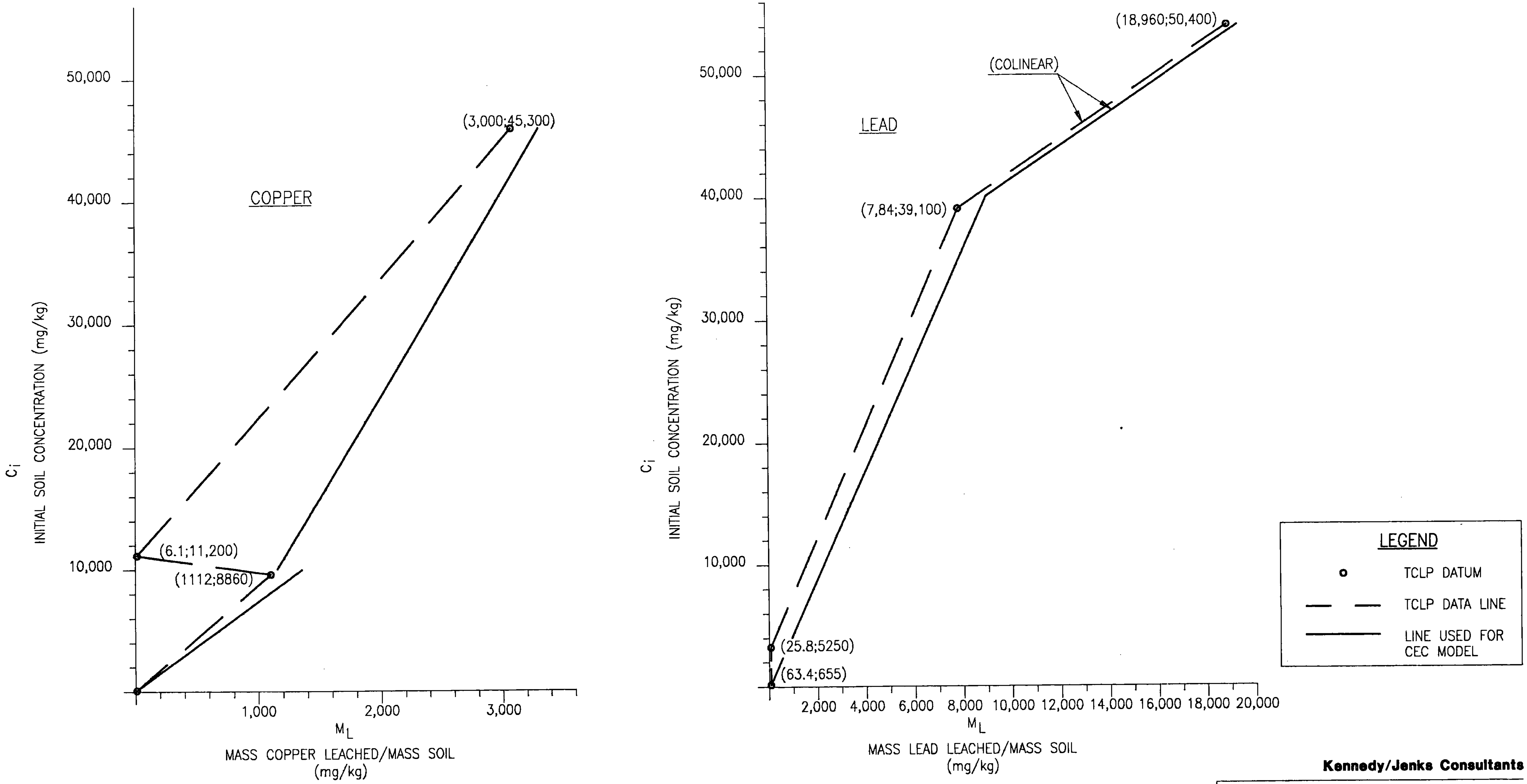
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WASHINGTON

RELATIONSHIP OF INITIAL SOIL CONCENTRATIONS TO TCLP LEACHABLE MASSES FOR CALCIUM AND MAGNESIUM

916055.19/P2SK181

FIGURE RI-10



C_i: $\geq$ 10,000 mg/kg; $M_L = \frac{C_i}{19.3} + 653$

C_i: 0 to <10,000 mg/kg; $M_L = \frac{C_i}{7.89} + 83.4$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

C_i: $\geq$ 40,000 mg/kg; $M_L = \frac{C_i}{1.02} - 30{,}451$

C_i: 0 to <40,000 mg/kg; $M_L = \frac{C_i}{2.63} - 185$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

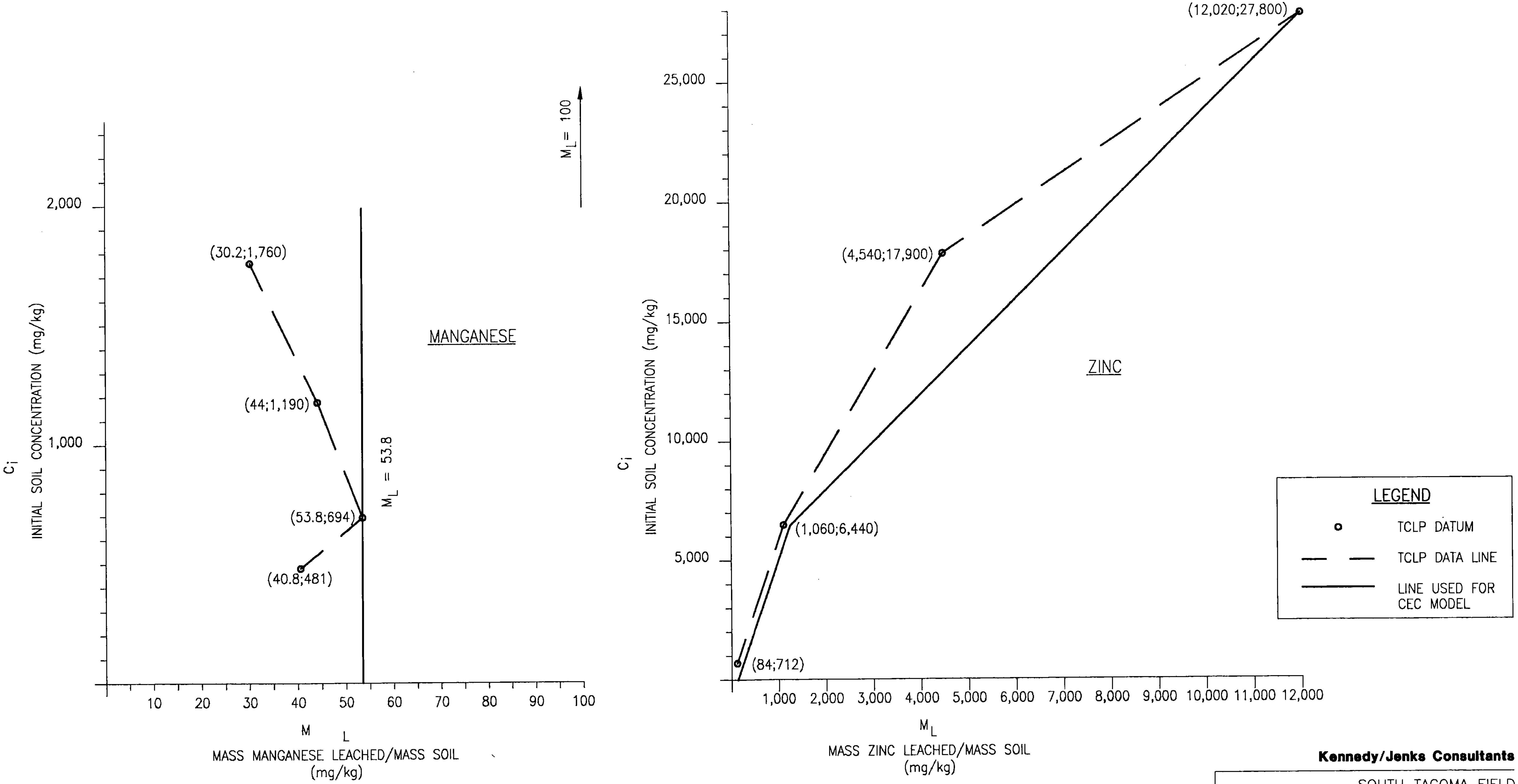
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WASHINGTON

RELATIONSHIP OF INITIAL SOIL CONCENTRATIONS TO TCLP LEACHABLE MASSES FOR COPPER AND LEAD

916055.19/P2SK179

FIGURE RI-11



C_i: $\geq$ 2,000 mg/kg; $M_L = 100$ mg/kg

C_i: 0 to <2,000 mg/kg; $M_L = 53.8$ mg/kg

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

C_i: $\geq$ 6,440 mg/kg; $M_L = \dfrac{C_i}{1.95} - 2243$

C_i: 0 to <6,440 mg/kg; $M_L = \dfrac{C_i}{5.87} - 37.1$

LINEAR EQUATIONS
DERIVED FOR LEACHABLE MASS

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WASHINGTON

RELATIONSHIP OF INITIAL SOIL CONCENTRATIONS TO TCLP LEACHABLE MASSES FOR MANGANESE AND ZINC

916055.19/P2SK180

FIGURE RI-12

This is a conservative assumption. The Phase II soil data for subsurface soil samples indicate that soil concentrations decrease rapidly with depth. Phase II data indicate that metal concentrations throughout most elevated concentration areas decrease by approximately one order of magnitude at a depth of 2 feet. By assuming that the surface soil concentration extends to 1-foot below grade, a worst-case situation is applied on a sitewide basis.

In several site areas (i.e., the Amsted property and the southwest corner of the BNR Railyard), fill materials with high metal concentrations were encountered during the subsurface investigation. In these areas, the source of leached metals (elevated zone) was assumed to be the entire volume of fill. For example, in the southwest corner of the BNR Railyard, the volume of soil from the surface to 6-feet below grade was assumed to leach copper, lead, manganese, and zinc.

- The charges of the metals species present in soil solution leaching from the upper 1-foot elevated zone of soil would be Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Pb^{2+}, Mn^{2+}, Zn^{2+}.

- The upper foot of soil (elevated zone) does not perform any retention function itself. This is a conservative assumption. Because of the organic nature of the topsoil observed at the site and the generally finer grained texture of the soil in the upper foot of the site, these soils probably have appreciable retention capacity.

6.3.2.3 Retention Assumptions. The following assumptions were made regarding the retention zone:

- The 18 inches of soil beneath the elevated zone is defined as a primary retention zone with an average CEC of 30 meq/100 g. This assumption is based on the subsurface soil data for CEC values collected during the Phase II Soil Investigation. During that investigation, the soil samples from

2 feet below grade had an average CEC value of 46.5 meq/100 g. The selection of a CEC value of 30 meq/100 g is regarded a conservative assumption because all but one measured CEC at a depth of 2 feet was 30 meq/100 g or greater, the lowest measured value was 17 meq/100 g.

- A secondary retention zone is defined from 2.5 feet to 20 feet below ground surface (the average depth of groundwater). This 17.5-foot thick layer is assigned a CEC value of 13 meq/100 g, which was the average CEC value for soil samples collected from deeper than 2 feet BGS during the Phase II Soil Investigation.

6.3.2.4 Sample Calculation. The following sample calculation illustrates the method used by the CEC evaluation model to compare available CEC to leachable metal masses. This calculation is for a 75x75-foot grid square at the STF site and uses the assumptions given above for calculating leachable masses and cumulative CEC in the retention zones. This grid square is assumed to have the following surface soil concentrations:

- Calcium (Ca) 10,000 mg/kg
- Magnesium (Mg) 4,000 mg/kg
- Sodium (Na) 500 mg/kg
- Potassium (K) 1,000 mg/kg
- Copper (Cu) 1,200 mg/kg
- Lead (Pb) 2,000 mg/kg
- Manganese (Mn) 1,000 mg/kg

- Zinc (Zn) 3,000 mg/kg.

Step 1. Calculate the number of equivalents required to adsorb a unit mass of each of metals shown above. This calculation uses the assumption that each of these metals is present primarily in the valence states shown.

- Ca^{2+} 40.08 g/molx1 mol/2 eq = 20.04 g Ca^{2+}/eq (e.g., 0.050 eq/g Ca^{2+})
- Mg^{2+} 24.31 g/molx1 mol/2 eq = 12.16 g Mg^{2+}/eq (e.g., 0.082 eq/g Mg^{2+})
- Na^{1+} 22.99 g/molx1 mol/1 eq = 22.99 g Na^{1+}/eq (e.g., 0.043 eq/g Na^{1+})
- K^{1+} 39.10 g/molx1 mol/1 eq = 39.10 g K^{1+}/eq (e.g., 0.026 eq/g K^{1+})
- Cu^{2+} 63.55 g/molx1 mol/2 eq = 31.77 g Cu^{2+}/eq (e.g., 0.032 eq/g Cu^{2+})
- Pb^{2+} 207.2 g/molx1 mol/2 eq = 103.6 g Pb^{2+}/eq (e.g., 0.010 eq/g Pb^{2+})
- Mn^{2+} 54.94 g/molx1 mol/2 eq = 27.47 g Mn^{2+}/eq (e.g., 0.036 eq/g Mn^{2+})
- Zn^{2+} 65.38 g/molx1 mol/2 eq = 32.69 g Zn^{2+}/eq (e.g., 0.031 eq/g Zn^{2+}).

Step 2. Calculate the mass of each of these metals that will be leached per kilogram of soil with the given initial concentrations. The leachable masses are calculated from the equations presented in Figures RI-9 through RI-12.

- Ca = 10,000 mg/kg; M = (10,000/4.44)-678 = 1,574 mg (leached Ca^{2+})/kg (soil)
- Mg = 4,000 mg/kg; M = (4,000/14.6)-176 = 98.0 mg (leached Mg^{2+})/kg (soil)

- Na = 500 mg/kg; M = 500 mg (leached Na^{1+})/kg (soil)

- K = 1,000 mg/kg; M = (1,000/7.6)-16.6 = 115 mg (leached K^{1+})/kg (soil)

- Cu = 1,200 mg/kg; M = (1,200/7.89)-83.4 = 235.5 mg (leached Cu^{2+})/kg (soil)

- Pb = 2,000 mg/kg; M = (2,000/2.63)-185 = 575 mg (leached Pb^{2+})/kg (soil)

- Mn = 1,000 mg/kg; M = 53.8 mg (leached Mn^{2+})/kg (soil)

- Zn = 3,000 mg/kg; M = (3,000/5.87)-37.1 = 474 mg (leached Zn^{2+})/kg (soil).

<u>Step 3</u>. Calculate the total mass of the upper 1 foot of soil in the sample grid. This assumes a unit weight of 110 pounds per cubic foot.

- 75'x75'x1' = 5,625 ft^3; 5,626 ft^3x110 lb/ft^3x1 kg/ 2.2 lb = 281,250 kg soil.

<u>Step 4</u>. Calculate the leachable mass of metals in the upper 1 foot of soil in the sample grid based on the results of Steps 2 and 3.

- 1,574 mg Ca^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 4.4×10^5 g Ca^{2+}

- 98.0 mg Mg^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 2.6×10^4 g Mg^{2+}

- 500 mg Na^{1+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 1.4×10^5 g Na^{1+}

- 115 mg K^{1+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 3.3×10^4 g K^{1+}
- 235.5 mg Cu^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 6.6×10^4 g Cu^{2+}
- 575 mg Pb^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 1.6×10^5 g Pb^{2+}
- 53.8 mg Mn^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 1.5×10^4 g Mn^{2+}
- 474 mg Zn^{2+}/kg (soil)x281,250 kg (soil)x1 g/1,000 mg = 1.3×10^5 g Zn^{2+}.

Step 5. Use the results of Step 1 to calculate the number of equivalents needed to sorb the masses of metals leached from the upper one foot of soil as predicted in Step 4.

- 4.4×10^5 g Ca^{2+}x0.050 eq/g Ca^{2+} = 22,000 eq
- 2.6×10^4 g Mg^{2+}x0.082 eq/g Mg^{1+} = 2,132 eq
- 1.4×10^5 g Na^{1+}x0.043 eq/g Na^{2+} = 6,020 eq
- 3.3×10^4 g K^{1+}x0.026 eq/g K^{1+} = 858 eq
- 6.6x104 g Cu^{2+}x0.0315 eq/g Cu^{2+} = 2,079 eq
- 1.6x105 g Pb^{2+}x0.010 eq/g Pb^{2+} = 1,600 eq
- 1.5x104 g Mn^{2+}x0.036 eq/g Mn^{2+} = 540 eq
- 1.3x105 g Zn^{2+}x0.031 eq/g Zn^{2+} = 4,030 eq

Total equivalents = 3.93x104 eq.

Step 6. Calculate the theoretical number of equivalents available in soil in the grid beneath the upper 1 foot of soil and initial groundwater (i.e., the retention zone). This zone is composed of two units: an upper unit that is 18 inches thick and has a CEC value of 30 meq/100 g (soil) and a lower unit that is 17.5 feet thick and has a CEC value of 13 meq/100 g.

- Soil volume of upper layer: 75'x75'x1.5'x115 lb/ft^{3}x1 kg/2.2 lb = 441,051 kg (soil)
- 441,051 kg(soil)x30 meq/100 g(soil)x1 eq/1,000 meqx100 g/0.1 kg = 1.3x105 eq
- Soil volume of lower layer: 75'x75'x17.5'x115 lb/ft^{3}x1 kg/2.2 lb = 5.1x106 kg (soil)
- 5.1x106 kg(soil)x13 meq/100 g(soil)x1 eq/1,000 meqx100 g/0.1 kg = 6.6x106 eq

Total equivalents available for sorption = $6.7\text{x}10^6$ eq.

This evaluation predicts that the total number of equivalents available ($6.7\text{x}10^6$ eq) to sorb leached metals in the retention zone is more than two orders of magnitude greater than the predicted total number of equivalents required ($3.93\text{x}10^4$ eq) to sorb the leachable metals from the elevated zone in this grid.

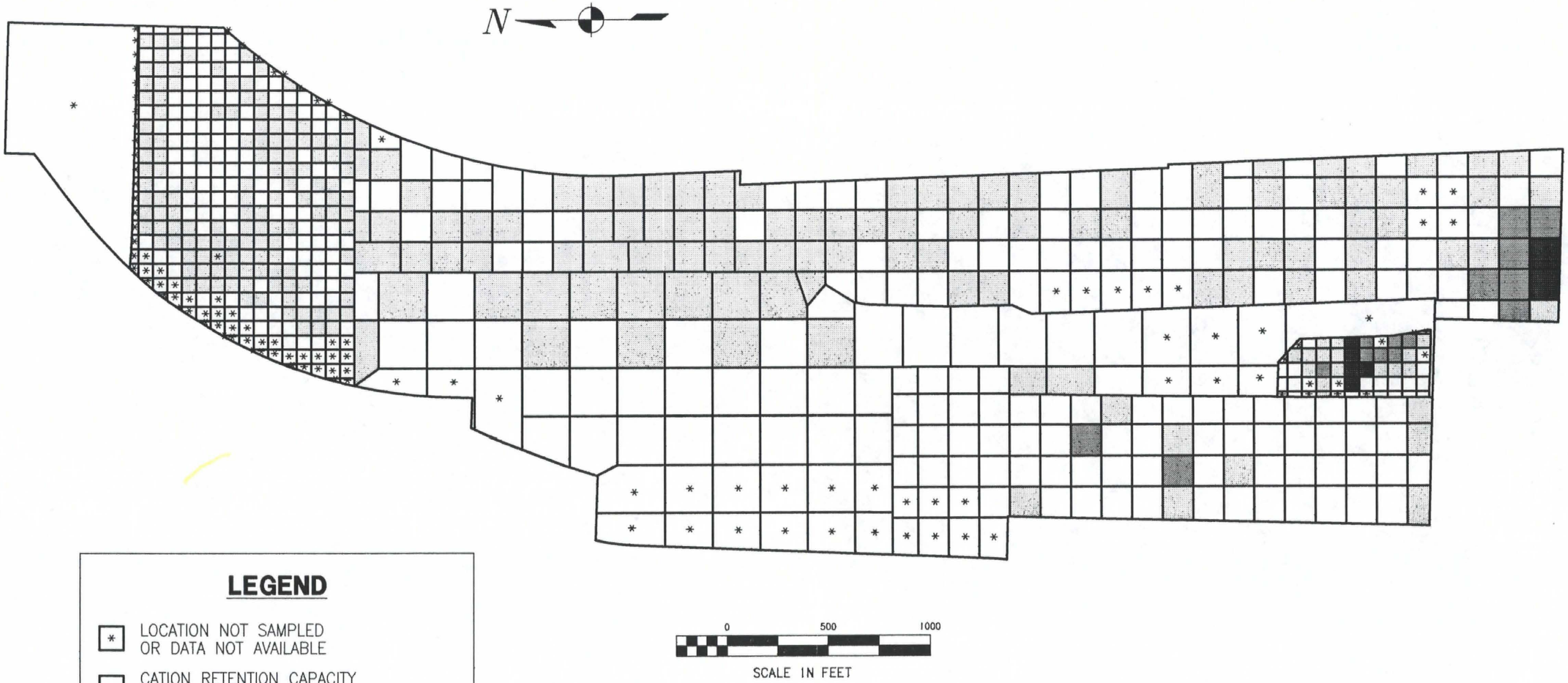
6.3.2.5 CEC Evaluation Results. The CEC evaluation described above was applied to each grid square at the STF site. This evaluation used ARC-INFO/GIS to calculate the leachable masses of each metal and cumulative CEC capacity required and available for each grid square for which metals concentrations data were available. Results of this evaluation are graphically presented in Figure RI-13.

After setting up the ARC-INFO/GIS program, a second run was performed using a 6-inch thick elevated zone, 18-inch thick primary retention zone, and 18-foot thick secondary retention zone. Though less conservative, this run (shown in Figure RI-14) is believed to more realistically portray actual site conditions. The modeling assumptions stated above were modified somewhat to better fit conditions in two areas of the site: the Amsted property and the southwest corner of the BNR Railyard.

On the Amsted property, the elevated zone (from which metals could leach) was expanded to encompass the thickness of the fill materials encountered during the subsurface investigation. The primary retention zone used throughout the rest of the site (i.e., upper layer with a CEC of 30 meq/100 g) was omitted and the only soils available for cation exchange were those assigned a CEC of 13 meq/100 g present from the base of the fill material to the top of the saturated zone. An attempt was made to evaluate each grid square individually based on the depth of fill material interpreted from the subsurface investigation.

Seven grid squares in the extreme southern portion of the BNR Railyard were modeled using assumptions consistent with those described above for the Amsted property. These grids were interpreted to each have about 6 feet of fill material during the subsurface soil investigation. The total depth of fill in these grids was assumed to be the elevated zone and the soil from 6 feet to 20 foot below grade was assumed to have a CEC of 13 meq/100 g.

Modeling results are shown in Figures RI-13 and RI-14. With the exception of the some filled areas, the retention zone in modeled areas throughout the site has greater CEC than required to adsorb the predicted masses of leached metals based on the model's assumptions. This finding is significant considering the very conservative assumptions made regarding leachable masses of metals and thickness/character of the retention media.



LEGEND

- ⊡ LOCATION NOT SAMPLED OR DATA NOT AVAILABLE
- ☐ CATION RETENTION CAPACITY >100x ESTIMATED CATION LOADING
- ░ CATION RETENTION CAPACITY 10x TO 100x ESTIMATED CATION LOADING
- ▒ CATION RETENTION CAPACITY 1x TO <10x ESTIMATED CATION LOADING
- ■ CATION RETENTION CAPACITY LESS THAN ESTIMATED CATION LOADING

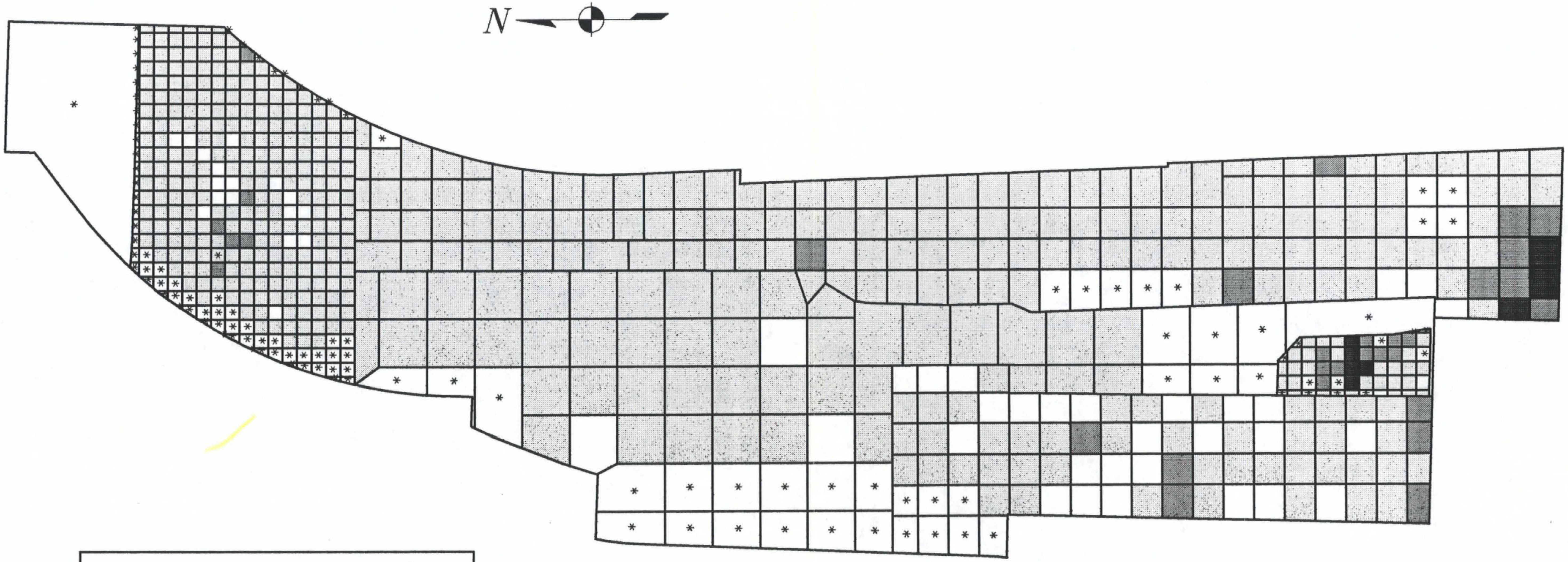
Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

COMPARISON OF ESTIMATED LEACHABLE CATION LOADING TO ESTIMATED UNSATURATED ZONE CATION RETENTION CAPACITY (6-INCH ELEVATED ZONE)

916055.19/P2SK188

FIGURE RI-14



LEGEND

- [*] LOCATION NOT SAMPLED OR DATA NOT AVAILABLE
- ☐ CATION RETENTION CAPACITY >100x ESTIMATED CATION LOADING
- ░ CATION RETENTION CAPACITY 10x TO 100x ESTIMATED CATION LOADING
- ▒ CATION RETENTION CAPACITY 1x TO <10x ESTIMATED CATION LOADING
- ■ CATION RETENTION CAPACITY LESS THAN ESTIMATED CATION LOADING

0 500 1000

SCALE IN FEET

Kennedy/Jenks Consultants

SOUTH TACOMA FIELD
TACOMA, WA

COMPARISON OF ESTIMATED LEACHABLE CATION LOADING TO ESTIMATED UNSATURATED ZONE CATION RETENTION CAPACITY (1-FOOT ELEVATED ZONE)

916055.19/P2SK187

FIGURE RI-13

Regardless of whether the elevated zone is defined as 6 inches or 1 foot thick, the estimated cumulative CEC for the retention zone throughout the vast majority of the site is at least 10 times greater than the estimated required total retention capacity.

The results show that several grid squares on the Amsted property and in the south end of the BNR Railyard contain more potentially leachable metals than the capacity available in the underlying soils to retain them. The diminished retention zone thicknesses in these areas (due to the presence of fill material) and the increased amount of leachable metals (due to the fill) are the major reasons for these results.

6.3.2.6 Conclusions. The following conclusions are based on the sitewide CEC evaluation:

- Although data from TCLP testing were used in this evaluation to simulate the worst-case conditions, the leachable masses predicted on the basis of TCLP are quite conservative and probably greatly exceed the masses that could actually be leached.

- Subsurface soils throughout the majority of the site appear to have many times the capacity theoretically required to retain (by cation exchange reactions) the metals that may be leached from surface soils. Considering the conservative nature of the assumptions used during this evaluation, it is reasonable to conclude that given the surplus CEC available in much of the site's vadose zone, a significant fraction of the metals that may be leached from surface soils will be retained and essentially immobilized by adsorption to soil particles during downward percolation through the vadose zone.

- A greater potential for soil solutions containing dissolved metals at concentrations of concern to migrate to the saturated zone exists in areas where appreciable quantities of subsurface fill materials are present. These areas include the Amsted property and the south end of the BNR Railyard.

6.3.3 Behavior and Migration of Organic Chemicals of Concern

This section presents a discussion of migration rates and potential fates for organic chemicals of concern at the STF site.

6.3.3.1 Estimation of Chemical Migration Rates. The migration rates of the organic chemicals of concern as dissolved species in a percolating or seeping aqueous solution were estimated using traditional numerical equations for organic chemical front migration. The numerical solutions consider retardation of the organic chemical front velocity due to solute-sediment interactions (adsorption).

As summarized in Section 6.1.3.2.1, the mobility of any chemical in soil is affected by its adsorption on soil. A non-adsorbing compound, such as chloride, moves through soil at essentially the same rate as water. Chemicals that are adsorbed onto soil will lag behind water as it moves through the soil, and the time required for the chemicals to move a given distance is increased. The greater this adsorption effect, the slower the chemical moves in soil. Adsorption isopleths are used to quantitatively describe adsorption. These isopleths reflect the relationship between soil concentration (defined as the amount of chemical adsorbed per unit weight of soil) and the solution phase concentration (concentration of the chemical dissolved in the liquid phase that is migrating through the soil pores at equilibrium). The linear adsorption isopleth is expressed as:

$$C_s = K_d C_w$$

where:

C_s = Amount of chemical adsorbed per unit weight of soil (mg/kg soil)
K_d = Adsorption constant (partition coefficient)
C_w = Amount of the chemical in the solution phase (mg/L).

The higher the K_d value the lower the mobility of a chemical in soil. In general, hydrophobic compounds (including PAHs) have high partition coefficients (Karickhoff et al. 1979; Means et al. 1980).

There is a strong correlation between adsorption of hydrophobic compounds by soil and the fraction of organic carbon content in the soil (f_{oc}). An adsorption constant normalized with respect to f_{oc} is independent of soil type (Karickhoff et al. 1979). Such an adsorption constant, K_{oc}, may be expressed as:

$$K_{oc} = \frac{K_d}{f_{oc}} \tag{14}$$

K_{oc} values have been correlated to solubility and melting points of organic chemicals and also to octanol/water partition efficients (K_{ow}). The use of K_d values based on K_{oc} and f_{oc} values is attractive since these K_d values are functions of only chemical properties and site-specific organic carbon contents for soil.

An important issue with respect to the validity of using K_d values based on measured f_{oc} values is whether the organic soil components actually dominate the sorption process. The use of K_d values calculated from measured f_{oc} values is based on the assumption that organic content plays the predominant role in soil sorption. However, there appears to be a critical level of organic content in the soil, f_{oc}^*, below which the inorganic matrix dominates the sorption processes (McCarty et al. 1981). The value of f_{oc}^* is dependent on a property of the soil (specific surface area) and a property of the chemical (n-octanol/water partition coefficient). For f_{oc}^*, as the surface area of the soil increases, the importance of soil organic matter decreases.

K_d values were calculated for the organic chemicals of concern at the STF site based on the maximum, minimum, and mean values for TOC contents in soil from the RI data. These values are shown in Table RI-30. For comparison, the critical organic fraction (f_{oc}*) at the site for each of the organic chemicals of concern was calculated using the following equation (McCarty et al. 1981; California DHS 1986).

$$f_{oc}* = \left(\frac{sa}{126}\right)\left(\frac{1}{k_{ow}^{\ 0.84}}\right) \tag{15}$$

where, sa is the surface area of the soil (in m^2/g), and K_{ow} is the n-octanol/water partition coefficient of the chemical of concern. An sa value of 25 m^2/g, typical of sandy loam (Dragun 1988), was used. These values are shown in Table RI-30. The calculated f_{oc}* for each chemical was compared with the values used to estimate the K_d values.

If f_{oc} is greater than or equal to f_{oc}*, the organic matrix of the soil will probably be dominant in sorption processes for that particular chemical at that site. Therefore, greater reliance can be placed on the estimated migration rates.

If f_{oc}* is less than f_{oc}, the inorganic matrix may predominate the sorption processes for that chemical.

K_d values were used to estimate the time required for an organic chemical front to travel through soil given an average recharge rate by estimating a retardation factor, which is defined as:

$$R = \frac{V_w}{V_c} \tag{16}$$

TABLE RI-30

DISTRIBUTION COEFFICIENTS (Kd), RETARDATION FACTORS (Vw/Vc) AND TRAVEL TIMES FOR CHEMICALS OF CONCERN AT THE SOUTH TACOMA FIELD SITE

Chemical of Concern	Case	Koc[a] (ml/g)	Kow[b] (ml/g)	foc*[c] (kg/kg)	Soil/Water Partition Coefficient (Kd)[d]			Saturated Retardation Factor (Vw/Vc)[e]				Time to Groundwater [f] Saturated Conditions (years)		Time to Groundwater[g] Unsaturated Conditions (years)		PRZM Unsaturated Zone Modeling[h]	
					Minimum[k]	Maximum[l]	Mean[m]	Minimum[k]	Maximum[l]	Mean[m]	Case 1[n]	Mean[m]	Case 1[n]	Mean[m]	Case 1[n]	Time to Ground-water (years)[i] Mean[m]	Migration in 100 years (cm)[j] Mean[m]
	foc (kg/kg)[o]	--[p]	--	--	6.00E-04	1.07E-01	1.48E-02	6.00E-04	1.07E-01	1.48E-02	6.00E-04	1.48E-02	6.00E-04	1.48E-02	6.00E-04	0.178	0.178
	Bulk Density,pb (lbs/ft^3)[q]	--	--	--	--	--	--	97.4	65.5	108.44	65.5	108.44	65.5	108.44	65.5	114	114
	Porosity,n (unitless)	--	--	--	--	--	--	0.43	0.54	0.328	0.17	0.328	0.17	--	--	--	--
	Moisture,O (unitless)	--	--	--	--	--	--	--	--	--	--	--	--	0.1	0.1	0.11	0.11
	Hydr. Cond.,K (cm/sec)[r]	--	--	--	--	--	--	--	--	--	--	0.00074	0.0023	--	--	--	--
Volatile Organics																	
Benzene[s]		83	132	3.28E-03	0.0498[t]	8.88	1.23	1.18	18.3	7.51	1.31	0.0643	0.0319	14.5	0.987	12.8	N/C
Ethylbenzene[s]		1100	1410	4.49E-04	0.660	118	16.3	3.39	230	87.2	5.07	0.747	0.00725	184	5.14	99	N/C
Toluene[s]		300	537	1.01E-03	0.180	32.1	4.44	1.65	63.4	24.5	2.11	0.210	0.00302	50.7	1.87	31	N/C
m-Xylene[u,v]		758	1580	4.08E-04	0.455	81.1	11.2	2.65	159	60.4	3.81	0.518	0.00544	127	3.74	70.1	N/C
o-Xylene[u,v]		283	589	9.35E-04	0.170	30.3	4.19	1.62	59.8	23.2	2.05	0.199	0.00293	47.8	1.80	29.9	N/C
p-Xylene[u,v]		677	1410	4.49E-04	0.406	72.4	10.0	2.47	142	54.1	3.51	0.463	0.00501	114	3.41	63.1	N/C
Total Xylenes[s]		240	1820	3.62E-04	0.144	25.7	3.55	1.52	50.9	19.8	1.89	0.170	0.00270	40.7	1.63	25.9	N/C
Chloroform[s]		31	93	4.41E-03	0.0186	3.32	0.459	1.07	7.44	3.43	1.11	0.0294	0.00159	5.82	0.775	8.2	N/C
Hexanone[v,w]		12	24	1.38E-02	0.00691	1.23	0.170	1.03	3.39	1.90	1.04	0.0163	0.00149	2.57	0.696	6.9	N/C
Tetrachloroethylene[s]		364	398	1.30E-03	0.218	38.9	5.39	1.79	76.7	29.5	2.35	0.253	0.00335	61.3	2.13	36.2	N/C
1,1,2-Trichloroethane[s]		56	295	1.67E-03	0.034	5.99	0.829	1.12	12.6	5.39	1.21	0.0462	0.00173	10.0	0.877	10.8	N/C
Semivolatile Organics																	
2,4-Dimethylphenol[v,x,y]		81.5	170	2.65E-03	0.0489	8.72	1.21	1.18	17.9	7.39	1.30	0.0633	0.00186	14.2	0.981	12.8	N/C
2-Methylnaphthalene[v,y]		3,560	7,410	1.11E-04	2.14	381	52.7	8.75	741	280	14.2	2.40	0.0203	594	15.2	N/C	180
Naphthalene[z]		1,240	2,000	3.35E-04	0.744	133	18.4	3.70	259	98.2	5.59	0.841	0.00799	207	5.71	N/C	504
Carcinogenic PAHs																	
Benzo(a)anthracene[s]		1,380,000	398,000	3.92E-06	828	148,000	20,400	3,010	287,000	108,000	5,110	927	7.30	230,000	5,640	N/C	0.48
Benzo(b)fluoranthene[s]		550,000	1,150,000	1.61E-06	330	58,900	8,140	1,200	114,000	43,100	2,040	369	2.91	91,700	2,250	N/C	1.2
Benzo(k)fluoranthene[s]		550,000	1,150,000	1.61E-06	330	58,900	8,140	1,200	114,000	43,100	2,040	369	2.91	91,700	2,250	N/C	1.2
Benzo(a)pyrene[s]		550,000	1,150,000	1.61E-06	330	58,900	8,140	1,200	114,000	43,100	2,040	369	2.91	91,700	2,250	N/C	1.2
Chrysene[s]		200,000	407,000	3.85E-06	120	21,400	2,960	436	41,600	15,700	742	134	1.06	33,300	817	N/C	3.3
Dibenzo(a,h)anthracene[s]		3,300,000	6,310,000	3.85E-07	1,980	353,000	48,800	7,180	686,000	259,000	12,200	2,220	17.5	550,000	13,500	N/C	0.2
Indeno(1,2,3-cd)pyrene[s]		1,600,000	3,160,000	6.88E-07	960	171,000	23,700	3,480	333,000	125,000	5,930	1,070	8.47	267,000	6,530	N/C	0.41
Polychlorinated biphenyls[s]		530,000	1,100,000	1.67E-06	318	56,700	7,840	1,150	110,000	41,500	1,960	356	2.81	88,400	2,160	N/C	1.2
Aroclor 1248[v,aa]		758,000	1,580,000	1.23E-06	455	81,100	11,200	1,650	158,000	59,400	2,810	509	4.01	126,000	3,100	N/C	0.87
Aroclor 1254[v,aa]		1,520,000	3,160,000	6.88E-07	912	163,000	22,500	3,310	316,000	119,000	5,630	1,020	8.04	253,000	6,210	N/C	0.43
Aroclor 1260[v,aa]		3,030,000	6,310,000	3.85E-07	1,820	324,000	44,800	6,600	630,000	237,000	11,200	2,030	16.0	505,000	12,400	N/C	0.22

TABLE RI-30

DISTRIBUTION COEFFICIENTS (Kd), RETARDATION FACTORS (Vw/Vc) AND TRAVEL TIMES FOR CHEMICALS OF CONCERN AT THE SOUTH TACOMA FIELD SITE

Notes:

[a] Koc is the organic carbon normalized soil/water partition coefficient for a specific compound at 20° Celsius.

[b] Kow is the octanol/water partition coefficient for a specific compound at 20° Celsius.

[c] Critical organic fraction (foc*) is the organic carbon content below which the inorganic matrix of the soil may predominate sorption processes. Therefore, Kd values calculated using foc values that are less than foc* may not accurately describe soil/water partition processes. foc* is calculated using the following equation (McCarty, et al, 1981); foc* = (sa/126)(1/Kow^0.84) where; sa is the surface area of the soil; assumed to be 25 m^2/g for sandy loam (Dragun, 1988).

[d] The soil/water partition coefficient (Kd) is calculated from the equation (Karickhoff, 1984); Kd = Koc x foc.

[e] Retardation factor under saturated conditions is the ratio of the velocity of water (Vw) to the velocity of contaminant (Vc). It is calculated from the equation: $Vw/Vc = (1 + [Kd \times \rho_b / n])$
where; ρ_b is bulk density (g/cm^3) and n is porosity

[f] Chemical travel time to groundwater under saturated conditions is based on a vertical distance (Z) to groundwater of 20 feet, and continuous downward movement of groundwater at the stated velocity. Velocity is divided by porosity as a correction factor.

[g] Chemical travel time (T) to groundwater under unsaturated conditions is based on a vertical distance (Z) to groundwater of 20 feet, and the assumption that saturated flow only occurs annually for that period of time required to percolate a 37-inch column of water (Vd) (equal to total annual precipitation) over a soil area having the specified hydraulic conductivity.
It is calculated from the equation: $T = Z\theta(1 + [Kd \times \rho_b / \theta])/Vd$ where; θ is moisture content (cm^3/cm^3).

[h] The Pesticide Root Zone Model (PRZM) Release 1 (EPA 1984) was used to calculate chemical migration in the unsaturated zone. Input parameters include those shown for foc, bulk density, and moisture content. Site conditions assumed include bare soil, no runoff, a one-foot thick source contamination zone, and approximately 37 inches of rain per year.

[i] Time to groundwater was calculated as the time when the soil concentration of the chemical modeled reached a maximum in the compartment located at 20 feet BGS.

[j] Chemical migration in 100 years was determined in one of two ways. In the case of semivolatiles, the distance of chemical migration was measured as the depth at which the greatest modeled chemical concentration occurred at the end of the 100 year period. For PAHs and PCBs chemical migration was measured as distance that the center of chemical mass had moved.

[k] The minimum case is calculated using soil characteristics for grid 370 at 7 foot depth, which had the lowest foc; 0.0006 kg/kg.

[l] The maximum case is calculated using soil characteristics for grid 899 at 2 foot depth, which had the highest foc; 0.107 kg/kg.

[m] The mean case is calculated using the average values for all soil characteristics. The mean velocity was calculated by averaging the values for each specific depth (2, 7, 10, & 12), and then averaging these four values together.

[n] Case 1 is calculated as a worst case using minimum reported values for foc, bulk density and porosity, and the maximum reported value for hydraulic conductivity.

[o] Fraction of organic carbon (foc) is calculated by dividing reported percent total organic carbon (TOC) by 100.

[p] -- Not used in calculation

[q] Reported dry density values are used for bulk density (ρb).

[r] Hydraulic Conductivity (K) is based on laboratory hydraulic conductivity tests.

[s] U.S. EPA, 1986.

[t] Shaded boxes represent those values calculated using a value of foc that is less than the critical organic fraction (foc*).

[u] Vershuren, 1983.

[v] Koc is calculated from the Kow value using the equation (Hassett et al., 1980); Koc = 0.48 Kow.

[w] Toxicological profile for 2-hexanone (ATSDR, 1990).

[x] National Library of Medicine, Hazardous Substances Databank, US Department of Health and Human Services.

[y] A range of values was given for Kow, the lowest value was used as a conservative assumption.

[z] Kow value is from Howard (1989); Koc calculated from the Kow value using the equation (Karickhoff et al., 1979); (Rao and Davidson, 1980); Koc = 0.62 Kow.

[aa] Toxicological profile for selected PCBs (ATSDR, 1987).

where:

R = Retardation factor
V_w = Water front velocity in soil = V_d/θ
θ = Soil moisture content (volumetric fraction)
V_d = Recharge rate (Darcy's velocity)
V_c = Chemical migration front velocity.

For this evaluation, water front velocity in the saturated zone was calculated using the assumption that effective porosity is the same as total porosity for practical purposes in coarse-grained soil. Therefore, volumetric soil moisture content, θ, was assumed to equal porosity, n for saturated flow conditions. Water front velocity in the unsaturated zone was estimated using the assumption that θ equaled 0.1 and that the recharge rate, V_d, equaled 37 inches/year (i.e., annual rainfall).

$$\text{Since } V_w = \frac{V_d}{\theta} \text{ (definition of } V_w \text{ above)}$$

$$R = \frac{\left(\frac{V_d}{\theta}\right)}{V_c}$$

or

$$R = \frac{V_w}{V_c} \qquad (17)$$

As discussed in Mahmood and Sims (1986), the retardation factor may also be expressed as:

$$R = 1 + \frac{\rho_b K_d}{\theta} \qquad (18)$$

where:

ρ_b = Soil bulk density.

By combining equations (17) and (18) the chemical migration front velocity (V_c) is derived:

$$\frac{V_w}{V_c} = 1 + \frac{\rho_b K_d}{\theta} \qquad (19)$$

Equation 19 can be rewritten as equation (4) (see Section 6.1.3.2.1).

V_c can also be described as the distance the chemical migration front travels per unit time as follows:

$$V_c = \frac{Z}{T} \qquad (20)$$

where:

Z = Distance

T = Time required to travel distance Z.

By substituting equation (20) into equation (19)

$$\frac{Z}{T} = V_w \left(1 + \frac{\rho_b K_d}{\theta}\right)^{-1}$$

or

$$T = Z \left(1 + \frac{\rho_b K_d}{\theta}\right) (V_w)^{-1} \qquad (21)$$

The travel time may be made site-specific by combining equation (21) and equation (14), which results in:

$$T = Z \left(1 + \frac{\rho_b}{\theta} K_{oc} f_{oc}\right) (V_w)^{-1} \qquad (22)$$

The vertical distance to groundwater was assigned a value of 20 feet. As shown in Table RI-30, calculations of retardation factors and travel times were made using several different values for bulk density, porosity, and hydraulic conductivity. Travel times were calculated for continuously saturated conditions under unit head and can be regarded as worst-case values for chemical movement. The saturated condition values for T shown in Table RI-30 are useful to estimate the possible movement rates for chemicals beneath the onsite surface water channel.

In addition to the estimation of chemical migration front travel times in the unsaturated zone using the methodology described in the foregoing, EPA's Pesticide Root Zone Model (PRZM), Release 1 was also used to estimate unsaturated zone chemical migration travel distances and times. PRZM is a dynamic, compartmental model used for simulating chemical movement in unsaturated soil systems within and below plant root zones (EPA 1984). The results of the modeling using PRZM are also presented in Table RI-30.

As shown in Table RI-30, total time required for probable carcinogenic PAHs to migrate the assumed distance of 20 feet ranged from about 1 year to nearly 2,220 years under continuously saturated conditions, and 800 years to 550,000 years under unsaturated conditions. Vertical migration distances for carcinogenic PAHs in the unsaturated zone over a 100-year period range from 0.2 to 3.3. cm based on PRZM modeling. The total time required for VOCs to migrate 20 feet ranged from 0.5 days to 9 months under continuously saturated conditions and 8 months to 184 years under unsaturated conditions. VOC migration times calculated using PRZM were to be slightly less than those calculated using equation (22).

The total time required for semivolatile organic compounds to migrate 20 feet ranged from 16 hours to 2.4 years under saturated conditions, and 1 year to 594 years under unsaturated conditions. The total time required for PCBs to migrate 20 feet ranged from 2.8 years to 2,030 years under saturated conditions and 2,160 to 505,000 years under unsaturated conditions. Vertical migration distances for PCBs in the unsaturated zone over a 100-year period range from 0.22 to 1.2 cm based on PRZM modeling.

6.3.3.2 Conclusions. Migration rates estimated for VOCs and semivolatile organics are considerably greater than those estimated for the higher molecular weight organic compounds. This is consistent with the known behavior of VOCs and semivolatile organic compounds in soil/water systems, and the fact that they were detected in groundwater during the RI. While some retardation due to sorption by organic matter in the saturated zone can be expected to influence the migration and fate of these chemicals, processes such as volatilization, dispersion and diffusion, and biotransformation (biodegradation) are expected to be more important in reducing their concentrations in groundwater.

Biodegradation of aromatic hydrocarbons, such as benzene and toluene, in the shallow saturated zone can occur relatively rapidly and can be expected to be among the most significant concentration reduction mechanisms for these chemicals in groundwater (Wilson et al. 1983; ATSDR 1987b).

PCBs are relatively insoluble in water and are known to sorb strongly to soil and sediment. Significant leaching is not expected under most soil conditions (ATSDR 1987c). The relative immobility of PCBs is demonstrated by the extremely long estimated migration travel times shown in Table RI-30. Biodegradation in soil and sediment is probably the ultimate fate of PCBs. This process involves reductive dehalogenation and can be expected to proceed relatively slowly (ATSDR 1987c).

PAHs are hydrophobic (water disliking) due to their nonpolarity (i.e., neutral molecules where there is a relatively even charge distribution over the molecular surface). The hydrophobic nature of PAHs plays an important role in determining their mobility in soil systems. Most PAHs in aquatic systems accumulate in sediment and are transported with aquatic sediment (ATSDR 1987a).

As shown in Table RI-30, the migration rates of the PAHs of concern in the soil/water system at STF are estimated to be extremely slow. In surface water, only a small amount of the PAHs of concern are expected to dissolve. Most likely these are subsequently degraded by photolysis and, to a lesser extent, by oxidation. The ultimate fate of PAHs in the soil/water system is believed to be biodegradation and biotransformation (EPA 1979c), although such processes are expected to proceed relatively slowly.

6.3.4 Evaluation of Metals Loading of Wetlands/Surface Water Channel Sediment

An evaluation of the potential significance of runon metals loading to wetland/surface water sediments was performed by calculating a hypothetical yearly incremental change in sediment concentrations for 17 elements. This evaluation was performed to provide a measure of the significance of the annual metals loading masses derived for the site during the Surface Water and Sediment Investigation (Appendix SW). The following section contains the assumptions used, results, and conclusions of this evaluation.

6.3.4.1 Assumptions. The following assumptions were used during this evaluation.

- The perennial wetland area in Reaches A and B receive the entire mass of metals deposited by runon.

- An average thickness of 1 foot of sediment throughout Reaches A and B is assumed to receive the full impact of all inorganics loading by surface water runon. The calculated wetland area of Reaches A and B is 220,000 square feet. Therefore, there are cubic feet of sediment subjected to loading in the evaluation.

- The average density of the sediment material is assumed to be 100 pounds/cubic foot. The result is a calculated mass of 220 million pounds of sediment subject to loading in the wetland area.

- Sediment mass is assumed to remain constant. The addition of sediment to the site by deposition of suspended solids in runon has been estimated and is negligible in comparison to sediment volume subjected to loading. In addition, this provides a conservative assumption as the addition of sediment would serve to diminish the impact of metals loading by increasing the mass of sediment affected.

- It is also assumed that metals deposited in the future will result in uniform and homogeneous incremental concentration increases throughout the 1-foot sediment zone selected for this evaluation.

- The metals loadings calculated during the Surface Water and Sediment Investigation depict a reasonably accurate and conservative estimate of actual metals loading to the site. These loadings were calculated using the Rational Method, which resulted in a runon volume of about 100 million gallons per year. This evaluation also assumes that all metals contained in runon are deposited in wetland sediments and that no metals leave the site in runoff.

- It is assumed that the runon quality data acquired during the RI are representative of an average year.

6.3.4.2 Results and Conclusions. Using the foregoing assumptions, it is possible to calculate the incremental annual increase of metal concentrations in sediment. An example of this calculation as it was performed for lead is presented below.

$$\frac{13\ lb}{220{,}000\ ft^3\ x\ \dfrac{100\ lb}{ft^3}}\ x\ 1x10^6 = 0.47\ mg/kg \qquad (23)$$

where:

13 lbs = Total annual lead loading
220,000 ft^3x100 lb/ft^3 = Mass of affected sediment
1x10^6 = Conversion factor for lb/lb to mg/kg
0.47 mg/kg = Annual increase in lead concentration.

Table RI-31 presents the results of this calculation for 17 elements in surface water runon.

TABLE RI-31

THEORETICAL ANNUAL INCREASE OF METAL CONCENTRATIONS IN SEDIMENT IN RESPONSE TO RUNON LOADING

Analyte	Average Detected Concentration in STF Sediment		Total Annual Runon Loading (kg)	Annual Incremental Increase in Concentration[a] (mg/kg)
	Wet Season (mg/kg)	Dry Season (mg/kg)		
Aluminum	19,408	21,315	929	92.5
Arsenic	11.6	17.0	2.05	0.20
Barium	103	195	10	1.0
Boron	3.46	4.89	10.9	1.1
Chromium	76.2	62.4	2.27	0.23
Cobalt	9.83	8.33	74.1	7.4
Copper	162	183	5.45	0.55
Iron	19,680	19,114	869	86.9
Lead	637	701	13.0	0.59
Magnesium	4,608	4,780	2,991	299
Manganese	259	291	29.5	2.95
Mercury	0.53	0.76	0	0
Nickel	53.2	38.5	3.64	0.36
Potassium	9.44	817	2,125	213
Sodium	458	469	24,637	2,464
Vanadium	48.8	53.8	2.27	0.23
Zinc	46.5	566	40	4.0

(a) Sediments in Reaches A and B.

The example presented above suggests that the potential significance of lead loading by surface water runon on wetland sediments is minimal. Using the average concentration of lead detected in sediment during the dry season sampling (701 mg/kg) and the calculated incremental annual change rate of 0.47 mg/kg/yr, a time period of 507 years would theoretically be required at the present rate of lead loading for the average sediment lead concentration to reach 1,000 mg/kg.

Although this evaluation is relatively simplistic, it does clarify the potential significance of metal loading values that may otherwise be misleading. An annual loading of 13 pounds of lead to the site appears to be appreciable. However, the evaluation illustrates that if the area and volume of sediment potentially affected are considered, the effect of adding 13 pounds of lead to the site annually is actually relatively small.

Based on this evaluation, the metals in runon that would increase sediment concentrations annually by greater than 1 mg/kg are aluminum, barium, boron, cobalt, iron, magnesium, manganese, potassium, sodium, and zinc. With the exception of barium, boron, cobalt and zinc, these metals are constituents of common rock-forming minerals (e.g., silicates, feldspars, plagioclases) and would be expected to comprise the bulk of suspended soil matter. In addition, sodium and potassium are generally quite soluble and may not accumulate in sediment to a significant degree.

Elements that are generally regarded as being of particular concern in aquatic environmental systems did not, based on this evaluation, make significant annual contributions to metals loading of the sediment. Arsenic, chromium, copper, lead, and mercury all have annual incremental concentration increase values of less than 0.6 mg/kg. Zinc had an annual concentration increase value of 3.2 mg/kg. Based on this value, it would required about 109 years for the average zinc concentration in sediment to reach 1,000 mg/kg.

Based on this evaluation, the metals loading values developed in the Surface Water and Sediment Investigation Report do not appear to represent a significant potential impact on the sediment in the wetlands area. When the average annual concentration increase over the volume of sediment theoretically subject to loading is considered, the effects on metal concentrations are relatively small. The actual deposition and distribution of metals in the wetlands sediment may be different from that assumed in this evaluation. This evaluation was intended to provide a more useful perspective for the metals loading values reported in Appendix SW.

7.0 SUMMARY AND CONCLUSIONS

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The STF RI was designed to provide a characterization of the nature and extent of chemicals of concern in the environment at the site that would be sufficient to permit 1) the determination of the potential risks these chemicals pose to human health and the environment, and 2) the selection of appropriate remedial action(s). The RI included the performance of 11 investigative studies of various environmental media to characterize the nature and extent of contamination onsite and address the data needs identified in EPA's Work Plan (ICF 1990b) and the STF FSAP (Kennedy/Jenks/Chilton 1991a). The RI tasks or studies were:

1. Phase I Soil Investigation (surface and subsurface)
2. Phase II Soil Investigation (surface and subsurface)
3. Groundwater Investigation
4. Hydraulic (Aquifer) Characterization
5. Surface Water and Sediment Investigation
6. Blackberry Investigation
7. Wetland Delineation and Endangered Plant Species Survey
8. Air Dispersion Modeling
9. Soil Gas Survey

10. Geophysical Survey

11. Subsurface Target Confirmation Investigation.

The RI fieldwork was conducted between February 1991 and August 1992. This section summarizes the findings and conclusions of the RI with respect to the nature and extent of onsite contamination, fate and mobility of chemicals of concern, and limitations of the RI data.

7.1 NATURE AND EXTENT OF CONTAMINATION

Based on the data collected during the RI and previous investigations at the STF site, the following conclusions can be made concerning the nature and extent of contamination:

- Concentrations of metals in blackberries from the STF site were similar to those in blackberries collected offsite. Concentrations of metals were low and undetected and EPA concluded that the measured concentrations posed no significant human health risks.

- There are no known endangered or threatened animal or plant species inhabiting the STF site.

- Based on the results of air dispersion modeling, concentrations of chemicals of concern in air are below all industrial screening levels onsite and below all residential screening levels offsite.

- During the soil gas survey, concentrations of halogenated VOCs generally were not detected; only low concentrations of one VOC (carbon tetrachloride) were detected in soil gas samples collected from Pioneer Builders Supply property.

- A comprehensive geophysical survey, which included electromagnetic, magnetometer, and ground penetrating radar techniques, was conducted to identify potential locations of tanks and drums. Of the 60 potential subsurface geophysical targets (tanks and drums), only two underground storage tanks (and no drums) were found using backhoe exploration procedures.

- The distribution of elevated chemical concentrations in onsite surface soil is patchy (i.e., no apparent concentration gradients). This distribution appears to be related to and consistent with specific activities that occurred in individual areas of the site.

- Concentrations of several metals in onsite soil in certain areas of the site are elevated in comparison to background levels. Onsite surface soil concentrations of copper, lead, and zinc are the most elevated in contrast to background levels and were mainly detected in samples from the Amsted property, BNR Dismantling Yard, and BNR Railyard. Soil samples from these areas also contained elevated concentrations of arsenic, beryllium, and cadmium, and to a lesser degree antimony, barium, chromium, cobalt, iron, manganese, mercury, and nickel. Elevated metal concentrations were also detected, but to a lesser degree, in surface soil samples from in the Former Swamp/Lakebed area. However, the assemblage of elevated metals is markedly different from the remaining areas of the STF site. Elevated concentrations of barium, cadmium, chromium, magnesium, manganese, nickel, and vanadium were more commonly detected in samples from the Former Swamp/Lakebed.

- PAHs were also detected in surface soil throughout the site at relatively low to moderate concentrations. Elevated PAH concentrations were detected sporadically in some areas where elevated concentrations of metals occurred (i.e., the Amsted property, BNR Dismantling Yard, BNR Railyard, and Former Swamp/Lakebed).

- Organic chemicals, such as phthalates and phenols, were also detected sporadically in surface soil, but do not constitute significant contamination in terms of concentration levels or areal extent. PCBs were detected in several surface soil samples at relatively low concentrations (i.e., only five samples contained concentrations greater than 5 mg/kg and the maximum detected concentrations was 42 mg/kg). Only trace concentrations of dioxins and dibenzofuran, consistent with typical industrial soil levels, were detected in surface soil samples.

- Metals and PAH concentrations exceeding background levels were generally confined to shallow soil (i.e., less than 2 feet deep), except in areas where fill materials have been placed. Such fill areas include portions of the Amsted property, TIP, Former Swamp/Lakebed, and the south end of the BNR Railyard.

- Elevated concentrations of arsenic, cadmium, chromium (total), copper, lead, mercury, zinc, and PAHs were detected in a number of shallow sediment samples collected from the onsite surface water channel. The major source of detectable contamination in onsite surface water is surface water runon from storm drain outfalls that drain nearby areas of the city. The detected concentrations are characteristic of urban runoff. Elevated concentrations of some metals (notably aluminum, copper, nickel, and zinc) were detected occasionally in individual onsite surface water samples, but it is not known whether metals were dissolved or adsorbed to suspended sediments. Runoff from the site was generally of better quality than runon, and the quantity of runoff was significantly less than the estimated runon.

- Elevated concentrations of PAHs were detected in subsurface soil sampled at and underlying the bottoms of the 10 dry wells at Tacoma City Light property. PCBs and carbazole were also detected in samples from many of the dry wells. Elevated concentrations of 1,3-dichlorobenzene, 1,4-dichlorobenzene, chlorobenzene, benzene, and xylenes were detected in samples from DW-20, which also contained the highest levels of PCBs. Concentrations elevated above background of lead, chromium, arsenic, copper, and mercury were detected in various dry well samples. Elevated concentrations of most chemicals were limited to a few feet in vertical and lateral extent. In general, concentrations of detected organic compounds decreased with depth. A few dry wells (i.e., DW-19, DW-20, DW-22, and DW-26) had detectable organic chemical concentrations in some samples from the lower unsaturated zone.

- Elevated concentrations of 1,2,4-trichlorobenzene, PCBs, and a complex petroleum hydrocarbon mixture were detected in unsaturated zone soil samples from the beneath and immediate surrounding the location where three underground tanks were removed at Pioneer Builders Supply. Concentration profiles were inverted in some borings (i.e., increasing concentrations with depth) in a manner consistent with those expected to result from discharges related to underground tank installations or soil contact with contaminated groundwater. The hydrocarbon mixture included detectable concentrations of toluene, xylenes, and ethyl benzene, as well as numerous TICs that were mostly in the carbon 8 to carbon 12 range. These hydrocarbons are commonly found in gasoline.

- Shallow groundwater quality beneath the STF site shows only minimal evidence of impacts as a result of current and/or historic site activities. No significant evidence of contamination was detected in the onsite deeper saturated zone monitoring wells. Although RI groundwater analytical results do not indicate the presence of a sitewide plume or appreciable regional impact to groundwater, four localized areas of the site were identified where appreciable variations in shallow groundwater chemical quality occurred.
    - The first area is the Pioneer Builders Supply property where the concentrations of ethyl benzene, 1,1,2-trichloroethane, and benzene were detected at concentrations above the MCLs. These

chemicals and a number of other hydrocarbon compounds detected in groundwater at this location may be attributed to a release(s) from the former underground storage tanks that were removed from this area or other sources. Analytical results of groundwater samples at this location also indicate the presence of low levels of PAHs and elevated iron and manganese. The iron and manganese are likely a result of reduced subsurface conditions caused by the presence of petroleum hydrocarbons.

- The second and third areas include contiguous portions of the Airport and Former Swamp/Lakebed areas, and the former railcar cleanout area in the south end of the BNR Railyard. Concentrations of some inorganic constituents (primarily iron and manganese) in these areas were detected at levels exceeding the 95% UCL of background concentrations. The reason for elevated metal concentrations is unclear. However, naturally elevated concentrations of some metals occur locally as a result of the surrounding geologic conditions or variations in groundwater pH and redox potentials. A study performed in the vicinity of the Tacoma Landfill, which is less than 1 mile from the site, indicated that iron and manganese concentration in the study area were generally above available EPA drinking water standards (Lum and Turney 1985).
- The fourth area includes the Amsted property where a relatively small volume of low miscibility, heavy fuel oil was encountered floating on the surface of the water table. The hydrocarbon contamination of this area is being investigated under a separate Consent Order with EPA (Region 10).

7.2 CHEMICAL FATE AND TRANSPORT

Based on the information developed during the RI, the following conclusions can be made concerning the potential transport and fate of chemicals of concern at the site:

- The current potential for chemical transport by surface water erosion, wind erosion, or volatilization is minimal. In the subsurface, leaching of chemicals with subsequent transport by moving groundwater appear to be the only potentially significant transport mechanisms.

- The resuspension and redeposition of soil and dust as a result of human activities (e.g., vehicular traffic, bike riding) could be a transport mechanism of potential concern. Presently, the nature of human activity and the level of vegetative cover at the site does not promote significant soil or dust transport.

- Migration rates estimated for VOCs and semivolatile organic compounds in soil are considerably greater than those estimated for the higher molecular weight organics. This is consistent with the known behavior of VOCs and semivolatile organic compounds in soil/water systems and the fact that they were detected locally in groundwater during the RI. While some retardation due to sorption by organic matter in the saturated zone can be expected to influence the migration and fate of these chemicals, processes such as volatilization, dispersion, diffusion, and biodegradation are expected to be more important in reducing their concentrations in groundwater.

- The metals present in onsite shallow soil and sediment tend to be relatively immobile inasmuch as they are only slightly leachable and there are a number of physical and chemical mechanisms that tend to retard and retain leached metals deeper in the subsurface. Leaching could move small amounts of soluble metals into the saturated zone in areas where they are present deeper in the subsurface (e.g., fill areas or Tacoma City Light dry wells). However, a number of mechanisms may still serve to retard their movement into groundwater.

- The potential dissolution and movement rates of PCBs and PAHs in soil and sediment at the site are negligible. These chemicals are expected to remain sorbed and decompose slowly within the soil/sediment matrices in which they were deposited.

- Surface water runon is contributing to the elevated metals and PAH concentrations in onsite surface water and sediment. The average annual increases in individual metal concentrations in onsite sediment (caused by the deposition of metals in runon) were estimated using the total volume of sediment theoretically subject to loading. Based on this evaluation, the long-term cumulative effects on overall metal concentrations in sediment appears likely to be relatively small.

- Minimal transport of metals from soil and sediment into the saturated soil zone (i.e., groundwater) is expected to occur. A greater potential for soil solutions containing dissolved metals at concentrations of concern to migrate to the saturated zone exists in areas where appreciable quantities of subsurface fill materials are present. These areas include the Amsted property and the south end of the BNR Railyard. However, metal concentrations in undisturbed soil and sediment may generally be expected to remain substantially constant.

7.3 DATA LIMITATIONS

A substantial amount of data was gathered during the RI. These data were subjected to rigorous QA/QC and validation procedures and are of good quality. In general, these data were sufficient to meet the RI objective of adequately characterizing the site and are adequate to perform the FS. The following limitations reflect areas of the site where data may be needed to complete a detailed remedial design.

- The vertical extent of detectable PAH and VOC concentrations was not determined in some of the dry wells at the Tacoma City Light property.
- The extent of soil and groundwater contamination at Pioneer Builders Supply property was not completely characterized.
- The thickness and lateral extent of metals-bearing fill in the south end of the BNR Railyard, TIP, and the Amsted property were not fully determined.
- The thickness of sediment containing elevated metals and PAHs in the surface water channel has not been characterized.

Based on the findings and conclusions of this RI, no additional sampling of these areas is needed to meet the objectives of the RI or to perform the FS. Focused investigations may be warranted based on the findings of the FS, issuance of the Record of Decision (ROD), and the remedial actions selected for implementation at the site.

8.0 REFERENCES

8.0 REFERENCES

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