Parker Landfill Project
Lyndonville, Vermont
Project No. 4905024

REMEDIAL INVESTIGATION REPORT

VOLUME 1 OF 10

Prepared on Behalf of:

THE PARKER LANDFILL TASK GROUP
LYNDONVILLE, VERMONT

Prepared By:

ENVIRONMENTAL SCIENCE &
ENGINEERING, INC. (ESE)

Submitted To:

U.S. EPA REGION 1
BOSTON, MASSACHUSETTS

DRAFT: NOVEMBER 12, 1992
FINAL: JANUARY 18, 1994
REVISED: MAY 2, 1994

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Engineering, Inc.
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May 2, 1994

Ms. Sheila Eckman, RPM
U.S. Environmental Protection Agency
Waste Management Division, HPS-CAN1
JFK Federal Building
Boston, MA 02203

RE: Revised Final Remedial Investigation Report
Parker Landfill Project (4905024)

Dear Ms. Eckman:

Enclosed are ten copies of the revised final Remedial Investigation Report (RI) and the Response to EPA Comments on the RI. The following insertions/deletions should be made to existing volumes, dated January 18, 1994:

Volume 1 of 10 - Discard existing Volume 1 in its entirety and replace with the enclosed Volume 1.

Volumes 2 - 10 - Remove and discard existing slip-in covers and replace with the enclosed new covers, reflecting the revision date.

Volume 2 of 10 - Remove and discard the following tables and replace with the corresponding enclosed tables:

4-27	4-28
4-29	4-30
4-32	4-33

Remove and discard the following figures and replace with the corresponding enclosed figures (note that Figure 5-3 no longer exists and has been combined with new Figure 5-2):

3-25	3-26	3-27	4-24
4-29	5-2		

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Five Overlook Drive Amherst, New Hampshire 03031 Phone (603) 672-2511 Fax (603) 672-2014

Volume 3 of 10 - Remove and discard the following plates and replace with the corresponding enclosed plates:

B	E	F	G	I
J	K	L	Q	

Volume 7 of 10 - Remove and discard the two page Bouwer & Rice table and replace it with the enclosed two page table.

If you have any questions, please call Gary Wilson or me.

Thank you.

ENVIRONMENTAL SCIENCE & ENGINEERING, INC.
Respectfully submitted,

David E. Andrews
Project Coordinator

cc: Lynda Wedderspoon, VT DEC (w/ enclosure)
Lou Rundio, MW&E
Julia Hagan, VTA
John Young, VTA
W. Gary Wilson, ESE

FILE:EPALET44.PRK

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DISCLAIMER

This document is a DRAFT document prepared by the Respondents to a government Administrative Order which has not received final acceptance from the U.S. Environmental Protection Agency. The opinions, findings, and conclusions expressed are those of the authors and not those of the U.S. Environmental Protection Agency or the State of Vermont.

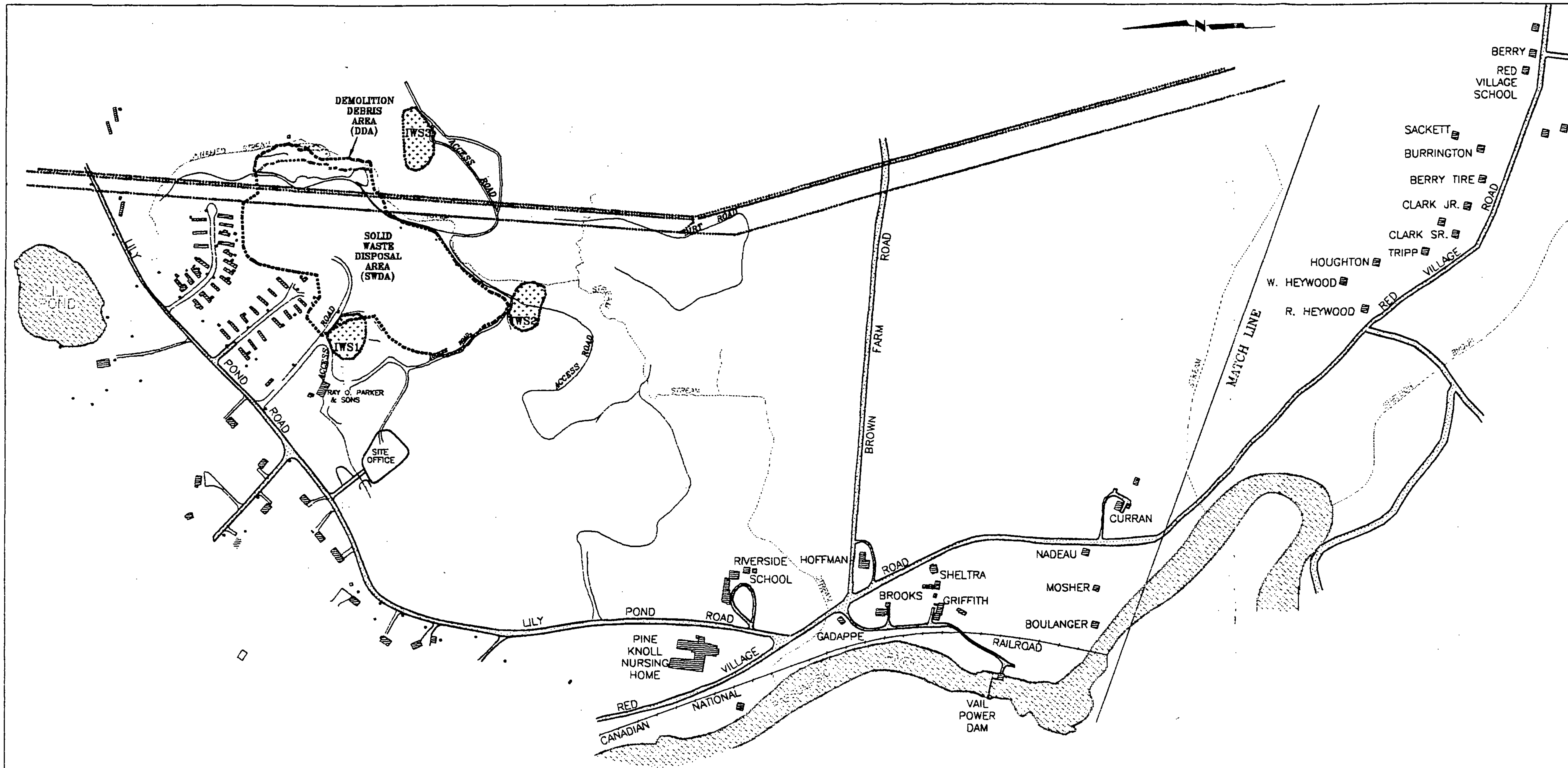
Executive Summary

EXECUTIVE SUMMARY

E.1 PURPOSE OF THE REPORT

These documents present the Remedial Investigation/Feasibility Study (RI/FS) which was completed for the Parker Landfill Project pursuant to the requirements of U.S. Environmental Protection Agency (EPA) Administrative Order by Consent, Docket Number I-90-1089 (Administrative Order), effective August 10, 1990. The Parker Landfill (Landfill) is located near the Village of Lyndonville, within the Town of Lyndon, Vermont. The Landfill is contained within approximately 25 acres of a 75 acre parcel on the southern side of Lily Pond Road, approximately 0.2 mile southeast of Lily Pond in the southeast portion of the Town of Lyndon, Caledonia County, Vermont. The Landfill (see Figure E-1) contains a solid waste disposal area (SWDA) and three smaller industrial waste areas (IWS Areas).

Investigation of the Landfill by the Vermont Department of Environmental Conservation (VTDEC) began in 1984 when routine sampling by the VTDEC revealed the presence of chlorinated volatile organic compounds (VOC) in monitoring wells in the vicinity of the SWDA and IWS Areas and in stream locations on the perimeter of the SWDA and IWS Areas. Follow-up sampling has detected VOC above Maximum Contaminant Levels (MCL) in five private wells south of the Landfill. During 1985, VTDEC completed a Preliminary Assessment and an Uncontrolled Hazardous Waste Site Evaluation. Based upon the results of those studies, EPA proposed the Landfill for listing on the National Priorities List on June 21, 1988. On February 16, 1990 the Landfill was listed on the National Priorities List. On August 10, 1990 the Respondents voluntarily entered into an Administrative Order with the EPA. This Administrative Order sets forth the requirements for the preparation and performance of a Remedial Investigation and Feasibility Study (RI/FS). The Remedial Investigation Report details the field studies performed and the data collected, to provide a comprehensive summary of the Phase 1A and Phase 1B Remedial Investigation (RI) activities, results, and data evaluations. Based on the conceptual model of study area conditions developed during the RI, the FS report



NOTES:

1. BASE MAP FROM "TOPOGRAPHIC WORKSHEET OF THE PARKER LANDFILL", DATED SEPTEMBER 5, 1987, PROVIDED BY EASTERN TOPOGRAPHICS, WOLFBORO, NEW HAMPSHIRE, TO A SCALE OF ONE INCH EQUALS 100 FEET.
2. SURVEY DATUM IS 1929 USGS MEAN SEA LEVEL.
3. PLAN AREA SOUTH OF MATCH LINE BASED ON USGS PROVISIONAL MAPS, BURKE MOUNTAIN AND LYNDONVILLE QUADRANGLES, 7.5 MINUTE SERIES, TO A SCALE OF 1:24000.
4. EXTENT OF IWS AND SWDA AREAS IS APPROXIMATE.

LEGEND

(stippled)	SNOW FENCE (SURROUNDING IWS AREAS)
·	LANDFILL LIMIT MONUMENT
•	UTILITY POLE
	DIRT ROAD
	POWERLINES

0 500 1000
SCALE IN FEET

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PLAN OF PARKER LANDFILL AND SURROUNDING VICINITY

FIGURE E-1

DRAWING NAME: CULEXEC.DWG		FILE NUMBER: 4905024	
SCALE: 1"=500'	REVISION: 0	DRAWN BY: PLM	DATE: 11/12/92

presents the identification of response areas, and identification, development, and evaluation of remedial alternatives for the Landfill.

E.2 STUDY AREA DESCRIPTION

The Landfill is located in an area of open hilly terrain. The topography of the region is generally hilly to mountainous. Several hills within a few miles of the Landfill have a vertical relief of 200 to 300 feet. Abutting the 75 acre parcel are woodlands, pasture land, and developed land. An unnamed stream traverses the Study Area, joins with two larger unnamed streams immediately southeast of the Landfill, and flows south and southwest to the Passumpsic River.

To the north, approximately 0.3 mile from the Landfill are three mobile home communities and seven single family homes, and beyond Lily Pond is a combination of pasture land, crop land, and woodland. To the west of the Landfill, about 0.5 mile, is a combination of woodland and a residential development (approximately 40 homes). To the south is a combination of woodland, pasture land, and crop land. A private school, a nursing home, and five single family homes are located about 0.5 mile south of the Landfill. East of the Landfill are hilly woodlands.

E.3 SUMMARY OF REMEDIAL INVESTIGATION FIELD INVESTIGATIONS

The area investigated during the RI (Study Area) includes the Landfill, areas west to Lily Pond Road, and south, on both sides of Red Village Road to the point where Red Village Road turns east. In order to evaluate the geology and hydrogeology of the Study Area, geophysical investigations were conducted, 39 test borings were completed, 73 monitoring and three observations wells were installed, and fourteen piezometers were installed in the unnamed stream and the Passumpsic River. The installation of monitoring and observation wells, in conjunction with existing monitoring wells within the Study Area and the conversion of the Curran and Riverside School wells into monitoring wells, results in a total of 92 monitoring wells. The monitoring wells were installed, based on the conceptual model, to provide hydrogeologic information and allow collection of groundwater samples for chemical analysis. Figure E-2 shows monitoring well locations.

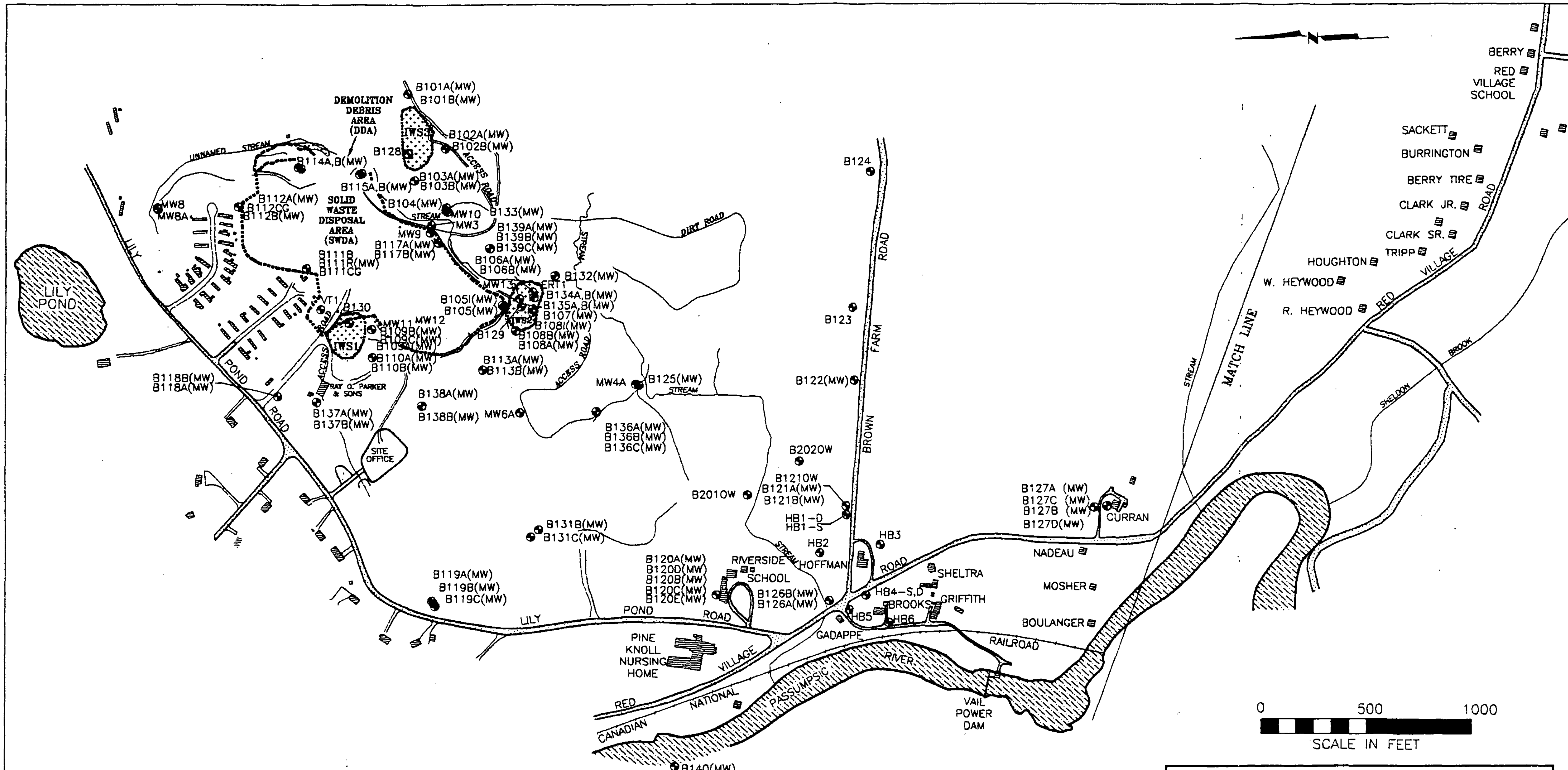
An air quality survey was performed during Phase 1A prior to beginning intrusive field work and after the completion of intrusive field work. A soil gas survey was conducted at each IWS Area to facilitate the selection of locations for test pits and borings. Surficial soil samples were collected from each IWS Area and the eastern boundary of the SWDA. Leachate from the SWDA, along the eastern boundary, was also sampled. Surface water and sediment samples were collected from the unnamed stream and a preliminary ecological assessment was conducted. Samples collected for laboratory analysis during Phase 1A were generally analyzed for the Target Compound List (TCL) organics and Target Analyte List (TAL) metals, pursuant to the requirements of the Contract Laboratory Program (CLP). Data generated by the laboratory at DQO Level 4 underwent data validation according to the EPA Region I Functional Guidelines for Data Validation.

E.3.1 GEOLOGY OF THE STUDY AREA

E.3.1.1 Surficial Geology

Four major surficial geologic deposits are of primary importance in the Study Area: esker deposits, an esker delta deposit, Proximal glacial lacustrine deposits (Proximal Units), and Distal glacial lacustrine deposits (Distal Units). An esker is located just beyond the western limit of the Study Area. The esker deposits consist of coarse to medium sand, gravel, and cobbles in graded and cross-bedded imbricated channel deposits, bounded by cross-bedded coarse to medium sand. Flow direction indicators such as cross-bedding patterns, horizontal grading, and imbrication indicate flow direction of glacial melt waters was toward the southwest, south, and southeast. Meltwater flow along the eastern flank of the esker was toward the southeast.

A west to east trending deposit of cross-bedded coarse to fine sand and gravel unit (the esker delta deposit) apparently disrupts the Distal Unit immediately south of the Landfill. Bedding



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4. EXTENT OF IWS AND SWDA AREAS IS APPROXIMATE.

LEGEND

	SNOW FENCE (SURROUNDING IWS AREAS)
	LANDFILL LIMIT MONUMENT
	DIRT ROAD
B130	LOCATION OF TEST BORING COMPLETED DURING 1991 AND 1992 FIELD SEASONS BY CUSHING AND SONS, INC. OF KEENE, NEW HAMPSHIRE AND ENVIRONMENTAL DRILLING, INC., OF STOWE, MASSACHUSETTS.
(MW)	INDICATES INSTALLATION OF A GROUNDWATER MONITORING WELL.
CG	INDICATES INSTALLATION OF A COMBUSTIBLE GAS MONITORING WELL.
MW10	LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR RAY O. PARKER AND SON PRIOR TO 1987.
ERT1	LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY, (ERT) DURING THE 1987 FIELD SEASON.

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TEST BORING/WELL LOCATIONS

FIGURE E-2

DRAWING NAME: BORWLEXE.DWG		FILE NUMBER: 490 5024	
SCALE: 1"=500'	REVISION: 0	DRAWN BY: PAD	DATE: 11/12/92

structure within the upper portion of this unit resembles deltaic top set, foreset, and bottom set beds. This unit may represent a prograding delta sequence extending in an easterly direction into a glacial lake. This unit grades northeasterly and easterly into predominantly fine sand, which is indistinguishable from the Proximal Unit.

The Proximal Unit consists of medium to fine sand and silty fine sand and extends in an easterly direction from the esker. Coarser units of coarse to medium sand were encountered at several test boring locations. The Proximal deposits are massive to thinly bedded. Grain size within the Proximal Unit decreases in an easterly direction, away from the esker. The Proximal Unit is extensive throughout the Study Area and underlies the SWDA and IWS Areas, and thickens toward the west and south. Visible bedding planes within these deposits dip toward the southeast. These deposits are interfingered with Distal Unit in the immediate vicinity of the Landfill and pinch out in an easterly direction against the underlying bedrock, which rises steeply toward the eastern highlands.

The Distal Unit, consisting of thinly interbedded to thinly interlaminated very find sand, silt, and clay overlies the basal Proximal Unit (lower Proximal) and is overlain by a shallow Proximal Unit (upper Proximal) in the immediate vicinity of the SWDA, IWS 1 and IWS 2. The Distal Unit exhibits maximum thickness immediately beneath the SWDA and decreases in thickness radially away from the SWDA. The Distal Unit deposits pinch out against bedrock along the eastern margin of the Study Area. The Distal Unit extends beyond the western boundary of the Landfill as indicated by its presence at B118 and by the existence of Lily Pond, which is interpreted to rest on Distal sediments.

E.3.1.2 Bedrock Geology

The bedrock geology of the Study Area was extensively mapped during the 1950s and 1960s by Dennis (1956) and Woodland (1965). Based upon the mappings, the Study Area is underlain by two formations: The Waits River Formation and the Gile Mountain Formation. The Waits River Formation consists of a quartzose limestone/phyllitic limestone member and an amphibolite member. The Gile Mountain Formation consists of a quartzose phyllite. The contact between the two formations is inferred to be gradational and located immediately east of the SWDA. To the east of the SWDA, the contact is inferred to trend in a northerly and southwesterly direction.

Bedrock structural data obtained in the field during the Limited Field Investigation (LFI), conducted during October 1990 to provide preliminary imputs for the RI/FS Work Plan, indicate the development of two joint sets discussed here as J_1 and J_2. J_1 generally strikes between N50°E and N60°E and dips to the northwest at 53 to 70 degrees. The trend of the occurrence of regolith, discussed previously, is coincident with the strike of the J_1 joint set and closely parallels the inferred contact between the Gile Mountain and Waits River Formations. The J_1 joints are most commonly filled with calcite and quartz. However, some of the joints observed during the LFI were open, with separations ranging from less than a tenth of an inch to one-inch in width.

J_2 strikes between N50°W and N55°W and dips toward the southwest at 67 to 80 degrees. J_2 joints striking N75°W were observed along the railroad easement near the Vail Dam and may indicate local slumping or rotation of exposed bedrock following construction of the railroad. The J_2 joints are the most common and persistent joints in the Lyndonville and Burke quadrangles and are visible as photoliners on air photographs. Published data for the Lyndonville Area (Dennis, 1956) indicate that on a regional scale the J_2 joints ar commonly not filled.

Bedrock elevations in the Study Area, determined from test borings, ranged from 723.39 to 561.9 feet above mean sea level. Contoured bedrock elevations based upon outcrop, test boring, and seismic data indicate that in the immediate vicinity of the Landfill, the bedrock surface generally dips gently toward the west. A northwest trending bedrock trough is located in the immediate vicinity of IWS 2 and extends northwest. The trend of this bedrock feature is in general agreement with the strike of the regional J_2 joint set. The bedrock topographic pattern appear to be controlled or strongly influenced by the regional J_1 and J_2 joint sets.

Test boring, rock coring, and seismic data indicate that a broad northeast-southwest trending fracture zone could exist along the eastern margin of the SWDA. Bedrock relief across the inferred fracture zone varies from approximately 120 feet at the northeast corner of the SWDA to 85 feet in the vicinity of IWS 2. Seismic data indicates the presence of a large swath of bedrock exhibiting bedrock seismic velocities that are indicative of highly weathered or fractured bedrock, which is generally 700 to 800 feet wide and extends in a southwesterly direction from IWS 3 to the Riverside School area.

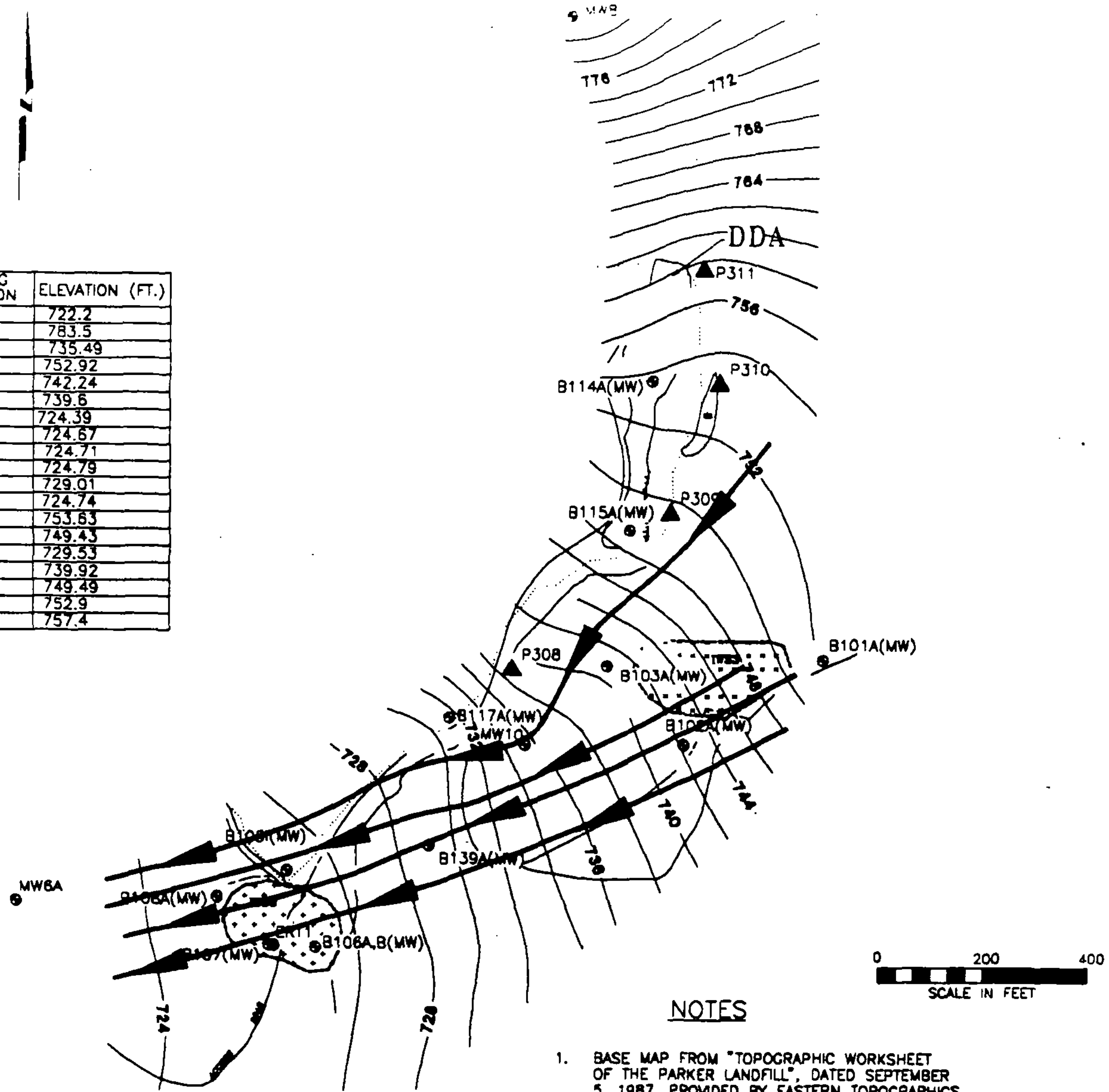
E.3.2 CONCEPTUAL MODEL OF THE STUDY AREA

Based on the results of the RI, the following summarizes the conceptual model for the Study Area:

- The Study Area is comprised of three primary hydrogeologic units: the Upper and Lower Proximal units (proximal glacial-lacustrine deposits), and the fractured bedrock. Over most of the site the Lower Proximal and fractured bedrock flow zones are separated from the Upper Proximal zone by the Distal unit (distal glacial-lacustrine deposits), which is a semi-confining unit. In terms of groundwater flow volume, the Lower Proximal zone is the principal water-bearing unit in the study area. The saturated portion of the Upper Proximal is completely contained within the Study Area and is not used for water supply. Private wells are installed in both the bedrock and the Lower Proximal, although residences in the vicinity of the Landfill are either connected to, or have access to the municipal water supply.

- South-southwesterly flow of groundwater in the upper Proximal portion of the aquifer is underlain by the lower permeability Distal Unit. This upper Proximal Unit constitutes a shallow migration pathway east of the Landfill. This preferential pathway results in the transport of VOC from IWS 3 to the general vicinity of IWS 2, as shown on Figure E-3.

- Four potential source areas within the Parker Landfill were identified during the RI: the SWDA, IWS 1, IWS 2, and IWS 3. The SWDA contains approximately



BORING LOCATION	ELEVATION (FT.)
MW6A	722.2
MW8A	783.5
MW10	735.49
B101A	752.92
B102A	742.24
B103A	739.6
B105I	724.39
B106A	724.67
B107	724.71
B108A	724.79
B139A	729.01
ERT1	724.74
B114A	753.63
B115A	749.43
B117A	729.53
P308	739.92
P309	749.49
P310	752.9
P311	757.4

NOTES

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3. PLAN AREA SOUTH OF MATCH LINE BASED ON USGS PROVISIONAL MAPS, BURKE MOUTAIN AND LYNDONVILLE QUADRANGLES, 7.5 MINUTE SERIES TO A SCALE OF 1:24000.
4. INTERPOLATION OF HEAD DISTRIBUTION WAS COMPUTED ON A 25 BY 25 FOOT GRID TO ENHANCE RESOLUTION AND DETAIL. HOWEVER, THE DATA SET WAS THEN MATHEMATICALLY SMOOTHED USING A 2 BY 2 MATRIX (WEIGHTED AVERAGE) METHOD. SMOOTHING WAS PERFORMED FOR THE PURPOSE OF DE-EMPHASIZING LOCALIZED VARIATION AND TO BETTER REPRESENT THE FLOW FIELD FOR THE UPPER PROXIMAL PORTION OF THE AQUIFER AS A WHOLE.
5. PIEZOMETRIC HEADS SHOWN WERE MEASURED ON JULY 28, 1992.

LEGEND

B130 ●	LOCATION OF TEST BORING COMPLETED DURING 1991 & 1992 FIELD SEASON BY CUSHING AND SONS, INC. OF KEENE, NEW HAMPSHIRE AND ENVIRONMENTAL DRILLING, INC., OF STOWE, MASSACHUSETTS.
(MW)	INDICATES INSTALLATION OF A GROUNDWATER MONITORING WELL.
MW10 ●	LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR RAY O. PARKER AND SON PRIOR TO 1987.
ERT1 ●	LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY, (ERT) DURING THE 1987 FIELD SEASON.
:::::::	SNOW FENCE (SURROUNDING IWS AREAS)
	DIRT ROAD
▲P311	LOCATION OF PIEZOMETER INSTALLED BY ESE PERSONNEL DURING THE 1991 FIELD SEASON.
772	GROUNDWATER CONTOUR. CONTOUR INTERVAL IS TWO FEET.
	STREAMLINE
	APPROXIMATE BOUNDARY OF SWDA

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PATHLINES OF TRAVEL FOR VOC IN THE UPPER PROXIMAL PORTION OF THE AQUIFER FROM IWS3

FIGURE E-3

DRAWING NAME: UPE3.DWG		FILE NUMBER: 490 5024	
SCALE: AS SHOWN	REVISION: 1	DRAWN BY: PAD	DATE: 01/18/94

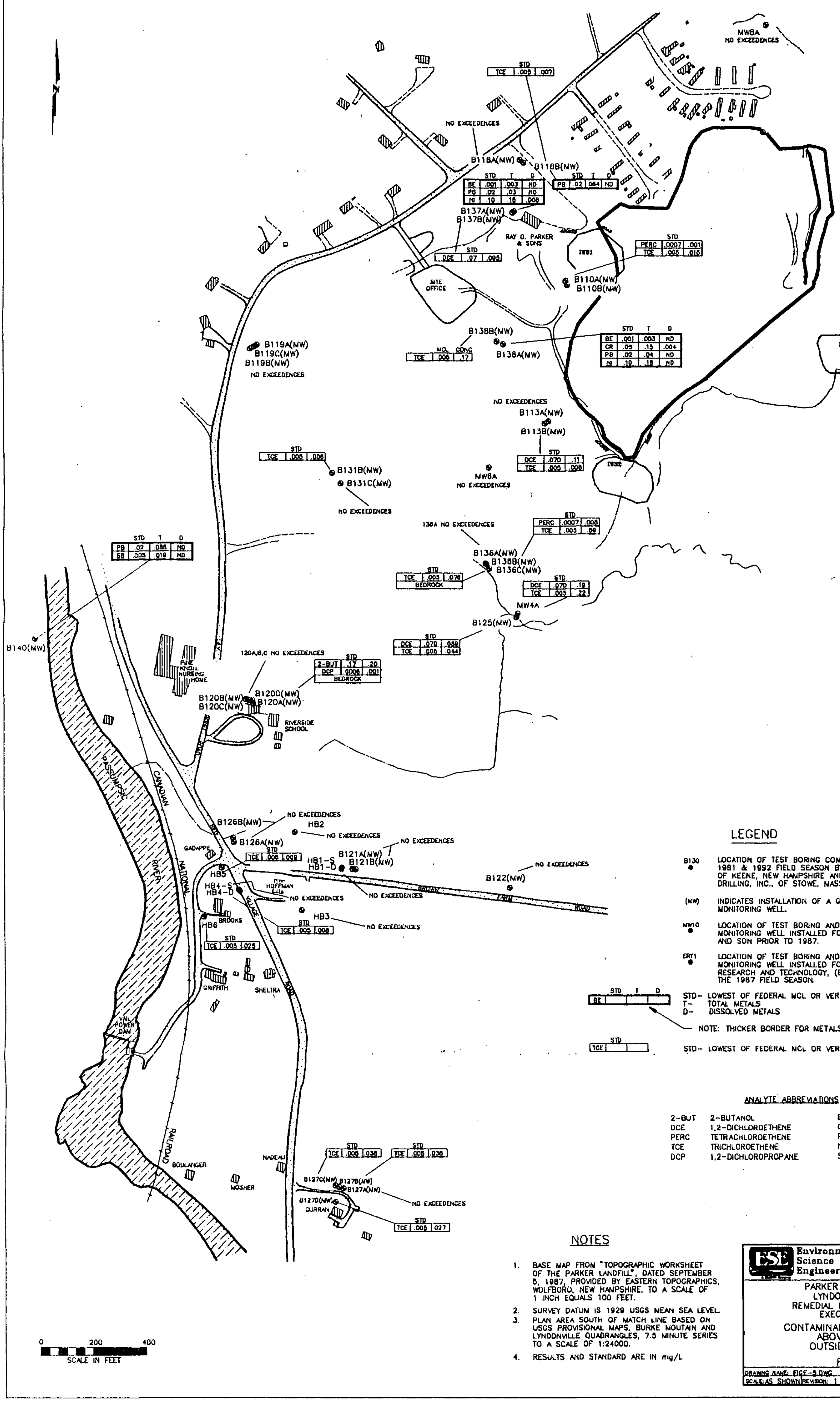
1.4 million cubic yards of solid waste and cover material. The three IWS Areas are smaller in size, and contain mixed soil and waste material including scrap metal, wood, plastic and empty, crushed drums.

- Waste in the SWDA is the source of leachate which contains mainly ketones (acetone, 2-butanone, 2-hexanone, 4-methyl-2-pentanone), benzene, ethyl benzene, toluene, xylene, phenolics (methyl phenol, benzoic acid, phenol), and various metals which were detected above and below background concentrations. Individual source areas within the SWDA cannot be identified and the whole SWDA is considered to be a diffuse source.

- The organic compounds found in the upper bedrock appear to have mainly originated in IWS 3 with minor contributions from the IWS 2 area. The contribution of chlorinated organic compounds from IWS 2 to bedrock appears to be limited. Chlorinated VOC have been detected immediately above the bedrock and in bedrock beneath IWS 2, at B132, and at the B136 well cluster. However, the chlorinated VOC found at these locations cannot be readily explained by migration from IWS 2. Although the presence of a fracture zone is conjectural, based on available data, the distribution of constituents suggests that chlorinated organic compounds originating from IWS 3 enter a bedrock fracture or fracture zone, which is likely to be parallel to the trend of the J_1 joint set. This fracture zone is encountered at B132 and is hydraulically connected to the bedrock fracture zone at B136. There appears to be a bedrock hydraulic connection between IWS 2/SWDA and the Riverside School area. It is likely that this hydraulic connection consists of one or more fractures aligned consistent with the orientation of the J_1 joint set. The fractures encountered at B136, assumed to be connected to bedrock beneath B132, likely also contribute chlorinated volatile constituents to the Riverside School area, with sub-parallel fracture sets carrying mixed constituents from IWS 2/SWDA.

- Figure E-4 shows the occurrence of contaminants above either Federal Maximum Contaminant Levels (MCL) or the Vermont Enforcement Standard, in areas outside and downgradient of the Landfill. The analytical data generally suggest that the presence of the non-chlorinated VOC, detected in the overburden above MCLs, is not widespread southwest of the Landfill.

- Soil samples from the IWS Areas indicate the presence of chlorinated and petroleum-related VOC, polynuclear aromatic hydrocarbons (PAH) and metals above and below background levels. Waste materials and the majority of contaminated soil within the three IWS Areas is located above the water table. The analytical data indicate that VOC levels within IWS 2 are generally higher than in the other IWS Areas, and calculations of the relative mass of VOC within the three areas indicate that the greatest mass of "total" VOC is contained within IWS 2. By comparing the analytical data, specifically the non-chlorinated VOC concentrations with chlorinated VOC concentrations, the IWS 2 Area does not appear to be a major source of chlorinated VOC to the groundwater. Chlorinated VOC concentrations detected in shallow groundwater in the IWS 2 Area range from approximately 0.02 mg/l to approximately 0.13 mg/l, or 1 order of magnitude less than chlorinated VOC concentrations in shallow groundwater in the vicinity of IWS 1 and IWS 3. However, one well is an exception with chlorinated VOC concentrations of approximately 76.6 mg/l. It is believed that this well is in a localized area of residual organic compounds. Although chlorinated VOC are found in the soils in IWS 2, fine-grained surficial soils and fairly rapid runoff appear to limit the volume of water flushing through these soils. By comparing the concentration of chlorinated VOC in the uppermost monitoring wells, which provide an indication of contaminant concentrations leaching into groundwater from IWS 2, with chlorinated VOC concentrations in the deeper monitoring wells, which provide an indication of contaminant concentrations migrating through the subsurface from other sources, it appears that most of the chlorinated VOC found in the groundwater in the vicinity of IWS 2 may have originated from the IWS 3 Area.



LEGEND

B130 ● LOCATION OF TEST BORING COMPLETED DURING 1981 & 1992 FIELD SEASON BY CUSHING AND SONS, INC. OF KEENE, NEW HAMPSHIRE AND ENVIRONMENTAL DRILLING, INC., OF STOWE, MASSACHUSETTS.

(NW) INDICATES INSTALLATION OF A GROUNDWATER MONITORING WELL.

MW10 ● LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR RAY O. PARKER AND SON PRIOR TO 1987.

ERT1 ● LOCATION OF TEST BORING AND GROUNDWATER MONITORING WELL INSTALLED FOR ENVIRONMENTAL RESEARCH AND TECHNOLOGY, (ERT) DURING THE 1987 FIELD SEASON.

STD T D / BE

STD- LOWEST OF FEDERAL MCL OR VERMONT ENFORCEMENT STANDARD
T- TOTAL METALS
D- DISSOLVED METALS

NOTE: THICKER BORDER FOR METALS.

STD / TCE

STD- LOWEST OF FEDERAL MCL OR VERMONT ENFORCEMENT STANDARD

ANALYTE ABBREVIATIONS

2-BUT	2-BUTANOL	BE	BERYLLIUM
DCE	1,2-DICHLOROETHENE	CR	CHRONIUM
PERC	TETRACHLOROETHENE	PB	LEAD
TCE	TRICHLOROETHENE	NI	NICKEL
DCP	1,2-DICHLOROPROPANE	SB	ANTIMONY

NOTES

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2. SURVEY DATUM IS 1929 USGS MEAN SEA LEVEL.
3. PLAN AREA SOUTH OF MATCH LINE BASED ON USGS PROVISIONAL MAPS, BURKE MOUTAIN AND LYNDONVILLE QUADRANGLES, 7.5 MINUTE SERIES TO A SCALE OF 1:24000.
4. RESULTS AND STANDARD ARE IN mg/L

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CONTAMINANTS IN GROUNDWATER ABOVE MCL OR VES OUTSIDE THE LANDFILL

FIGURE E-4

DRAWING NAME: FIGE-5.DWG | FILE NUMBER: 490 5024
SCALE: AS SHOWN | REVISION: 1 | DRAWN BY: PAD | DATE: 1/18/94

- Because of the complex nature of the geology in this area, and the convergence of migration pathways, separate plumes from the IWS Areas and SWDA cannot be distinguished.

- Extensive investigations during the RI defined the physical limits of waste material within IWS 1, 2, 3. These waste materials lie within the unsaturated zone. Soil containing much lower concentrations of Contaminants of Concern was also detected below the waste material in IWS 2 and 3. Some of these detections were in the saturated zone. Although saturated zone detections of Contaminants of Concern were limited in the immediate vicinity of the IWS Areas, it is possible, based on historic disposal practices, that dense nonaqueous phase liquids (DNAPL) are present within the saturated zone. The location of DNAPL, as residual or pools, if present in the subsurface, is difficult or impossible to determine. Although there is no direct evidence that DNAPL is present within the saturated zone, its potential presence must be acknowledged because of the impact this may have on the effectiveness of remedial measures.

- Similarly, overburden TCE contamination at B127B and B127C is unlikely to have resulted from transport in the overburden, given the transport times discussed in Section 5.3.4.2 of the RI.

E.4 SUMMARY OF FEASIBILITY STUDY

E.4.1 IDENTIFICATION OF RESPONSE AREAS AND REMEDIAL ACTION OBJECTIVES

Based on the data collected during the RI, and the results of the risk assessment completed by EPA, two response areas were identified for evaluation in the FS: (1) the SWDA and IWS Areas (1, 2, and 3), and (2) groundwater. The following specific remedial action objectives were identified for each response area:

SWDA and IWS Areas

- Minimize, to the extent practicable, the potential for transfer of hazardous substances from the soil and solid waste into the groundwater, surface water, and sediment;

- Prevent direct contact/ingestion of soil or solid waste posing a potential total cancer risk greater than 10^{-4} to 10^{-6}, or a potential hazard index greater than one; and

- Comply with federal and state ARARs.

The remedial objectives for the SWDA and IWS Areas are addressed by the caps which will be placed over these areas as the presumptive remedy (see section E.4.2). The caps will prevent direct contact with soil or solid waste within the SWDA and IWS Areas, and will minimize the potential for transfer of Contaminants of Concern from the unsaturated zone to groundwater through rainfall infiltration. Due to the presumptive remedy, remediation goals calculated based on exposure risk and leaching potential would only be relevant to the No Action Alternative. Therefore, remediation goals for soil in the SWDA and IWS Areas are not developed.

Groundwater

- Prevent ingestion of groundwater containing Contaminants of Concern in excess of federal or state standards, or posing a potential total cancer risk greater than 10^{-4} to 10^{-6}, or a potential hazard index greater than one; and

- Comply with federal and state ARARs.

E.4.2 PRESUMPTIVE REMEDY

Under its Superfund Accelerated Cleanup Model (SACM), EPA has established the concept of presumptive remedy as a mechanism to streamline site studies and cleanup actions, thereby, improving consistency, reducing costs, and increasing the pace at which Superfund Sites are remediated. EPA's Directive *Presumptive Remedy for CERCLA Municipal Landfill Sites* (EPA, 1993b) establishes containment (capping) as the presumptive remedy for CERCLA municipal landfills. Because there may be a potential human health risk associated with direct contact with subsurface soil and waste debris in the IWS Areas and because the SWDA, as a municipal landfill, must be closed with a cap, EPA has supported the concept of capping as the presumptive remedy for the Parker Landfill. Therefore, the FS focuses primarily on evaluating whether measures in addition to capping (i.e., groundwater control and potential hot spot remediation) may be appropriate.

As stated in EPA's *Guidance for Conducting Remedial Investigations/Feasibility Studies for CERCLA Municipal Landfill Sites* (EPA, 1991), "hot spots that are appropriate for excavation and removal should be in discrete, accessible locations of a landfill where a waste type or mixture of wastes presents a principal threat to human health or the environment. The area should be large enough so that remediation will significantly reduce the risk posed by the overall site and small enough to be reasonably practicable for removal and/or treatment." To evaluate the potential significance of each IWS Area as a "hot spot," as mentioned previously, the relative amounts of VOC in IWS 1, IWS 2, and IWS 3, presented on the basis of mass, were calculated. The results of this analysis indicate that IWS 3 only contains 14% of the total VOC mass, and IWS 1 only contains 7% of the total VOC mass estimated to exist in the three IWS Areas. Therefore, removal of the VOC mass from IWS 1 or IWS 3 would not significantly reduce the risk posed by the site. Furthermore, these areas will be capped in accordance with the presumptive remedy, and rainfall infiltration and percolation from these areas will be prevented. IWS 2, however, contains 79% of the mass of "total" VOC within the IWS Areas. Based on this analysis, in accordance with EPA guidance, of the three IWS Areas, only IWS 2 was considered as a potential "hot spot" and evaluated for potential removal and treatment or disposal.

E.4.3 PRELIMINARY AND INITIAL SCREENING OF ALTERNATIVES

During the preliminary screening, the general response measures considered applicable for each of the identified response areas were identified. For each general response measure, remediation technologies, and processes specific to these technologies, were then identified. A preliminary screening of these technologies and specific processes was conducted to determine their applicability and technical feasibility. Those remedial technologies considered ineffective or unsuitable for implementation were eliminated from further consideration during the preliminary technology screening. Then, in order to simplify the subsequent development and evaluation of alternatives without limiting flexibility during remedial design, representative technologies/process options were selected.

The representative technologies/process options that remained after the preliminary screening were developed into potential remedial alternatives. The remedial alternatives for Groundwater and the SWDA and IWS Areas at the Parker Landfill are:

Alternative 1:	No Action;
Alternative 2:	Containment (SWDA, IWS 1, 2 and 3)/No Source Control Groundwater Extraction;
Alternative 3:	Containment (SWDA, IWS 1, 2 and 3)/Source Control Groundwater Extraction;
Alternative 4:	Containment (SWDA, IWS 1, 2 and 3)/In-situ Soil Vapor Extraction of IWS 2 Area/No Source Control Groundwater Extraction;
Alternative 5:	Containment (SWDA, IWS 1, 2 and 3)/In-situ Soil Vapor Extraction of IWS 2 Area/Source Control Groundwater Extraction;

Alternative 6: Containment (SWDA, IWS 1 and 3)/Excavation and Off-site Incineration of IWS 2 Materials/No Source Control Groundwater Extraction;

Alternative 7: Containment (SWDA, IWS 1 and 3)/Excavation and Off-site Incineration of IWS 2 Materials/Source Control Groundwater Extraction; and

Alternative 8: Downgradient Groundwater Extraction/Treatment/ Discharge (may be combined with Alternatives 2 through 7).

Alternative 8A: Downgradient Groundwater Extraction/Combined with Alternatives 2, 4, or 6 (No Source Control Groundwater Extraction System).

Alternative 8B: Downgradient Groundwater Extraction/Combined with Alternatives 3, 5, or 7 (Source Control Groundwater Extraction System).

An initial screening evaluation, which consisted of an evaluation of each alternative's effectiveness and implementability, was conducted on each of the potential remedial alternatives. Those alternatives that would have significant adverse impacts or would not adequately contribute to the protection of public health or the environment were eliminated from further consideration. In addition, an order of magnitude cost comparison between alternatives that would provide a commensurate level of protection to public health and the environment was conducted.

Two alternatives were eliminated during the initial screening. Alternative 6: Containment (SWDA, IWS 1 and 3)/Excavation and Off-Site Incineration of IWS 2 Materials/No Source Control Groundwater Extraction, and Alternative 7: Containment (SWDA, IWS 1 and

3)/Excavation and Off-Site Incineration of IWS 2 Materials/Source Control Groundwater Extraction were eliminated because they would offer very limited additional benefits and minimal risk reduction relative to other alternatives, yet would be more costly to implement and would pose significant potential worker and community exposure and implementability concerns.

Alternatives 4 and 5 were retained for further evaluation as a VOC-reduction measure, because it is the presumptive remedy for CERCLA Sites with VOC in soils (EPA 540-F-93-048) and the National Contingency Plan (NCP) and EPA guidance specify that the range of alternatives to be considered includes treatment alternatives, to the extent practicable. EPA presumptive remedy guidance states, however, that vacuum extraction may or may not be appropriate for VOC-contaminated soils, depending on site-specific conditions.

E.4.4 DETAILED EVALUATION

A detailed evaluation, based on seven of the nine criteria enumerated in the NCP, was conducted on the remedial alternatives remaining after the initial screening. The remaining two criteria (state and community acceptance) will be evaluated by EPA following public comment. The following alternatives were evaluated in detail in the FS:

Alternative 1:	No Action
Alternative 2:	Containment (SWDA, IWS 1, 2, and 3)/No Source Control Groundwater
Alternative 3:	Containment (SWDA, IWS 1, 2, and 3)/Source Control Groundwater
Alternative 4:	Containment (SWDA, IWS 1, 2, and 3)/In-Situ Soil Vapor Extraction Within IWS 2/No Source Control Groundwater
Alternative 5:	Containment (SWDA, IWS 1, 2, and 3)/In-Situ Soil Vapor Extraction Within IWS 2/Source Control Groundwater
Alternative 8:	Downgradient Groundwater Extraction/Treatment/Discharge (may be combined with Alternatives 2 through 5)

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Alternative 8A: Downgradient Groundwater Extraction/Combined with Alternatives 2 or 4 (No Source Control Groundwater Extraction System).

Alternative 8B: Downgradient Groundwater Extraction/Combined with Alternatives 3 or 5 (Source Control Groundwater Extraction System).

The strengths and weaknesses of the alternatives relative to one another, with respect to each criterion, are:

- *Overall Protection of Human Health and the Environment*

  All of the alternatives except for the No Action Alternative provide a similar level of human health protection with respect to the potential for direct contact with soil and solid waste material, since they all include the construction of caps and deed restrictions to protect cap integrity. There would be some potential short-term risk of exposure to soil and solid waste material during cap construction and any demolition debris relocation under all of these alternatives. There would be a greater level of potential short-term risk to workers associated with Alternatives 4 and 5, since they would also involve construction of a soil vapor extraction system in IWS 2.

  All of the alternatives, except for "No Action", would include institutional controls to prevent the ingestion of groundwater that may pose a health risk. Cooperation from the State, municipality and the public are required to implement these controls. Residences downgradient of the SWDA and IWS Areas where Contaminants of Concern have been detected are currently, or have the option of being connected to the Village of Lyndonville's municipal water supply.

  Implementation of capping measures alone, without a groundwater extraction measure (Alternative 2), would effectively eliminate the migration of constituents via infiltration from SWDA and IWS Area sources located above the water table, and therefore would result in an improvement in downgradient groundwater quality. The extent to which potential source materials in the saturated zone may continue to impact groundwater cannot be determined. Therefore, the degree of groundwater quality improvement and timeframe for reduction of levels to remediation goals is unpredictable within the foreseeable future.

If a source control groundwater extraction measure (Alternatives 3, 5, and 8B) and/or a downgradient extraction system (Alternatives 8A and 8B) was also included, there would be only a small improvement in overall human health protectiveness relative to Alternative 2, since protection would be accomplished through institutional controls for approximately 60 years (downgradient of the source control extraction system) or more (within the SWDA and IWS Areas). Under Alternatives 3 and 5, the migration of impacted groundwater from the SWDA and IWS Areas would be prevented and additional improvement in downgradient groundwater quality would occur. However, the timeframe for reduction of levels in groundwater within the area contained by the source control extraction system is unpredictable within the foreseeable future. Groundwater standards would not be reached downgradient of the source control groundwater extraction system for approximately 60 years after the system was in place. Implementation of a downgradient extraction system (Alternatives 8A and 8B) would contain the known downgradient extent of the contaminant plume but would not accelerate the reduction of constituent levels in impacted groundwater.

Installation and operation of a soil vapor extraction system within IWS 2 (Alternatives 4 and 5) would not significantly reduce human health risks or impacts to groundwater, since the cap alone would prevent migration of constituents from the unsaturated zone within IWS 2.

The physical impacts to wetlands under Alternatives 2 through 8 would be similar, and would be primarily associated with filling as a result of cap construction. The design of the caps for the SWDA and IWS Areas may incorporate waste reconfiguration to minimize wetlands impacts and will include a storm water control system including a detention pond which could incorporate wetlands mitigation after establishment of vegetative cover on the cap system. Under all of the alternatives which incorporate a cap (Alternatives 2, 3, 4, 5 and 8) there would be a reduction of erosion and sedimentation impacts to the stream and sediment relative to Alternative 1.

- *Compliance with ARARs*

Alternative 1 (No Action) generally does not comply with chemical-, action-, or location-specific ARARs. In contrast, Alternative 2 will meet both action-specific and location-specific ARARs and portions of chemical-specific ARARs. However, this alternative will not comply with federal or state groundwater standards, such as the maximum permissible concentrations of hazardous constituents in groundwater established by the state or the federal MCLs, for Contaminants of Concern.

For any of the alternatives, concentrations of Contaminants of Concern may remain above groundwater standards within the SWDA and IWS Areas for an unpredictable timeframe, although for Alternatives 2 through 8, the levels would reduce due to the effects of the caps and groundwater flushing, dispersion, and natural degradation processes. Alternatives 3, 5, and 8B include a source control groundwater extraction system. Even with the source control groundwater extraction system, groundwater concentrations of Contaminants of Concern in the SWDA and IWS Areas will not attain ARARs, and downgradient of the system, concentrations are estimated to take approximately 60 years, following installation and start-up, to meet ARARs for these alternatives.

Similar to Alternative 2, Alternatives 3 through 8 also comply with action- and location-specific ARARs.

- *Long-Term Effectiveness and Permanence*

The magnitude of residual risk associated with the potential for direct contact with Contaminants of Concern in soil and debris would be similar under Alternatives 2, 3, 4, 5, and 8 because they include a cap. Cap systems are proven, in general, to perform reliably in the long-term. Alternative 1 would not address the potential for exposure to Contaminants of Concern in soil and debris.

Although there would be some improvement in groundwater quality associated with cap installation under any of the alternatives (except for Alternative 1), the degree of groundwater quality improvement and time to achieve groundwater standards beneath the SWDA and IWS Areas is not predictable for the foreseeable future under any of the alternatives. Under alternatives including a source control groundwater extraction system (Alternatives 3, 5 and 8B), and/or a downgradient extraction system (Alternatives 8A and 8B), a remediation timeframe can be calculated for groundwater downgradient of the source control extraction system, since the extraction system would prevent the movement of contaminated groundwater beyond the SWDA and IWS Areas and allow downgradient groundwater levels to reduce at a predictable rate. However, calculations indicate that levels within this area would not reduce to groundwater standards for approximately 60 years after a system was in place, even if a downgradient extraction system is included. Therefore, in the long term, under any of the alternatives except for No Action, protectiveness would be achieved primarily through institutional controls preventing groundwater use. Institutional controls can perform reliably in the long-term, although they require the cooperation of the State, municipality and the public. Residences downgradient of the SWDA and IWS Areas where Contaminants of Concern have been detected are currently, or have the option of being connected to the Village of Lyndonville's municipal water supply.

Although there have been effectiveness problems associated with the use of extraction and treatment systems for aquifer remediation, extraction systems have been used reliably as containment systems which hydraulically prevent contaminant migration. The source control extraction treatment system would need to remain in operation for an indeterminant time period (beyond 60 years) to maintain downgradient groundwater quality improvement. Extraction well fouling can be addressed by routine maintenance and monitoring. The groundwater treatment system would generate considerable amounts of residual materials, as compared to the Contaminants of Concern treated, which would require off-site treatment or disposal.

The operation of an SVE system in IWS 2 would not significantly improve the long-term effectiveness of remedial measures relative to other Alternatives that include a cap (Alternatives 2, 3 and 8 without SVE). The caps would reliably prevent direct contact with and leaching from Contaminants of Concern within the unsaturated zone in IWS 2. Even under current conditions, waste materials within the unsaturated zone in IWS 2 do not appear to be significantly impacting groundwater. The long-term effectiveness of the SVE system may be limited due to the presence of low permeability soils and the presence of debris, which could cause VOC removal along preferential pathways and leave contaminants in high concentration areas. Some VOC would be permanently removed from soil at IWS 2; however, residual material from the operation of the SVE system would require off-site treatment or disposal.

- *Reduction of Toxicity, Mobility, and Volume through Treatment*

The degree of expected reduction in toxicity, mobility and volume (TMV) through treatment cannot be calculated for any of the alternatives because the total contaminant mass associated with source materials within the SWDA and IWS Areas cannot be accurately determined. Similarly, the degree to which treatment would reduce the inherent hazard posed by Contaminants of Concern in the SWDA and IWS Areas cannot be reliably estimated; however, this reduction would be minimal, since the human health and environmental risk associated with Contaminants of Concern in the SWDA and IWS Areas would be primarily controlled through capping and institutional controls. Although groundwater extraction and treatment under Alternatives 3, 5 and 8 would remove toxicity from the groundwater, the timeframe for reduction of levels in groundwater within the SWDA and IWS Areas is unpredictable within the foreseeable future. Downgradient of the extraction system, groundwater standards would not be reached for approximately 60 years. Therefore, under any alternative, the risk of exposure to groundwater will be primarily controlled through implementation of institutional restrictions on groundwater use.

Under Alternative 2, although groundwater quality would improve, the toxicity of Contaminants of Concern would not be reduced through treatment, and treatment residuals would not be generated. Under Alternatives 3, 5, and 8, the toxicity of Contaminants of Concern in extracted groundwater would be reduced through treatment and under Alternatives 4 and 5 and the medium and high cost scenarios for 8A and 8B, VOC would be removed from IWS 2 by the soil vapor extraction system. However, the toxicity would be transferred to treatment residuals which would then require appropriate treatment/disposal, perhaps as hazardous material. Alternatives 3 and 5 would generate an estimated 4.6 tons/year spent carbon and 427 tons/year dewatered metal sludge; Alternative 8B would generate an estimated 6.7 tons/year spent carbon and 536 tons/year dewatered metal sludge; Alternative 8A would generate an estimated 5.2 tons/year spent carbon and 161 tons/year dewatered metal sludge. Alternatives including a soil vapor extraction system would generate approximately 3 tons/year of spent carbon from this system.

- *Short-Term Effectiveness*

Most of the alternatives would provide a similar level of protection of the community and workers during remedial action implementation. Alternative 1 (No Action) would pose the lowest potential risk to the community and workers during remedial action implementation. Potential short-term risks associated with Alternatives 2, 3, and 8 would be small, and would be primarily associated with construction of the cap and any relocation of demolition debris, and for alternatives involving extraction and treatment of groundwater construction of the discharge pipeline to the Passumpsic River. Alternatives 4 and 5 and possibly 8A and 8B would pose a greater potential short-term exposure risk, since they may also involve construction of an in-situ SVE system within IWS 2.

Under all of the alternatives except for Alternative 1, wetlands impacts would be primarily associated with construction of the cap. In the northern portion of the site, a portion of the Unnamed Stream may be routed through a culvert beneath the cap or relocated adjacent to the SWDA cap. However, the design of the caps for the SWDA and IWS Areas would include a storm water system, including a detention pond, which could incorporate wetlands mitigation.

Protection would not be achieved by Alternative 1, since exposure to soil and debris that may pose a health risk would not be prevented. Under Alternatives 2 through 8, protection would be achieved in the short and long term, primarily through capping and institutional controls. The potential for exposure to soil and solid waste that may contain Contaminants of Concern under Alternatives 2 through 8 would be eliminated immediately after construction of the cap. Short-term protectiveness, with respect to exposure to groundwater under Alternatives 2, 3, 4, 5 and 8, would be achieved through the implementation of institutional controls preventing impacted groundwater use.

Although there would be some short-term improvement in groundwater quality, compared with No Action due to the presence of the caps (Alternatives 2 through 8) and groundwater extraction and treatment systems (Alternatives 3, 5, and 8), there will be no short-term attainment of groundwater remedial goals with any alternative.

The implementation time for Alternative 1 would be minimal, since the No Action alternative only involves performing a five-year site review. It has been estimated that Alternative 2 would take approximately 24 months to implement, and Alternative

4 would take approximately 27 months. The estimated implementation time for the remaining alternatives is approximately 34 months.

- *Implementability*

Alternative 1 would be the easiest to implement, since it would only involve performing a five year site review. Construction and maintenance of the caps under Alternatives 2 through 8 could be implemented without significant difficulty, as services and materials are available. Caps have been demonstrated to be reliable at many sites. Periodic inspections of the caps to ensure that they continue to effectively prevent direct contact with soil and solid waste containing Contaminants of Concern above remediation goals would be necessary. Groundwater monitoring and institutional controls, also included in Alternatives 2 through 8, could be easily implemented. Groundwater monitoring is ongoing and could be continued. Institutional controls would be readily implemented since a public water supply is available to the impacted area, although the cooperation of landowners, the Town, and the State of Vermont would be required.

Installation and operation of the extraction wells, treatment system, and discharge pipeline to the Passumpsic River would utilize standard construction services, techniques, and materials, which would be available, and these systems should perform reliably. Measures would need to be taken to minimize the potential for remobilization of subsurface nonaqueous-phase contaminants, if they exist, during well installation and pumping. Initial calculations of the potential discharge limits for some metals based on available attenuation of the Passumpsic River showed values which may be difficult to technically attain. Appropriate handling and disposal of groundwater treatment system residuals would be necessary. Easements would be required for construction of the discharge pipeline, and compliance with substantive requirements of the NPDES program would be necessary for discharge of the treated groundwater to the Passumpsic River.

Vacuum extraction systems have been implemented at other sites. However, SVE may be difficult to implement successfully in IWS 2. Due to the low permeability of soil and presence of buried debris in IWS 2, it may be difficult to achieve adequate and/or homogeneous air flow, which can cause VOC constituents to be eliminated sporadically, with high concentrations remaining in lower permeability zones. Removal and treatment of residual materials from operation of the SVE treatment system would require appropriate handling and off-site disposal.

As discussed above, Alternatives 3, 4, 5, and 8 would involve the off-site disposal of treatment residuals. The nearest lined hazardous waste disposal facilities are located in New York, Ohio, Indiana, and Maine. Waste transportation to these facilities can be expensive, and some of these landfills also have restrictions in accepting hazardous waste. The long-term availability of such facilities is uncertain, since only a few have been permitted in recent years; off-site disposal capacity would be needed for a time period that is unpredictable in the foreseeable future.

- *Cost Analysis*

Alternative 1 would be the least costly to implement ($40 to $50 thousand total present worth with a medium-case present worth cost estimate of $40 thousand; total present worth costs are rounded to the nearest $10,000), since it would only involve performing a five-year site review. The estimated total present worth cost to implement Alternative 2 could range from $10.4 to $19.3 million, with a medium-case cost estimate of $13.6 million. The costs for this alternative would be principally associated with the construction of caps over the SWDA and IWS Areas. If in-situ soil vapor extraction within IWS 2 is also included (Alternative 4), this would add $1 million or more to the total present worth cost estimate. The total present worth cost range for Alternative 4 is estimated at $11.8 million to $22.1 million (the estimated medium-case present worth cost is $15.5 million). The costs specifically associated with implementation of the SVE system would vary depending on the air flow and mass-loading rates.

The costs associated with the remaining alternatives (Alternatives 3, 5, 8A, and 8B) would be significantly (100% or more) higher because they involve the extraction, treatment, and discharge of groundwater. The estimated total present worth costs for Alternative 3 (capping with source control groundwater extraction) would range from $19 to $38 million, with a medium-case cost estimate of $28.2 million. Alternative 5 (which also includes SVE within IWS 2) low, medium, and high total present worth cost estimates are $20.4, $30 and $40.7 million, respectively. The range of costs associated with Alternative 8A, which includes capping and downgradient groundwater extraction, and possibly also SVE within IWS 2, is $18.8 to $39.1 million (total present worth). The medium-case cost estimate for this alternative is $28.4 million. The low- and medium-case cost estimates for Alternative 8B are $21.5 million (combined with the low case of Alternative 3) and $32.5 million (combined with the medium-case of Alternative 5), respectively. The most expensive alternative to construct and operate would be Alternative 8B (capping, downgradient groundwater extraction, and source control groundwater extraction) with in-situ soil vapor extraction within IWS 2. The total present worth costs for this alternative could range up to $43.4 million.

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Text

1.0 INTRODUCTION

1.1 PURPOSE OF THE REPORT

This document presents the Remedial Investigation Report (Report) which was completed for the Parker Landfill Project pursuant to the requirements of U.S. Environmental Protection Agency (EPA) Administrative Order by Consent, Docket Number I-90-1089 (Order), effective August 10, 1990. The Parker Landfill is located near the Village of Lyndonville, within the Town of Lyndon, Vermont (see Figure 1-1). The area investigated during the RI (Study Area) includes the Parker Landfill and the area west to Lily Pond Road and south along both sides of Red Village Road to approximately the Curran residence. The Parker Landfill (Landfill) is a waste disposal facility which, from 1972 to the present, has been used for disposal of wastes ranging from residential and industrial wastes to construction debris.

The Landfill is contained within approximately 25 acres of a 75 acre parcel on the southern side of Lily Pond Road, approximately 0.2 mile southeast of Lily Pond in the southeastern portion of the Town of Lyndon, Caledonia County, Vermont. The Landfill contains a Solid Waste Disposal Area (SWDA) and three smaller industrial waste areas (IWS Areas).

Investigation of the Landfill by the Vermont Department of Environmental Conservation (VDEC) began in 1984 when routine sampling by the VDEC revealed the presence of chlorinated volatile organic compounds (VOC) in monitoring wells at the Landfill and in stream locations along the perimeter of the Landfill. Follow-up sampling has detected VOC above Maximum Contaminant Levels (MCLs) in five private wells south of the Landfill. During 1985, VDEC completed a Preliminary Assessment and an Uncontrolled Hazardous Waste Site Evaluation. Based upon the results of those studies, EPA proposed the Landfill for listing on the National Priorities List on June 21, 1988.

On February 16, 1990 the Parker Landfill was listed on the National Priorities List. On August 10, 1990 the Respondents voluntarily entered into an Administrative Order with the EPA. This Administrative Order sets forth the requirements for the preparation and performance of a Remedial Investigation and Feasibility Study (RI/FS).

This Report is the fifth major deliverable under the Order. A Limited Field Investigation (LFI) was performed by ESE during October 1990. Prior to performing that work, a Work Plan for the LFI was completed and submitted to EPA on September 7, 1990, and revised on October 5, 1990. The results of the LFI were included in the RI/FS Work Plan. The second major deliverable, the RI/FS Work Plan (Work Plan), presenting the project plans for completion of the Phase 1A field investigations, was submitted to EPA on November 30, 1990, and revised on March 5, 1991 and April 25, 1991. Finally, as part of the Phase 1A investigations, a Public Health and Ecological Data Analysis Report was submitted to EPA on December 13, 1991. An Initial Site Characterization Report - Phase 1A was submitted along with a Phase 1B Work Plan, to EPA on February 10, 1992.

As an initial step toward meeting the objectives of the RI/FS, a conceptual model of the Landfill was developed, including identification of general response areas/media that would be investigated during the RI, as part of the Work Plan. To evaluate each potential general response area, the following field studies were undertaken:

- Survey
- Soils and Sources of Contaminants Investigation
- Subsurface and Hydrogeological Investigation
- Air Quality Study
- Surface Water and Sediment Investigation
- Ecological Investigation
- Long-Term Monitoring

The Phase 1A Work Plan was approved by EPA and field work began on April 15, 1991. The Phase 1A drilling program was completed on July 27, 1991. An Initial Site Characterization Report, and Phase 1B Work Plan were submitted to EPA on February 10, 1992. Phase 1B Field work was begun on May 13, 1992. The Phase 1B drilling program was started on May 19, 1992 and was completed on July 10, 1992. RI field activities were performed as set forth in the Work Plans, unless deviations are noted herein. This Report details the field studies performed, and the data collected, to provide a comprehensive summary of the Remedial Investigation activities, results, and data evaluations.

1.2 BACKGROUND

1.2.1 Area Description, Demography, and Land Use

The Landfill is located within 25 acres of a 75 acre parcel on the southern side of Lily Pond Road, approximately 0.2 mile southeast of Lily Pond, in the southeast portion of the Town of Lyndon, Caledonia County, Vermont (See Figure 1-1). The Landfill is located in an area of open hilly terrain, within the Vermont Piedmont physiographic province. The topography of the region is generally hilly to mountainous. Several hills within a few miles of the Landfill have a vertical relief of 200 to 300 feet. The topography generally increases in elevation in a northeast direction and decreases in elevation to the southwest, toward the Passumpsic River. Abutting the 75 acre parcel are woodlands, pasture land, and residences. An unnamed stream traverses the Study Area, joins with two larger unnamed streams immediately southeast of the Landfill, and flows south and southwest to the Passumpsic River.

The area in the immediate vicinity of the Landfill is open, mainly unvegetated, hilly terrain. To the north, within 0.3 mile of the Landfill are three mobile home communities and seven single family homes (see Figure 1-2). To the north of the Landfill, beyond Lily Pond, is a combination of pasture land, crop land, and woodland. To the west of the Landfill, within 0.5

mile, is a combination of woodland and a residential development (approximately 40 homes). To the south is a combination of woodland, pasture land, and crop land. A private school, a nursing home, and five single family homes are located within 0.5 mile south of the Landfill. East of the Landfill are hilly woodlands.

The Village of Lyndonville operates a municipal water system supplying water to the residences (including the trailer parks) north and west of the Landfill, the nursing home, and the housing development west of the Landfill. An extension of that water line was installed in the fall 1991, extending the availability of municipal water to homes along Red Village Road down to the area of the Curran residence. Six of ten residences located along this water line have been connected to the municipal water system and no longer use their wells. The remaining four residences utilize private wells. Eleven additional residences, utilizing private wells, are located further along Red Village Road, east of the Curran residence. It is estimated that private wells within a three mile radius of the Landfill serve a population of approximately 500. Specific private supply well data for the residences along Red Village Road is presented in Sections 2.10, 2.12, 4.2.3, and 4.2.4.

The Village of Lyndonville, located northwest of the Landfill, has a population of about 1,400 people. The Village of Lyndonville municipal well field, located approximately two miles north of the Landfill, serves a population of approximately 3200 people, including the transient population of the Lyndon State College. An activated carbon treatment system is installed at the well field, and Village municipal water is treated prior to distribution. No plans exist currently to develop other groundwater resources for consumption. The Lyndonville Town Plan (1984) indicates that the well field had a usage of 540,000 gallons per day (gpd) in 1984, with a capacity of 1,000,000 gpd. Expanded usage of untreated water for municipal consumption is unlikely.

1.2.2 Operational History

The Landfill vicinity was used as the town disposal area starting in the late 1950's. Aerial photos dated May 13, 1962 indicate solid waste disposal activities were limited to the vicinity of the current Ray O. Parker & Sons, Inc. garage (due southwest of IWS 1). These early operations consisted of dump and burn procedures. The Parker Landfill was first approved as a disposal facility for solid waste on July 17, 1971 by the District No. 7 Environmental Commission and Land Use Permit No. 700002. Approval for a sanitary landfill under the authority of the Vermont Health Regulations was granted on October 20, 1971. Formal operation of the landfill by Ray O. Parker & Sons, Inc. began in 1972. At various times during the Landfill's operation, three additional and separate areas of the property (designated as IWS Areas 1,2 and 3) were utilized for disposal of industrial wastes. These industrial wastes included waste oils, chlorinated solvent sludges, metal plating rinse waters, and other miscellaneous industrial wastes.

The general locations of the three industrial waste disposal areas (IWS 1, IWS 2, and IWS 3) are indicated in Figure 1-2. IWS 1 is located along the Landfill access road, west of the SWDA. This disposal area was used from 1972 until 1977 (5 years). IWS 2 which consist of three discrete disposal pits is located at the extreme southeastern tip of the SWDA, approximately 200 feet west of the unnamed stream. These pits were used in 1977 and 1978 (2 years). IWS 3 is more remote than the others from the SWDA and consists of three discrete disposal pits. It is located on a wooded hill east of the SWDA and east of the unnamed stream. These pits were utilized between 1978 and 1983 (5 years). Industrial waste disposal at the Parker Landfill ceased in 1983.

In addition to the Respondents, numerous other companies have been identified by EPA as having disposed of materials defined as hazardous substances at the Landfill. The types of wastes identified as reportedly disposed are shown below:

trichloroethene	barium chloride
sodium hydroxide	chromium and nickel plating rinse waters
1,1,1-trichloroethane	polyester resin
acetone	mercury
lacquer and stain sludge	electroplating sludge
paint sludge	water soluble coolants
tetrachloroethene	

1.2.3 Previous Investigations

During the period from 1984 to the present, investigations have been performed in the Parker Landfill area in order to provide a preliminary assessment of the nature and extent of any contamination. These investigations have been performed by the Vermont Agency for Environmental Conservation (VDEC), Marshfield Engineering (for Parker), ERT (for Vermont American Corporation), and ESE (for respondents).

1.2.3.1 Monitoring Well Installations

Nine monitoring wells were installed by Marshfield Engineering in 1979 (MW1 through 9). Of these, none are currently operational. An additional 17 monitoring wells and 2 well points were installed in the Study Area between 1983 and 1986. Eight of the wells and the well points were installed by Marshfield Engineering on and in the immediate vicinity of the Parker Landfill. These are labeled MW4A, MW6A, MW8A, MW10 through MW14, WP1, and WP2 on Figure 1-3. The AEC installed 8 monitoring wells (at the locations labeled HB1 through HB6 on Figure 1-3) at 6 locations in 1984. One monitoring well, labeled ERT-1, was installed by ERT adjacent to IWS 2 and the unnamed stream in 1986. MW14 was subsequently destroyed during landfill borrow activities.

1.2.3.2 Minipiezometer Installations

Twenty five minipiezometers were installed by the VDEC in the stream bed, from the head of the stream along its length to where it joins with the Passumpsic River. Many of these minipiezometers are no longer in place. The viability of the remaining minipiezometers for data collection is questionable. Therefore, these minipiezometers were not used during the Remedial Investigation.

1.2.3.3 Ground and Surface Water Sampling and Analysis

Table 1-1 summarizes the groundwater and surface water sampling and analyses that have been performed from 1984 through 1987. Data have been collected from sampling points that include the monitoring wells, minipiezometers, the stream, and residential wells in the area.

1.2.3.4 Soil Sampling and Analysis

Soil samples were collected from varying depths during the drilling of monitoring wells MW11, MW13, MW14 and MW8A in 1984. The soil samples obtained from these borings were analyzed in the field for the presence of TCE by VDEC personnel using a portable gas chromatograph (GC).

To determine if the stream water had been responsible for contamination of soils in the vicinity of the stream, the VDEC collected and analyzed surface soil samples to determine if VOC were present. Soil sampling was conducted at 14 locations on the Riverside School property. Four of these locations were in the pasture. The pasture samples were collected along two lines; one immediately adjacent to the stream (in the floodplain), and the second set back from the stream (a distance dependent upon the local topography). All of the samples were analyzed in the field for TCE, using a portable gas chromatograph.

1.2.3.5 Disposal Area Investigation

In the fall of 1986 an investigation of IWS 2 was performed by ERT (ERT, 1987). Nine test pits were excavated to examine the horizontal and vertical extent of the disposal area and visually characterize the waste material and underlying soil. Three borings (B-1, B-2, and B-3), along with data from the test pits, provided a determination of the vertical extent of waste materials. Soil samples were collected and selectively analyzed for VOC, base neutral/acid extractable compounds, EP-toxicity metals, ignitability, corrosivity, and reactivity. Monitoring well ERT-1 was installed between IWS 2 and the stream during the IWS 2 investigation.

1.3 LIMITED FIELD INVESTIGATION

During October of 1990 ESE performed a Limited Field Investigation (LFI) to collect data to assist in the development of the RI/FS Work Plan. The results of the LFI were presented in the RI/FS Work Plan. The following activities were performed for the LFI:

Site Survey - ESE installed 22 stakes in the unnamed stream at 500 foot intervals. These stake locations were used for identification of sediment screening locations during the LFI and as reference points for samples collected during the RI investigations. ESE sent letters and access agreements to persons owning property on which ESE might have needed access during the RI/FS investigations.

Riverside School Well Location - On November 20, 1990, ESE conducted a search for the wellhead of the private supply well at the Riverside School, using a Fisher TW-6M-Scope metal detector, and determined that the most likely location of the wellhead was 2-3 feet north of the two shut-off valves which are visible at ground level on the north side of the school building. This location was confirmed by excavation of the wellhead during the Phase 1A field program.

Geological Reconnaissance - During October, 1990, an ESE geologist performed a detailed reconnaissance of the Landfill and the surrounding area. This reconnaissance included walking power-line easements, railroad easements, surface-water courses (including the unnamed stream and its tributaries), and roadways. This visual information was compared to the geologic map presented by ERT in its September 1987 RI Work Plan and published geologic data. Additionally, aerial photographs, topographic maps, and bedrock structural data for the area were obtained and reviewed.

Wetlands Delineation - During October, 1990, ESE conducted a wetlands delineation of the Landfill and surrounding area. Based upon vegetation and soil types, areas found to meet the criteria for wetlands' designation were flagged. A wetlands delineation report was prepared discussing the results of the field work and providing maps detailing the location of wetlands.

Air Quality Survey - A monitoring survey at breathing-zone height was completed in October, 1990, utilizing visual observations and direct monitoring instruments (OVA, HNu, specific hydrogen sulfide, and hydrogen cyanide continuous monitors).

Soil Gas Survey - During October, 1990, five soil gas survey lines were conducted in the areas around the SWDA and the IWS Areas.

Field Screening of Sediments - During October, 1990, ESE collected sediment samples at each of the stream stake locations and performed headspace screening with a field GC for VOC.

Evaluation of Existing Monitoring Systems - During October, 1990, ESE inspected existing monitoring wells and minipiezometers. ESE also performed a headspace analysis (using a field gas chromatograph) for VOC on the air within the casing of each monitoring well and on a water sample collected from each well. Additionally, ESE purged the existing monitoring wells and measured the recovery rate to determine whether the wells were functional for use during the RI.

1.4 REPORT ORGANIZATION

Volume 1 of this Report presents the Remedial Investigation Report for field investigations. Volume 2 contains all figures and tables referenced in the Report. Volume 3 contains all Plates referenced in the Report. Volume 4 and following volumes contain appendices referenced in the Report.

The Report is presented in six sections, following the Executive Summary. An overview of the RI field investigations is presented in Section 2, which briefly describes the various studies, discusses problems encountered, if any, and describes changes or deviations from the Work Plan. Section 3 presents the findings of studies designed to determine the physical characteristics of the Study Area. Section 4 presents the findings of studies designed to determine the nature and extent of contamination within the Study Area. Section 5 discusses the fate and transport mechanisms associated with the Constituents of Concern. Section 6 presents the detailed conceptual model of the Study Area resulting from the analysis of the data presented in the previous sections, and presents ESE's interpretation of the results and the potential impacts to the Study Area.

2.0 RI FIELD INVESTIGATIONS

The RI investigations were structured in a phased approach in an effort to build on previous data. The RI was developed in two phases, Phase 1A and 1B. Phase 1A was structured based on the information collected during previous investigations, as described in Section 1 of this report. Phase 1B investigations were designed based on the results of the Phase 1A investigations, including an analysis of the Phase 1A data as compared to previous data. The following table summarizes the work performed, objectives, and reports produced:

<table>
<tr><th>TASKS PERFORMED</th><th>DATES PERFORMED</th><th>OBJECTIVES</th><th>REPORTS</th></tr>
<tr><td colspan="4">PHASE 1A</td></tr>
<tr><td>Site Survey</td><td>April, 1991</td><td rowspan="10">Provide general overall understanding of Study Area, potential contaminant pathways, potential source areas, and potential receptors.

Provide data on nature and extent of contaminants in air, surface/subsurface soils, groundwater, and surface water/sediment.

Provide data on site geology/hydrogeology</td><td rowspan="10">Interim Letter Report on Soil Gas Survey (May 13, 1991);

Interim Letter Report on Surface Water/Sediment Sampling and Preliminary ecological Assessment (August 9, 1991);

Public Health and Ecological Data Analysis Report (December 13, 1991);

Initial Site Characterization Report-Phase 1A (February 10, 1992);
Phase 1B Work Plan (February 10, 1992).</td></tr>
<tr><td>Soil Gas Survey</td><td>April/May 1991</td></tr>
<tr><td>Leachate Sampling[1]</td><td>November 1991</td></tr>
<tr><td>Surficial Soil Sampling[1]</td><td>Sept/November 1991</td></tr>
<tr><td>Surface Geophysics[2]</td><td>April 1991</td></tr>
<tr><td>Test Pits[1]</td><td>May 1991</td></tr>
<tr><td>Test Borings[1]</td><td>April-July 1991</td></tr>
<tr><td>Monitoring Wells[3]
GW Sampling/
Analyses</td><td>April-July 1991
Rd 1: Sept 1991,
Rd 2: November 1991</td></tr>
<tr><td>Hydrologic Testing[4]</td><td>May-November 1991</td></tr>
<tr><td>Air Quality Monitoring[5]</td><td>Rd 1: May 1991
Rd 2: September/
October 1991</td></tr>
</table>

TASKS PERFORMED	DATES PERFORMED	OBJECTIVES	REPORTS
Combustible Gas Monitoring	July/November 1991		
Surface Water/ Sediment Sampling	Rd 1: May 1991 Rd 2: September 1991		
Ecological Studies[6]	June/August/ October 1991		
SWDA Delineation[7]	April 1991		
PHASE 1B			
Surface Geophysics[8]	May 1992	Provide additional data to better define/understand the conceptual model developed in Phase 1A and assure data necessary to development of feasibility studies has been collected.	Draft Remedial Investigation Report (November 12, 1992)
Borehole Geophysics[9]	May/July 1992		
Test Borings[1]	May-July 1992		
Monitoring Wells[10] GW Sampling/ Analysis[11]	May-July 1992 July 1992		
POST-SCREENING FIELD INVESTIGATIONS			
Test Borings/ Well Installation	July 1993 - August 1993	Provide data on hydraulic character of the aquifers.	Presented in revised Remedial Investigation Report for the first time.
Pump Tests	August 1993 - September 1993		
Soil Sampling for Geotechnical	August 1993	Provide data on physical characteristics of unconsolidated materials.	

Notes:

1. Included analytical testing.
2. Included GPR and magnetic surveys of SWDA & IWS Areas, and seismic refraction profiling across the Study Area.
3. Included installation of 50 monitoring wells and 3 observation wells, at 37 locations throughout the Study Area.
4. Included stream piezometers, ground water level measurements, slug tests, constant flow tests, and bedrock packer testing.
5. Included field measurements survey and VOC and asbestos eight hour sampling.

6. Included review of wetlands delineation and surface water/sediment data, water quality surveys, and benthic macroinvertebrate study.
7. Included installation and survey of monuments to mark boundaries.
8. Included seismic refraction profiling.
9. Included fluid conductivity, fluid temperature, electromagnetic induction, natural gamma, and three-arm caliper runs. Performed at Riverside School and Curran residence wells.
10. Included installation of 19 monitoring wells at 11 locations.
11. Included all existing and new wells.

This section provides an overview of the RI Phase 1A and Phase 1B field investigation. Sections 3 and 4 present the results of the investigations. Field investigations were conducted pursuant to the procedures set forth in the Work Plans. Deviations from those procedures, or changes required by field conditions or negotiated with EPA, are noted in the discussions below.

2.1 SURVEY AND SECURITY

2.1.1 Base Map and Survey

Vermont American Corporation, in 1987, commissioned the production of a topographic base map at a scale that was usable for other portions of the project. It was prepared from the Burke Mountain United States Geological Survey (USGS) quadrangle and from a computer generated topographic map prepared by an aerial mapping firm. The map is at a scale of 1:1200, or 1 inch equals 100 feet. The aerial mapping firm, Eastern Topographic of Wolfeboro, New Hampshire, obtained the necessary photographs on April 24, 1985 and September 5, 1987, from which the Landfill could be mapped and contoured. Ground truth was established using a USGS Mean Sea Level Datum of 1929 with topography shown at intervals of 2 feet. The contours were then checked for accuracy using ground control information and standard survey techniques. The base plan was later provided to ESE at a scale of 1 inch equals 200 feet.

In April 1991, a 50 foot survey grid was established and staked across the Landfill, by Truline, St. Johnsbury, Vermont, a Vermont Registered Land Surveyor. The datum for the baseline survey grid is USGS Mean Sea Level Datum 1929. A plan showing the baseline survey grid is provided on Plate A. Geophysical, geological, chemical, and topographical data points have been surveyed and identified on the base map. Figures presented in this Report are generated from the base map. The areas south of Brown Farm Road and around the Route 5 bridge, which were not on the original Eastern Topographic map, have been digitized from the USGS quadrangle. The base map for the RI Field Investigations is presented on Plate B.

2.1.2 Study Area Security

As described in Section 3 of the Site Management Plan in the Phase 1A Work Plan, ESE created a field office/storage area at the Study Area. Access to the area was made directly from Lily Pond Road to avoid interfering with ongoing SWDA activities. Otherwise, the components of the field office area were set up as identified in the Phase 1A Work Plan.

The three IWS Areas were differentiated as exclusion zones areas by installing orange snow fencing around each area. Signs warning of the potential hazardous nature of the areas were posted along the perimeter of each IWS Area. Access roads to each area were controlled with a chain-link fence gate. Warning signs were also posted on roads, trails, along the stream, and on easements around and within the Landfill.

2.2 SOIL GAS SURVEY

As discussed in Section 3 of the Phase 1A Work Plan, soil vapor surveys were completed between April 17 and May 2, 1991. The soil vapor surveys were conducted at 25 foot grid intervals across each IWS area, as a means of locating areas of elevated VOC concentrations. This information was used to refine the location of test pits and borings during the Phase 1A and any subsequent subsurface investigations. The data were also used to determine the need for modifications, if any, to the site-specific Health & Safety Plan; and for preliminary evaluation of the potential hazards associated with removal of the debris mass, should removal be considered as a potential remedial alternative. The initial survey grids extended one grid point (25 feet) beyond the estimated limits of each IWS Area except where physical conditions limited the aerial extent of the survey. Additional soil vapor points were added to grid lines as needed to determine the limits of elevated VOC concentrations. To resolve high concentration points and determine contamination limits, additional soil vapor points were sampled on May 9 and 10, 1991.

As described in the Phase 1A Work Plan, hydrogen sulfide (H_2S), hydrogen cyanide (HCN) and methane were measured using direct read instruments. The soil vapor VOC samples were then collected in glass bombs and a 250 $\mu\ell$ soil vapor sample was injected into a portable Photovac 10S50 gas chromatograph (GC) for analysis. Any sample generating a peak with an area beyond the integration capabilities of the GC was re-analyzed using a smaller injection volume. All re-analyzed samples were normalized to a 250 $\mu\ell$ volume. GC performance was established at the beginning of each work day and after every 20th sample by analyzing standards (trichloroethene, 1,1,1-trichloroethane, trans-1,2-dichloroethene, and benzene), blanks, and duplicates.

The Phase 1A Work Plan scope of work for the soil vapor survey included the measurement of vinyl chloride. Vinyl chloride standards were analyzed during the soil vapor survey. The retention time for vinyl chloride is very early, however, and the early part of the chromatogram contains numerous spurious peaks. As a result, it was not possible to differentiate vinyl chloride and, therefore, vinyl chloride concentrations were not calculated. This deviation from the Phase 1A Work Plan was described in ESE's interim letter report to EPA, dated May 13, 1991 presenting the preliminary results of the soil vapor surveys.

Saturated soil conditions (due to the spring thaw) caused occasional plugging of the slots in the soil vapor probes. At some locations, therefore, data was not obtained due to the inability to prevent plugging.

Since H_2S and methane were both measured by the MSA 361 (gas detector, in different modes), the MSA 361 was initially attached to the sampling probe effluent. After the H_2S and methane measurements were recorded, the MSA 361 was removed and an HCN meter attached to the sampling probe effluent. Following the measurement of HCN, the meter was removed and the glass bomb was attached to the probe effluent for purging and collection of soil vapor for VOC analysis.

IWS 1

Twenty-nine (29) sampling points were initially sampled at IWS 1 as shown on Figure 2-1. An additional 17 soil vapor points were sampled to determine the extent of contamination at the northeastern boundary of IWS 1. Off-scale LEL readings were encountered at IWS 1, which resulted in the MSA 361 meter being calibrated to read 25% LEL, using a 50% LEL standard, and the measured value multiplied by 2.

IWS 2

There were 34 soil vapor points initially sampled at IWS 2. In addition, 22 soil vapor points were sampled to determine the northern, southern, western and eastern boundaries between high and low concentration points. Because of off-scale LEL readings, soil vapor points following SG2-7 (consecutive) were sampled with the MSA 361 meter calibrated to 25% LEL (as discussed above), and sample readings multiplied by 2. Figure 2-2 shows the soil vapor sampling locations for IWS 2.

IWS 3

Fifty-nine (59) soil vapor points were initially sampled at IWS 3. The soil vapor sampling locations for IWS 3 are shown on Figure 2-3. Four additional points were sampled both around SG3-36 and around SG3-41 to delineate areas of elevated VOC concentrations. Due to soil conditions that caused plugging of the probe, soil vapor points SG3-32 through SG3-41 were sampled at a depth of 2.5 feet.

Methane Measurements in Trailer Park

In addition to the soil vapor surveys performed in the IWS Areas, methane readings were taken in the vicinity of the trailer park, north and west of the SWDA, to determine safety considerations necessary for the seismic refraction survey and drilling activities planned for locations in the trailer park. The information was also useful in placement of combustible gas wells. On April 24, 1991, ESE took 20 methane readings from soil probes located at 50 foot intervals, as indicated in Figure 2-4. Methane was not detected at any of the 20 locations.

2.3 SURFACE CHARACTERIZATION

As described in Section 4 of the Phase 1A Work Plan, leachate samples were collected at the leachate seeps along the east side of the SWDA, and surficial soil samples were obtained from areas of leachate-stained soils and from each IWS Area. Surface characterization was scheduled to be completed early in the field program. However, rainfall amounts during the spring and summer were very low, and leachate did not flow in any significant quantity during the main field program. Precipitation increased significantly during late September and October, causing the leachate seeps to flow steadily. Leachate samples were collected, therefore, during the second round of groundwater sampling in November, 1991. At EPA's request, the surficial soil samples were scheduled to be collected concurrent with the leachate samples. At the end of the first groundwater sampling round, because it appeared uncertain whether leachate flow would allow sampling during Phase 1A, ESE requested, and EPA agreed, that surficial soil samples not associated with the leachate flows be collected. Surficial soil samples associated with the leachate flows were subsequently taken concurrent with the leachate samples.

2.3.1 Leachate Samples

Leachate samples were collected on November 14, 1991. Leachate was sampled at locations 801, 802, and 804, as shown on Figure 2-5. Leachate was not flowing at, or in the vicinity of, location 803. The sampling procedure proposed in the Phase 1A Work Plan was significantly altered, due to field conditions. The Work Plan sets forth a procedure whereby a bucket is buried in the path of the leachate stream. Just prior to leachate collection, the top of the bucket is removed and a stainless steel bowl set into the bucket. Leachate is collected in the bowl and samples removed and transferred to sampling containers. This procedure was used at sample location 802. At sample locations 801 and 804, the stability of the soil and the flow volume of leachate made it impossible to keep the bucket in place. At locations 801 and 804, therefore, the leachate was collected directly into a stainless steel bowl by holding the bowl in the path of the flowing leachate. Transfer of samples to the appropriate sample containers was accomplished as described in the Work Plan. Table 2-1 shows the samples collected and analyses performed. Leachate sampling results are discussed in Section 4.1.2.2.

2.3.2 Surficial Soil Samples

Surficial soil samples were collected on September 11, 1991, from sample locations 701, 702, 703, 707, 708, 709, 710, 711, 712, 713, and 714, as shown on Figure 2-5. Although sufficient leachate was not flowing for leachate collection in the areas of sample locations 701-703, there was sufficient stained soil to allow surficial soil to be collected. Surficial soil samples were collected from the areas of leachate staining on the road east of the SWDA (704, 705, and 706) on November 19, 1991. A background surficial soil sample was collected from boring location

B101 on November 25, 1991. Surficial soil samples were collected as described in the Phase 1A Work Plan. Table 2-2 shows the samples collected and analyses performed. Surficial soil sampling results are discussed in Section 4.1.2.1.

2.4 SURFACE GEOPHYSICS

A comprehensive geophysical survey of the Landfill and Study Area was completed by Weston Geophysical Corporation of Westboro, Massachusetts, using ground penetrating radar (GPR), magnetic, and seismic refraction techniques. Although the specific purpose/goal of each survey was location specific, the general purpose of the geophysical survey program was to determine: (1) the horizontal and vertical limits of waste material in the SWDA and IWS areas; (2) the general nature and distribution of the waste materials in the waste disposal areas; and (3) geologic conditions throughout the Study Area. GPR and magnetometer surveys were completed at each IWS area, the SWDA, and the DDA. Seismic refraction survey activities were conducted at the SWDA and in non-landfill portions of the Study Area. With the exception of IWS 2, seismic refraction surveys were not conducted at the IWS Areas.

2.4.1 Ground Penetrating Radar Surveys

GPR survey data acquisition was generally completed in accordance with the requirements set forth in Section 5.3 of the Phase 1A Work Plan. Each IWS Area and the DDA were surveyed on a 10 ft. grid system referenced to the baseline 50 ft. grid system. The beginning and ending points of each GPR traverse were given alphanumeric identifications to locate these points on the baseline grid. The locations of the GPR survey lines completed during this study are shown on Figures 2-6 through 2-9. Three GPR traverses were completed in a north-south orientation in the northeastern portion of the SWDA, as shown on Figure 2-6 to identify the northern limit of the SWDA. Prior to conducting GPR traverses, the GPR system was calibrated at a culvert (located 3 feet below grade to the immediate north of IWS 1) where "background" GPR soil velocities were anticipated.

A digital ground penetrating radar system (GSSI model SIR-10) with filtering and color amplitude plotting capabilities was used to acquire the radar data. A 500 MHz antenna was used at the IWS Areas and throughout most of the DDA and SWDA. GPR data was acquired at selected portions of the DDA and SWDA using a 300 MHz antenna to provide a greater investigative depth. All GPR data acquired in the field was stored on magnetic disks and immediately played back on a color monitor for confirmation of data acquisition, quality, and to allow for field interpretation.

A comprehensive discussion of the theoretical basis/operation of the GPR technique is provided in the Weston Geophysical Corporation Report provided in Appendix A. The results of the GPR survey program are presented in Section 3.2.

2.4.2 Magnetic Survey

Magnetic surveys were conducted in accordance with Section 5.3 of the Phase 1A Work Plan. Magnetic surveys were completed at each IWS Area and the DDA on a 10 ft. grid system referenced to the baseline grid system. A magnetic survey was completed across the SWDA by taking magnetic field measurements at 50 ft. intervals along the baseline grid system. The locations at which magnetic surveys were completed at the IWS Areas and DDA are shown on Figures 2-10 through 2-14. The boundaries of the magnetic survey of the SWDA are shown on Figure 2-10.

Magnetic field measurements were collected using a digital total-field magnetometer (Geometrics model G-856). Over 1,300 magnetic field measurements were obtained in the IWS Areas and the DDA. Background magnetic field measurements were obtained in areas interpreted to be free of ferrous metal debris and free from interference from overhead power lines. Diurnal variations were measured at approximately 60 minute intervals.

Additional information on the theoretical basis and operation of this technique is presented in the Weston Geophysical Corporation Report provided in Appendix A. The results of the magnetic surveys are provided in Section 3.2.

2.4.3 Seismic Refraction Profiling

2.4.3.1 Phase 1A Seismic Refraction Profiling

Seismic refraction profiling was conducted in accordance with Section 5.3 of the Phase 1A Work Plan. Seismic profiling was completed along eight seismic survey lines, by Weston Geophysical Corporation, shown as Lines A-A′ through H-H′ on Plate C. Three seismic survey Lines (A-A′ through C-C′) were completed across the surface of the SWDA to determine the lateral and vertical extent of the solid waste within the SWDA, as well as the geologic conditions beneath the SWDA. Seismic survey Lines D-D′ through H-H′ were completed outside the SWDA to determine geologic conditions between the landfill and private supply wells located south of the landfill.

Seismic refraction data were acquired along the seismic survey lines using a digital 24-channel seismograph (ABEM Terraloc) with 10 to 100 ft. geophone spacings. Generally, geophone spreads were 400 ft. in length. Seismic energy was generated with small explosive charges. Seismic refraction Lines A-A′, B-B′, and C-C′ were positioned to traverse the existing SWDA and were up to 1,800 ft. in length. Each of these lines consisted of a single 24-channel spread, with geophone spacings of 20 to 100 feet. A short section of Line A (stations 11+30 to 13+80) was re-shot with 10-ft. geophone spacings to measure average landfill seismic velocities. Shotholes drilled to depths of approximately 20 ft. were located at Line A-A′ stations 0+00 and

16+50, Line B-B′ at station 0+00, and Line C-C′ at station 0+00. The remaining shotholes on these lines were placed with a steel bar and sledge hammer, and were two to four feet deep.

Lines A-A′ through C-C′ were designed to enable estimation of landfill thickness without emplacement of borings directly through the SWDA debris mass. This was accomplished using a long geophone spread, and measuring delays in seismic arrival time from a refracting interface (water table or bedrock surface). This "delay time" analysis was augmented by correlating the nearest test boring data with seismically-inferred depths to groundwater and bedrock.

Seismic Lines D-D′ through H-H′ were designed to measure approximate depths to groundwater, bedrock, and any identifiable overburden stratigraphy. Geophone spread lengths were 680 ft. (geophone intervals of 20 and 40 ft.) along Line E-E′ and 400 ft. (geophone intervals of 10 to 20 ft.) along Lines D-D′ through H-H′. Bedrock velocities determined along Line D-D′ north of station 21+50 are less certain due to irregular topography and the presence of buried solid waste. All seismically-determined depths to bedrock were compared to subsequently obtained test boring data to determine whether the seismic survey results were within the design criteria for this project, as stated in the Phase 1A Work Plan.

Bedrock depths could not be seismically determined along Line A-A′ because the limited number of geophones which could be placed on natural ground were insufficient for detection of the relatively deep bedrock. The specific locations/spacing of shots and geophones are summarized on Table 2-3.

Seismic data were recorded on hardcopy and magnetic diskette to provide permanent, duplicate copies of each seismogram. Data analysis was accomplished using the crossover distance method described in Weston's Report (provided in Appendix A) and augmented by delay time analysis on Lines A-A′, B-B′, and C-C′. Seismic refraction data were presented to ESE as profiles showing depths to refracting interfaces, such as groundwater and bedrock. Ground surface elevations shown on the profiles were derived from a topographic map of the Study Area, surveyed elevations provided by ESE, and Weston field notes.

Several minor changes in the position of seismic survey lines, from those proposed in the Work Plan, were necessary due to surface topography and the need for ground truth through completion of test borings at locations accessible by drill rigs. Survey Line C-C′ was moved south to coincide with the Landfill access road, due to the close proximity of a steep cut bank and mobile homes to the originally planned location. Point B′ was shifted south to accommodate termination of the seismic line at a viable drilling location for ground control and confirmation of survey results. Seismic Line F-F′ was relocated slightly toward the north to accommodate the local topography. A dog-leg was inserted into seismic Line H-H′ to reduce the effect of surface topography and avoid passing too close to an aboveground propane storage tank. Seismic Line D-D′, originally designed to terminate north of the DDA, was terminated near the center of the DDA due to high LEL readings and numerous obstructions within intended shotholes. The results of the seismic refraction survey are presented in Section 3.2.

2.4.3.2 Phase 1B Seismic Refraction Profiling

A seismic refraction survey was completed at selected locations in the Study Area by Weston Geophysical Corporation during the period May 13 through May 18, 1992 and May 20, 1992. The seismic refraction profiling was conducted in accordance with Section 2.1 of the Phase 1B Work Plan.

A total of 6,060 feet of seismic refraction profiles were acquired along four traverses shown as Lines I-I′, J-J′, K-K′, and L-L′ on Plate C. The seismic survey was completed to: (a) delineate a potential northeast-southwest trending fracture zone previously inferred to extend from the vicinity of IWS 3 to IWS 2 and ultimately to the vicinity of the Riverside School and nearby residences; (b) delineate the eastern and southern limits of an inferred north-south trending bedrock trough inferred to extend from the vicinity of IWS 1 toward IWS 2; and (c) characterize bedrock depths, and the presence or absence of large scale weathering/fracturing zones.

Seismic data were collected with a digital 24-channel seismograph (ABEM Terraloc) using end-to-end 400-foot geophone spreads with offset shots; geophone intervals were 10 and 20 feet. The typical geophone array is summarized on Table 1 of the Weston Geophysical Report in Appendix B. Shot point locations are shown on Figure 2 of the Weston Geophysical report in Appendix B. Shot point intervals were typically 100 feet throughout each geophone array, with offset shots at 100-foot intervals from array end points. The offset shotpoints produced, in effect, a 48-channel, 800 foot geophone spread for each seismogram wherever offset shots could be performed. Highly irregular ground surface topography and loose soil conditions deterred the use of offset shots in some areas.

Seismic energy was generated by small explosive charges placed in shallow (3 to 5 feet) holes driven with a bar and sledgehammer and/or drilled with a two-person power auger. In addition, shotholes in the vicinity of IWS 2 were screened for methane, H_2S, and HCN by ESE personnel before loading the explosive charges. Ambient atmospheric conditions were also screened immediately following each shot prior to re-entrance of Weston Geophysical personnel into the work zone. Methane, H_2S, and HCN were not detected during the screening operations.

To endeavor to obtain the highest-quality refraction data, test shots were detonated to determine an optimal low-cut analog filter setting. A low-cut analog filter of 50 Hz was used to attenuate background noise and enhance data quality. Post-acquisition digital filtering was also performed on several seismograms. Representative filtered and unfiltered seismograms were FAXED on a daily basis to EPA's oversight contractor for real time review and comment on the quality of the survey data and recommendations for improving survey procedures and data manipulation options. The use of digital filtering was particularly effective in recovering seismic refraction arrivals obscured by occasional frost layer interference. "Frost breaks" arrive before seismic refraction arrivals and can prevent refraction arrival identification. However, frost breaks were noted on only a few geophones on a limited amount of seismograms, and most of these "frost-affected" refraction arrivals were recovered using a high-cut digital filter of 200 Hz.

Data analysis was accomplished with the crossover-distance technique and, where possible, bedrock seismic velocities were also derived with the Generalized Reciprocal Method (GRM) using the computer program GREMIX. In some areas of anomalous bedrock topography, GRM was used to check the crossover distance-computed bedrock depths. An expanded discussion of the seismic refraction technique and interpretation methods is included in Appendix A of the Weston Geophysical Report (Appendix B of this report). Seismograms (raw and filtered), accompanying field notes, and GRM analysis results are presented in the appendices of the Weston Geophysical Report. Minor relocation and adjustment of the seismic lines were necessary due to excessive topographic relief and physical barriers.

2.4.4 Borehole Geophysical Logging

Borehole geophysical logging was performed in the Riverside School and Curran supply wells once the school and Curran home were connected and serviced by the municipal water supply distribution system. Borehole logging of the Riverside School Well was conducted on May 29, 1992 and logging of the Curran Supply Well was conducted on July 31, 1992. The borehole geophysical logging was performed by Weston Geophysical Corporation and included fluid conductivity, fluid temperature, electromagnetic induction (EM), natural gamma, and three-arm caliper runs over the entire borehole length of 260 feet. The sondes were calibrated and used with a Robertson Portalog to record the data in digital format. All logging runs were repeated at least once for quality control purposes. Logging measurements were referenced with respect to ground surface (depth of zero feet). The depth error ranged from 0.0 to 0.3 inches following completion of each logging run; depth errors typically result from slippage of the logging cable over the pulley.

The logging sequence was as follows: 1) a fluid conductivity, fluid temperature, and natural gamma sonde was used, acquiring data at a rate of 10 to 12 feet per minute, top to bottom, to assure fluid measurements in a relatively unmixed borehole fluid, 2) an EM induction sonde collected data during downhole and uphole logging runs at a rate of 12 to 15 feet per minute, 3) a three-arm caliper sonde collected data from bottom to top at a rate of 12 to 15 feet per minute, and 4) the well was purged by ESE personnel, allowed to recharge, and the fluid conductivity, temperature, and natural gamma sonde was used again.

The borehole logging was completed in accordance with Section 2.3 of the Phase 1B Work Plan with the exception that fluid conductivity and natural gamma logging were substituted for the proposed spontaneous potential (SP) and single point resistance (SPR) logging due to instrument availability. Weston Geophysical made the substitution assuring ESE that the methods were technically comparable and would satisfy the goals of the borehole logging program.

2.5 SUBSURFACE INVESTIGATIONS

This section outlines work conducted during the RI subsurface investigations, as set forth in Section 6 of the Phase 1A Work Plan and Section 2.2 of the Phase 1B Work Plan. The subsurface investigation was generally designed to investigate the subsurface conditions and geology of the Study Area using historical data in the form of aerial photographs, existing well logs, and pertinent investigation reports, and to add new data from test pits/test trenches, test borings, and physical and chemical testing of soil samples. The subsurface investigation was focussed on five areas: the SWDA (potential source), the three IWS Areas (potential sources), and residences with private supply (potential receptors), and the areal extent of contamination which may have been released from the Landfill. The subsurface information collected in this investigation is supplemented with a compilation of surficial features that play an integral part in understanding the Study Area conditions. These surficial features (e.g., bedrock outcrops, geomorphic units, surface water bodies, etc.) were determined during the LFI.

A combination of test pits/test trenches and test borings, combined with geophysical data, were used to determine the lithology and stratigraphy of the geologic deposits and formations across the study area. Soil samples were collected and evaluated for physical parameters which effect chemical transport and partitioning between water and soil.

Test pits/test trenches were completed exclusively within the three IWS Areas to determine shallow subsurface conditions, determine the horizontal and vertical extent of waste materials, and investigate areas of concern/interest identified during the completion of the GPR, magnetometer, and soil vapor surveys of the IWS Areas. Test borings were completed throughout the Study Area to determine general subsurface geologic conditions, but were largely concentrated in the immediate vicinity of the SWDA, DDA, and IWS Areas. The results of the subsurface investigations is presented in Sections 3 and 4.

2.5.1 Test Pits

A total of 9 test pits and 7 test trenches were excavated by Cushing & Sons, Inc. of Keene, New Hampshire during the Phase 1A investigation between May 22, 1991 and May 28, 1991. Test pit and test trench locations were based upon the results of soil vapor, GPR, and magnetometer surveys of the IWS Areas. Proposed locations were submitted to EPA in an interim letter report. Final test pit and test trench locations were approved by EPA prior to initiating the test pit and test trench operations. The locations at which test pits and test trenches were completed are shown on Figures 2-15 through 2-17. Four test pits (P901 through P904) and five test trenches (TT3-1 through TT3-5) were completed at IWS 3. Two test pits (P905 and P906) and one test trench (TT2-1) were completed at IWS 2. Three test pits (P907 through P909) and one test trench (TT1-1) was completed at IWS 1. Test pit logs are provided in Appendix C.

The test pits and test trenches were excavated to a maximum depth of 13 ft. in accordance with the criteria established in the Phase 1A Work Plan. The upper one to two feet of soil at each pit/trench location was excavated and placed on a large sheet of plastic to minimize introduction of ground surface contamination. The remainder of the waste/soil excavated from each pit/trench was then placed on a second sheet of plastic to minimize introduction of ground surface contamination and to allow for segregation of surficial soil/waste from deeper soil/waste. Upon completion of most of the excavations, a two foot thick layer of bentonite was placed in the bottom of the excavation. A bentonite seal was not placed on the bottom of test pits P904 and P905. The "deep" soil/waste was then placed back into the excavation along with the associated plastic sheeting. The surficial waste/soil was then placed back into the excavation along with the associated plastic sheeting. The ground surface in the immediate vicinity was then compacted and slightly re-graded to the approximate original grade. Finally, the center of each excavation was staked and labelled. The location of each excavation was then surveyed by Truline to establish ground control.

In general, soil/waste samples were obtained from each excavation using a stainless steel beaker mounted on a telescoping pole. The waste samples were obtained by scraping the beaker against different parts of the test pit wall. This represents a variation from the Work Plan, which called for scraping waste samples from a limited portion of the test pit wall. This variation was necessary due to the density of the materials and difficulty scraping material off the wall of the test pit. The sampling method resulted in a sample of soils/waste composited from the test pit. No samples were collected from test pit P904. This test pit was completed at EPA's request, to check an area where the soil vapor survey indicated an increased VOC concentration. This area was upgradient from any areas where disposal activities were reported. Excavation of the test pit showed only natural, undisturbed soil in the area. No indications of waste products or HNu screening values above background were observed. The walls and ground surface surrounding excavations P906 and P908 were dangerously unstable and periodically collapsed. The Site Safety Officer determined that it was unsafe to attempt sampling these test pits as originally planned, since using the beaker and telescoping pole required standing near the edge of the excavation. Therefore, soil/waste samples at these locations were obtained as composite samples from various locations in the excavated soil/waste pile and/or the backhoe bucket.

In general, one sample of the waste and one sample of the natural underlying soil were obtained from each test pit and submitted to Aquatec, Inc. of Colchester, Vermont to be analyzed for Full TAL/TCL Compounds by CLP Protocols (DQO Level 4). In addition, samples of the waste were submitted to the laboratory for analysis for RCRA Characteristics, (Ignitability, Corrosivity, TCLP, and Reactivity), Waste Characterization (Chemical Oxygen Demand (COD)), Total Organic Carbon (TOC), Total Petroleum Hydrocarbons (TPH), Total Organic Halides (TOH), Kjeldahl Nitrogen, Ammonia Nitrate, Total Phosphorous, Chloride, Total Nitrogen and Nitrate/Nitrite Nitrogen).

Additionally, duplicate soil and waste samples were placed in screw-top glass jars, covered with aluminum foil, sealed with a plastic lid, placed in a cooler with blue ice, and transported to the field laboratory to be headspace screened for the presence of detectable volatile organic compounds. Headspace screening was performed using an HNu Systems Model PI101 photoionization analyzer with a 10.2 eV probe. Headspace screening field logs are provided in Appendix D. Due to the large volume of soil/waste required for the analytical samples, the initial volume of soil/waste removed from each test pit was placed in sample jars for the analysis described in the preceding paragraph. Therefore, the "duplicate" soil/waste samples for headspace screening were obtained from a second sampling bowl and do not represent true "duplicate samples".

Samples of the natural soils immediately below the waste horizon in each test pit were obtained as described above, placed in two four-liter plastic jars, and submitted to D'Appolonia of Monroeville, Pennsylvania to be analyzed for the following physical parameters: bulk dry minimum and maximum density, grain size distribution, and total effective porosity. Table 2-4 summarizes the soil samples obtained in each test pit and the analyses performed on each sample.

2.5.2 Borings

2.5.2.1 Phase 1A Test Borings

A total of 32 test borings (B101 through B115 and B117 through B131) were completed at 32 well cluster locations across the study area, as shown on Figure 2-18 by Cushing & Sons, Inc. (Keene, New Hampshire and Lyndonville, Vermont) and Environmental Drilling, Inc. of Barre, Massachusetts between April 30, 1991 and July 27, 1991. The test borings were completed in accordance with the Phase 1A Work Plan, except as noted herein. The borings ranged in depth from 22 ft. to 280 ft. below the ground surface. Five of the borings (B101 through B104, and B128) were located in the immediate vicinity of IWS 3. Five borings (B105 through B108, and B129) were located in the immediate vicinity of IWS 2 and three borings (B109, B110, and B130) were located in the vicinity of IWS 1. An additional six borings (B111 through B115 and B117) were located along the perimeter of the SWDA. The remaining borings were located outside the Landfill. B116, originally planned to be located along the eastern perimeter of the SWDA, was eliminated from the program with the concurrence of EPA.

The test borings/monitoring wells in each cluster are labeled with the boring location number followed by a letter suffix. The suffixes (A,B,C, etc) indicate increasing termination/screen depth below the ground surface. Borings/wells with the suffix A represent the shallowest boring/well in the cluster. The reader must refer to Table 2-10 to determine whether the well is a bridging well, intermediate depth well, or a "Top of Rock" (TOR) well.

All of the borings, with the exception of B131, were completed using hollow-stem auger or air-rotary drilling techniques in the unsaturated zone and drive-and-wash drilling techniques in the saturated zone. Each boring was completed using hollow-stem-augers to a depth of approximately 10 to 20 ft. below the groundwater table or air-rotary drilling until groundwater was encountered. Upon reaching a depth of 10 to 20 ft. below the groundwater table, the hollow-stem-augers were withdrawn from the borehole and four- or six-inch (inside diameter) flush joint casing was telescoped down to the bottom of the borehole. The remainder of the boring was then completed using standard drive-and-wash drilling techniques. Several of the boreholes (B111, B118, and B119) were advanced to greater depths into the saturated zone and represent deviations from the Work Plan. Air rotary drilling was used to complete the unsaturated zone drilling at boring locations B109B, B110B, and B113B. The use of air rotary drilling at these locations represents a deviation from the Work Plan, which called for the use of air rotary drilling outside the Landfill. Boring logs are provided in Appendix E.

Most drilling locations were located at well clusters where more than one groundwater monitoring well was to be installed. At these locations the test boring was initiated at the proposed location where the deepest groundwater monitoring well was to be installed. Subsequent groundwater monitoring wells in the cluster were then installed in non-logged and non-sampled boreholes. However, due to scheduling difficulties resulting from greater than anticipated depths to bedrock, it was necessary to start some of the test borings at locations where shallow (bridging) groundwater monitoring wells were proposed. In these cases, the borehole for the shallow groundwater monitoring well was sampled and logged. As more powerful drill rigs became available later in the drilling program, drill rigs were set-up approximately 10 ft. down gradient of the completed shallow wells. The shallow portion of the deep borehole for the proposed deep groundwater monitoring well was then completed to the depth of the shallow well without sampling. Sampling of subsurface soils in the deep borehole was resumed below the depth of the shallow wells.

Bedrock was cored, to the indicated depths, in borings B101 (5 ft.), B102 (15.9 ft.), B103 (5.4 ft.), B107 (14.7 ft.), B109 (15.3 ft.), B111 (5 ft.), B112 (22 ft.), B113 (5 ft.), B114 (3.1 ft.), B115 (20.8 ft.), B119 (5 ft.), B120 (28.7 ft.), B121 (5 ft.), B122 (5 ft.), B125 (15.4 ft.), B126 (174.9 ft.), and B127 (10 ft.) to confirm depth to bedrock, to allow for packer testing of bedrock in selected coreholes, or to allow for the installation of bedrock groundwater monitoring wells. Rock coring was accomplished using standard and wireline nominal two inch inside diameter core barrels. Table 2-5 summarizes the test boring procedures and general test boring data for each boring.

Boring B131 was first attempted using hollow stem augers until auger refusal was encountered at a depth of 138 feet. The augers were removed from the borehole and 6-inch inside diameter casing was telescoped down the open borehole. However, the casing became sand locked at a depth of 110 feet. The six-inch casing was removed from the borehole and 7.5-inch casing was driven to a depth of 105 feet. Six-inch casing was then telescoped through the 7.5-inch casing and advanced using the drive-and-wash technique until casing refusal was encountered at 166 feet. The borehole was then drilled open-hole to a depth of 227 feet. Uncontrollable heaving sands were encountered at 217 feet. Attempts were made to control the heaving sand by supplying a constant head of water to the borehole. The attempts at controlling the heaving sand proved ineffective. The drillers attempted to telescope four-inch casing to the bottom of the borehole but could not advance the casing beyond a depth of 191 feet. At this point ESE made the decision to pull the casing and allowed the borehole to collapse to a depth of 175 feet. An intermediate depth groundwater monitoring well was installed at a depth of 175 feet. The well screen was installed over a depth interval of 165 to 175 feet. Upon completion of the well installation, the borehole was then filled with tremie grout and the casing removed.

A second attempt to complete B131 to bedrock was attempted 59 feet south of the original location. With the prior concurrence of EPA, a hybrid drive-and-wash and mud rotary drilling procedure was used to complete the boring. An open borehole was advanced using mud rotary drilling from the ground surface to a depth of 160 feet (five feet above the top of the intermediate well screen). Ten-inch drill casing was then driven to a depth of 160 feet. The drill mud (bentonite) within the casing was then flushed to the ground surface and the casing was driven to a depth of 171.5 ft. using drive-and-wash procedures. Based upon visible ground surface topography, it was determined that the termination depth of 171.5 feet for the drive-and-wash procedure was below the bottom of the previously installed intermediate well screen. Open hole mud rotary drilling was resumed to refusal at a depth of 229 feet using an 8.75-inch roller bit. Preliminary seismic refraction data suggested a depth to bedrock of approximately 245 feet. However, weathered bedrock was encountered at 224 feet. The drilling mud filter cake on the borehole wall was removed by overreaming the borehole using a 9.25 inch roller bit and copious amounts of water.

Bedrock was planned to be cored (5 ft.) in boring B131 to confirm the depth to bedrock. However, a rock coring rig was not available to core B131 for several days after bedrock was encountered. To avoid delay, the decision was made to confirm bedrock refusal by using a roller bit to drill five feet into the bedrock.

Drilling difficulties were also encountered at B108 where four inch drill casing could not be advanced below a depth of 100 feet using a standard 300 pound hammer. Two 300 pound hammers were used in tandem (net weight of 600 pounds) to drive the casing to refusal at 124 feet. The boring was continued open hole to spoon refusal at 173 feet.

Actual depths to bedrock exceeded anticipated depths to bedrock at most drilling locations by 70 to 100%. In many cases the anticipated depth to bedrock (based on previously and poorly completed seismic surveys prior to 1990) were in error by nearly 100 feet or more. The deeper bedrock depths resulted in significant project delays. In an attempt to minimize the impact of the increased depth to bedrock, ESE proposed to EPA that boring B116 be deleted from the program for Phase 1A. After consideration, EPA concurred with ESE's recommendation. To maintain the required depth to bedrock and bedrock permeability database, ESE cored the 15 ft. of bedrock originally planned for B116 while completing test boring B115. Additionally, due to core barrel failure, only 10 ft. of bedrock was cored in boring B127C rather than the originally planned 15 feet.

2.5.2.2 Phase 1B Test Borings

A total of eleven test borings (B105I, B108I, B132 through B140) were completed at eleven test boring locations across the Study Area, as shown on Figure 2-18, by Environmental Drilling, Inc. of Barre, Massachusetts between May 19, 1992 and July 10, 1992. The test borings were completed in accordance with Section 2.2 of the Phase 1B Work Plan. Test boring logs are provided in Appendix E and boring specific drilling procedures are summarized in Table 2-5. The borings ranged in depth from 23 feet (B140) to 263.15 (B137B) feet below the ground surface. Four of the borings (B105I, B108I, B134 and B135) were completed in the immediate vicinity of IWS 2. Boring B132 was completed on the easterly side of the unnamed stream, due southeast of IWS 2. Boring B139 was completed on the easterly side of the unnamed stream, midway between IWS 3 and IWS 2. Boring B133 was completed as a companion boring to B104 and MW10, immediately downslope and south of IWS 3. B136 was completed downgradient from IWS 2, approximately one-third of the distance between IWS 2 and the Riverside School. B140 was completed on the westerly side of the Passumpsic River, west-northwest of the Riverside School.

Borings B105I, B108I, B132, B134, B135, B136, and B139 were completed using drive and wash drilling procedures. Boring B140 was completed with hollow stem augers. A combination of hollow-stem auger, drive and wash, and mud rotary drilling were used to complete borings B137 and B138.

Boring B137B was completed using hollow stem augers to a depth of 117.5 feet at which point the augers were removed from the borehole and 7-inch casing was advanced using drive and wash drilling to a depth of 95 feet. Five-inch casing was then telescoped through the 7-inch casing and advanced to a depth of 143.5 feet using drive and wash drilling techniques. Mud rotary drilling was then used to advance the borehole from 143.5 feet to a depth of 223 feet. Four-inch casing was then telescoped to 223 feet and the casing was flushed with tap water to remove the drilling mud. The four-inch casing was then advanced by drive and wash drilling to refusal on bedrock at a depth of 257 feet. Companion well B137A was installed in an unsampled borehole completed using only drive and wash drilling techniques.

Boring B138B was drilled with hollow stem augers to a depth of 98 feet, at which point, the augers were removed from the borehole and five-inch casing was telescoped to 93 feet. The five-inch casing was then advanced using drive and wash drilling to a depth of 122 feet. The borehole was then advanced with mud rotary drilling and a 4 5/8-inch bit to a depth of 195 feet. Four-inch casing was then telescoped to a depth of 195 feet and the casing was flushed clean of mud. The borehole was then advanced to refusal on bedrock at 216 feet. The unsampled borehole for well B138A was advanced only with drive and wash drilling.

Bedrock was cored to the indicated depths, in borings B132 (24.2 feet), B136 (65 feet), B137 (5 feet), B138 (5.9 feet), and B139 (28.8 feet) in accordance with Section 2.2 of the Phase 1B Work Plan.

2.5.2.3 Sampling

Soil samples were generally obtained in each boring at the sampling interval established in the Phase 1A and Phase 1B Work Plans. All soil samples acquired during the test boring program were obtained with a standard 24 inch long, 1-3/8 inch diameter split-spoon sampler driven with a 140 pound hammer falling a distance of 30 inches. Soil densities encountered during the drilling program precluded the use of a wire-line five foot soil core barrel for soil sampling, as originally planned. Soil sampling intervals for each boring are presented on Table 2-5.

Heaving sands were encountered in borings B111 (136 ft. to 150 ft.), B118 (145 ft. to 159.5 ft.), B121 (104 ft. to refusal at 139.5 ft.), B131 (217 ft. to refusal at 224 ft.), and B113 (158 ft. to 162 ft.) and could not be controlled through telescoping to four inch casing or maintaining a constant head of drill water. The occurrence of uncontrollable heaving sand conditions resulted in abandonment of continuous sampling efforts. In these cases, heaved soils were sampled at five foot intervals until the boring was terminated or heaving conditions ceased to occur.

Due to the significant delays resulting from the greater than anticipated depths to bedrock in the Study Area and the extreme depth (100 ft.) to the groundwater surface in the vicinity of borings B110 and B113, ESE proposed to EPA that the unsaturated overburden at these boring locations be sampled on a ten foot sampling interval to a depth of 100 feet, or until groundwater was encountered, whichever was shallower, rather than the originally established continuous sampling interval. EPA concurred with ESE's recommendation. Boring B110 was sampled on a ten foot sampling interval from the ground surface to a depth of 90 ft., below which continuous soil sampling was initiated. Due to continuous spoon refusals, boring B110 was sampled on a five foot sampling interval from a depth of 126 ft. to casing refusal at a depth of 148 ft. Boring B113 was sampled on a ten foot sampling interval from the ground surface to a depth of 79 ft., below which continuous soil sampling was initiated.

Split-spoon soil samplers containing soil samples were opened and screened with a photoionization detector (PID) immediately upon removal from the borehole. Soil samples yielding open split-spoon screening readings above 10 parts-per-million (PPM) were immediately placed in laboratory supplied sample jars for possible analysis for Full TCL/TAL Compounds. Additionally, any soil sample yielding an elevated field screening reading above 1 PPM above background but below 10 PPM were placed in headspace screening jars, as described above, and transported to the field laboratory. The remainder of the sample was placed in two 40 ml VOA vials for potential TCL-VOC analysis. In the field laboratory, the soil samples were allowed to warm to room temperature for one to three hours to allow the sample to develop a representative concentration of headspace vapors. After the headspace development period the headspace in each sample jar was screened with a PID in accordance with the field sampling plan. Based on the results of the field and laboratory headspace screening, a maximum of two soil samples from any boring were submitted to the analytical laboratory. Additional soil samples were submitted for TCL-VOC analysis at the Site Manager's discretion.

Soil samples were also obtained at the capillary fringe in four SWDA borings. The Work Plan called for sampling from five of seven SWDA borings. With the elimination of B116, only four borings were still available for sampling. These samples were also submitted for analysis of Full TCL/TAL Compounds. Additionally, soil samples from various test borings and major soil units in the Study Area were selected by the Project Geologist and submitted to D'Appolonia to be tested for physical parameters. Table 2-6 presents a list of the soil samples submitted for analytical laboratory analysis and the analyses performed on the samples. Field headspace screening results are provided on Table 2-7. Laboratory headspace screening results are provided on Table 2-8. Table 2-9 presents a list of test boring soil samples submitted for physical parameter testing. The results of the physical parameter testing are provided in Appendix F.

2.6 HYDROGEOLOGICAL INVESTIGATIONS

Fifty groundwater monitoring wells (B101A through B117B, and B118A through B131C) and three groundwater observation wells (B121-OW, B201, and B202) were installed at 37 well cluster locations by Cushing & Sons, Inc. and Environmental Drilling, Inc. for the Phase 1A investigation between April 30, 1991 and July 27, 1991. Nineteen (19) groundwater monitoring wells (B105I, B108I, B132 through B140) were installed at eleven (11) well cluster locations for the Phase 1B investigation by Environmental Drilling, Inc. between May 19, 1992 and July 10, 1992. The Riverside School and Curran residence were connected to the municipal water system and the associated supply wells were incorporated into the groundwater monitoring well system. The installation of the Phase 1A and Phase 1B groundwater monitoring wells, three observation wells and acquisition of the two private supply wells in conjunction with existing monitoring wells resulted in a total monitoring well network of 92 wells. The locations at which these wells were installed are shown on Plate D and in Figure 2-18. Groundwater monitoring well installation logs detailing the well construction specifications are provided in Appendix G.

Each newly installed Phase 1A groundwater monitoring well cluster generally consisted of a shallow well (bridging well) and a deep well installed at the bedrock surface (Top of Rock Well (TOR well)). The bridging wells were generally installed with 15 feet of well screen extending from five feet above the groundwater table to ten feet below the groundwater table. The TOR wells were generally installed with ten feet of well screen extending from approximately 1 foot below the bedrock surface to 9 feet above the bedrock surface. Intermediate depth wells with screen lengths of 10 feet were installed at selected well clusters in accordance with the Phase 1A Work Plan and later negotiations with EPA. The Phase 1B wells included TOR and bridging wells, as well as, monitoring wells installed at the surface of the Distal Glacial Lacustrine deposit (referred to as Top-of-Distal or TOD wells) and within the bedrock. Phase 1B well construction was identical to the construction of the Phase 1A wells except that well riser pipes installed during Phase 1B consisted of Schedule 80 PVC rather than Schedule 40 PVC. All well installations were completed in accordance with the Phase 1A and Phase 1B Work Plans, unless otherwise noted in this report.

2.6.1 Well Installation

Well construction details for each well installed during the groundwater monitoring well/observation well installation program are presented on Groundwater Monitoring Well Installation Reports provided in Appendix G, and summarized on Table 2-10. Observation wells installed during completion of the Phase 1A field program were identical in construction and installation to the bridging groundwater monitoring wells with the exception that borehole cuttings were used to backfill the annulus between the riser pipe and borehole wall from the surface of the bentonite seal to a depth of approximately two feet below the ground surface.

The top of casing elevation and ground surface elevation for each groundwater monitoring/observation well and acquired private supply well were surveyed by Truline shortly after completion of the well installation/conversion to monitoring well status. The well construction details, formations screened, ground surface elevations, and top of casing elevations are presented on Table 2-10.

IWS 3

TOR and bridging wells were installed at locations B101, B102 and B103 in accordance with the Phase 1A Work Plan. Due to the presence of a highly weathered bedrock zone near the bedrock surface well B102B was installed with the bottom of the well screen at a depth of 5.7 feet below the weathered bedrock surface (1.3 ft. into sound bedrock). An additional intermediate depth well was installed at B103 due to the saturated overburden thickness, as required by the Phase 1A Work Plan. Due to the presence of a highly weathered bedrock zone at the bedrock surface, well B103C was installed with the bottom of the well screen at a depth of 6.1 feet below the weathered bedrock surface. A TOR well (B104) was installed as a companion well to shallow well MW10A. The Work Plan required that a 4-inch diameter monitoring well be installed at B104; however, a 2-inch diameter monitoring well was installed instead. The apparent low permeability of the overburden soil at this location rendered the installation of a 4-inch well no more useful than a 2-inch well. The Work Plan criteria required installation of an intermediate depth well at location B104 due to the saturated overburden thickness. However, due to drilling delays incurred as a result of the greater than anticipated bedrock depths, ESE recommended to EPA that the installation of an intermediate depth well be postponed until Phase 1B (if necessary). EPA concurred with ESE's recommendation. An additional companion well (B133) was installed immediately adjacent to wells MW10 and B104 during Phase 1B. B133 was installed in the Upper Proximal with the well point located directly above the upper surface of the semi-confining Distal Lacustrine unit and has a screen length of 10 feet.

IWS 2

TOR wells and bridging wells were installed at cluster locations B106 and B108. Well B106B was installed with the bottom of the well screen located 4 feet above the bedrock surface rather than 0.5 to 1 foot below the bedrock the bedrock surface. This variation from the Work Plan was the result of overfilling the bedrock borehole with bentonite. A TOR well was installed at location B105. A TOR well was scheduled to be installed at location B107 as a companion well to shallow well ERT1. However, EPA requested that the well be installed at the surface of a very dense soil horizon believed to be locally extensive across the Study Area. In accordance with EPA's request, well B107 was installed at this surface. The Work Plan required that a 4-inch diameter monitoring well be installed at B104; however, a 2-inch diameter monitoring well was installed instead. The apparent low permeability of the overburden soil at this location rendered the installation of a 4-inch well no more useful than a 2-inch well. Phase 1A Work plan criteria required the installation of intermediate depth wells at locations B105 through B108 due to the saturated overburden thickness. However, due to drilling delays incurred as a result of the greater than anticipated bedrock depths, ESE recommended to EPA that the installation of intermediate depth wells be postponed until Phase 1B (if necessary). EPA concurred with ESE's recommendation.

To refine the knowledge of subsurface geologic and hydrogeologic conditions in the immediate vicinity of IWS 2, additional wells were installed in and around IWS 2 during the Phase 1B investigation. "Top of Distal" (TOD) wells consisting of 10 foot well screens installed with the well point immediately above the upper surface of the semi-confining Distal were installed at B105I and B108I to determine the nature of groundwater contaminant migration along the Distal Surface. Well B108I was installed with the bottom of the well screen located immediately above the Distal surface, as defined by the depth to Distal shown on boring log B108. However, the boring log for B108I indicates that B108I was installed within a transitional zone between Proximal and Distal Lacustrine deposits. Well B134B was installed as a TOD well immediately adjacent to ERT 1 to evaluate groundwater quality in the lower portion of the Upper Proximal at this location. An additional well (B134A) was installed with a 10 foot well screen and well point located immediately above a 4 foot thick clay layer to evaluate the significance of the clay with regard to contaminant migration. A TOR well (B135B) and a TOD well (B135A) were installed as companion wells to B107 to evaluate groundwater quality in the lower portion of the Upper Proximal and the lower portion of the Lower Proximal. The well screen for B135A actually extends to a depth of 2 feet below the surface of the Distal.

A TOR well was installed southeast of IWS 2 and on the eastern side of the unnamed stream to evaluate the potential for southeasterly migration of groundwater contaminants from IWS 2. This well was positioned along strike of the regional J_2 joint set (refer to Section 3.2) and within a bedrock depression identified during the Phase 1B seismic refraction survey. Well cluster B139, consisting of a bridging well (B139A), TOR well (B139B), and bedrock well (B139C), was installed on the easterly side of the unnamed stream, midway between cluster B117 and B105, to refine knowledge of groundwater contaminant concentrations and migration pathways between IWS 3 and IWS 2. The top of the well screen for B139A is actually located approximately 5 feet below the groundwater surface. Well B139C was added to the well installation program due to the fractured nature of the bedrock at this location.

IWS 1

TOR wells were installed at cluster locations B109 and B110 in accordance with the Phase 1A Work Plan. An intermediate depth well and bridging well were also installed at location B109 due to the saturated overburden thickness, as required by the Work Plan. Well B109C (TOR) failed due to either screen collapse, in response to excessive depth of installation, or deformation resulting from heat of hydration as the bentonite-cement grout cured. Since the original drill casing could not be removed during the well installation procedure, ESE made the decision to install another well screen and riser assembly within the original cased hole. A wing bit was used to drill out the bentonite-cement grout, and the PVC well material, to bedrock. A replacement well assembly was then installed in the original borehole. Well B110B was installed with the bottom of the well screen at a depth of 2.5 feet below the bedrock surface due to strong persistent suggestions of EPA's oversight contractor's representative and the related confusion associated with the field discussions. A bridging well was also installed at B110 due to the anticipated saturated overburden thickness.

A TOR well was installed at location B111 in accordance with the Phase 1A Work Plan. The originally installed well at B111 was apparently damaged during removal of the hollow-stem augers during the borehole grouting procedure. This damaged well was abandoned by tremie grouting the inside of the well with a bentonite-cement grout. A replacement well (B111R) was drilled without soil sampling, approximately 20 ft. north of the original location.

Well cluster B137 was installed due west of IWS 1 to evaluate the potential for westward migration of groundwater contamination from IWS 1. This well cluster was installed in accordance with the Phase 1B Work Plan and consisted of a TOR well (B137B) and a bridging well B137A.

SWDA

A TOR well and bridging well were installed at locations B112 and B117 in accordance with the Phase 1A Work Plan. The bottom of the well screen in B112B was installed at a depth of 3.9 feet below the bedrock surface. The TOR well B117B is set on top of the bedrock surface, not one foot below the bedrock surface; this represents a deviation from the Work Plan. TOR wells were also installed at locations B113 through B115 in accordance with the Phase 1A Work Plan. The bottom of the TOR well at location B113 was installed at a depth of 4.9 ft. below the bedrock surface (rather than one foot as planned) due to lingering confusion related to oversight discussions at B110B. The bottom of the well screen for well B115B was installed 11.6 feet above the surface of the sound bedrock due to the presence of a boulder which prevented the driller from seating the drill casing on bedrock prior to installing the well. The uncased portion of the borehole collapsed prior to the installation of the well screen. Bridging wells were also installed at locations B113 through B115 due to the depth of saturated overburden thickness, as required by the Work Plan. Work Plan criteria required the installation of intermediate wells at locations B113 through B115 due to the saturated overburden thickness. However, due to significant drilling delays incurred as a result of the greater than anticipated depth to bedrock, ESE recommended to EPA that the installation of intermediate wells be postponed until Phase 1B (if necessary). EPA concurred with ESE's recommendations. ESE also recommended to EPA, and EPA agreed, that installation of the TOR well at proposed location B116 be postponed until Phase 1B (if necessary).

Well cluster B138 was installed west of IWS 2 and well cluster B113 in accordance with the Phase 1A and Phase 1B Work Plans to aid in determining the extent and nature of westward groundwater contaminant migration from IWS 2 and the SWDA.

OTHER AREAS

A TOR and bridging well were installed at location B118 in accordance with the Phase 1A Work Plan. Due to concern that failure of the PVC well screen might occur because of the loading associated with the excessive depth of the TOR well, ESE opted to install a stainless steel well screen in this well. Work Plan criteria required the installation of an intermediate depth well at location B118. However, installation of this well was delayed, with EPA approval, until Phase 1B (if necessary), to reduce drilling delays resulting from the greater than anticipated bedrock depths. TOR, bridging, and intermediate depth wells were installed at locations B119, B120, and B127 in accordance with the Work Plan. The TOR well B120C was set 4.5 feet below the bedrock surface. A shallow bedrock well (B120D) was also installed at location B120. This well was installed with 1.5-inch diameter well material rather than the designed two inch well pipe due to concerns that an adequate filter pack and bentonite seal could not be installed through the narrow annulus between the well pipe and the drill casing. The bottom of the well screen for well B127C was installed 0.7 feet above the bedrock surface.

An intermediate depth well and a TOR well were installed at location B121 in accordance with the Work Plan. A bridging groundwater observation well (B121-OW) was also installed at location B121 to allow for more accurate determination of groundwater and vertical hydraulic gradients at this location. The installation of this well was not included in the original scope of work, and therefore was never included in the well development program established in the Work Plan.

TOR wells were installed at locations B122 and B125 in accordance with the Phase 1A Work Plan. The bottom of the well screen for well B125 was installed 1.5 feet above the bedrock surface. This deviation from the Work Plan occurred because the core barrel used to core bedrock at this location sheared-off and was lost in the corehole. The drill casing was bumped back and the borehole was allowed to collapse to produce a zone of natural soil between the lost core barrel and the bottom of the well. A TOR well and deep bedrock well were installed at location B126 in accordance with the Phase 1A Work Plan. In deviation from the Work Plan, the deep bedrock well was installed as an open-rock hole with a seal at the bedrock surface and standard water well casing extending to the ground surface. The well is protected with a locking metal lid welded to the casing.

A TOR well, bridging well, and intermediate depth well were installed at location B127 in accordance with the Phase 1A Work Plan. TOR and intermediate depth wells were installed at location B131 according to the Phase 1A Work Plan due to the saturated overburden thickness. To facilitate purging and sampling of the excessively deep TOR well, the well was installed with four-inch diameter stainless steel well materials rather than the designed two-inch PVC materials. Installation of the four-inch diameter well material allowed installation of a three-inch diameter submersible pump for rapid well purging. The use of stainless steel well materials also reduced the risk of well material failure due to the excessive depth of well B131C. This well was also installed with the bottom of the well screen located 2 feet below the bedrock surface. The installation of the originally designed bridging well was attempted at this location. During discussions with EPA it was determined that in the interest of completing the field program with minimal delay, installation of the bridging well should be delayed until Phase 1B (if necessary).

Groundwater observation wells were installed at locations B121, B201 and B202 to provide additional groundwater level data points.

The Work Plan stated that all TOR wells located outside the Landfill were to be installed with the well point sitting on top of the bedrock surface and not penetrating the bedrock. However, the following TOR wells were completed with the well points installed 0.5 to 2 feet below the bedrock surface: B118B; B121B; B122 and B131B.

Well cluster B136 was installed in accordance with the Phase 1B Work Plan to determine the extent and potential pathways for groundwater contaminant migration from the IWS 2 vicinity to the Riverside School supply well. This well cluster consists of a bridging well (B136A), TOR well (B136B) and a bedrock well (B136C). The borehole for well B136C was terminated at a depth of 192 feet. The fractured portion of the well was isolated with packers and purged and a groundwater sample was obtained from the isolated zone. Field GC analysis of the headspace in the groundwater sample vial revealed the presence of volatile organic compounds at interpreted concentrations exceeding those detected at the Riverside School well. Although the boring log for B136C suggests the bottom of the well screen for B136B may be located 1.8 feet above the bedrock surface, well screen B136B was installed with the bottom of the screen at a height of 1.2 feet above the bedrock surface at location B136B.

2.6.2 Well Development

Groundwater monitoring and observation wells installed during the Phase 1A drilling program were developed after a minimum stabilization period of three days after well installation. Many of the wells were developed more than three weeks after installation. Due to the extremely fine grain size of the formations screened by wells, the depth of many of the wells, and the relatively low permeability of the screened formations, development procedures involving over-pumping, bailing, combined surge block, or pumping/bailing were not viable development procedures for this program. Excessive silting of many wells precluded use of small diameter (less than two inch outside diameter) submersible, bladder, or air lift pumps. ESE was concerned that low well yields (which was made worse by the abnormally dry summer), combined with a heavy sediment load, would destroy or at best clog pumps, resulting in excessive delays in the well development schedule. Development by surging with air was viewed as the least favorable development method due to concerns of air entrapment within the filter pack and aeration of the formation, with related volatilization of contaminants.

After careful consideration, ESE made the decision to surge the wells with water obtained from the Lyndonville Municipal Water Distribution System. The development procedure consisted of surging the well screen in two to six-inch increments starting at the top of the well screen and progressing in a downward direction. Well development ceased when visible suspended matter could no longer be observed or when repeated attempts at clearing the screen were unsuccessful due to very fine silts and sands.

EPA requested that every effort be made to limit the volume of water used in the development process and that two "development volumes" (the water volume equivalent to the volume of water lost to the formation during development of the well) of water be purged from each well upon completion of the development program. To conform to EPA requirements, ESE kept accurate records of the volume of development water lost to wells developed after July 10, 1991 (prior to this date records of estimated total water quantity used for each well cluster had been maintained but records of the volume of water returned to the ground surface were not recorded), and the volume of water recovered at each well. Water quantities were measured using a water meter attached to the downwell pipe. Upon return to the surface, the water quantity was measured by means of calibrated stock tubs. The well development volume data and development dates are provided on Table 2-11. Additionally, at the request of EPA the water surged from each well during development was periodically screened with a turbidity meter, pH meter, and temperature/specific conductance meter. As further requested by EPA, well development was terminated at each well after turbidity readings were consistently less than or equal to 5 NTU.

Attempts to develop wells B118B, B131B, and B131C by surging with water, failed due to the inability of the water to sustain the necessary velocity to lift fine particles, from the screened intervals, to the surface. With EPA approval, ESE developed these wells by surging with air. As with other wells, these wells were monitored for consistency in temperature/specific conductance, pH, and turbidity measurements, and upon reaching the third consistent reading, development was ceased.

Well development was started on June 11,1991 and continued simultaneously with the drilling program until completion on August 8, 1991.

Due to the fine grain size distribution of the formations screened and EPA concerns associated with the introduction of large volumes of water to the screened formations during Phase 1A, all wells installed during Phase 1B were developed by overpumping with a "Waterra Pump" (inertial pump) followed by low flow pumping with an "Arch" air lift pump (where necessary due to siltation within the well screen). Pumping rates used at each well were optimized to provide sufficient flow to wash and surge the filter pack without disturbing the filter pack media or the adjacent formation.

2.6.3 Well Purging

This section discusses the purging performed following well development during Phase 1A, as part of the overall monitoring well installation process. Additionally, as discussed in Section 2.6.4, all wells were purged a second time, as required, during groundwater sampling, just prior to sampling.

The equivalent of two volumes of water released (lost) to the screened formations during development or the equivalent of two times the total volume of water used during development, if total "lost" volumes were not known, were purged from most wells. Well purging was accomplished on a nearly 24-hour basis using a combination of piston pumps with electric or gasoline powered pump jacks, small diameter submersible pumps, large diameter submersible pumps, and a variety of centrifugal pumps. Small submersible pumps were used to purge TOR and intermediate depth two-inch diameter wells. Large diameter submersible pumps were permanently installed in wells B120C, B126B, B131B and B131C. Piston pumps (Brainard-Kilman hand pumps) with electric or gasoline powered pump jacks were used to purge deep bridging wells and other wells where obstructions or sediment load precluded use of submersible pumps within the well screen. Centrifugal pumps were generally used to purge shallow wells in which the groundwater table was less than twenty feet below the ground surface. Purge volumes and rates were determined in two ways. Stock water tubs of 124 to 350 gallons in capacity were used to collect purged groundwater at numerous well locations. Purge volumes were recorded/calculated by filling and emptying the tubs until the required volume was purged from the well. In other cases sustained pump rates were calculated by recording the time required to fill tubs or two gallon pails. The required pumping time for purging was then calculated and the pumps were run continuously with regular refueling until the required purge volume was removed from the well.

Well purging data is provided on Table 2-11. The purging of twice the total water volume used during development was understood to be a large overestimate of the actual volume which likely needed to be purged. However, for wells where the actual volume of water lost to the formation was not known (prior to July 10, 1991), it was viewed as an acceptable alternative. Unfortunately, the use of this criteria resulted in exorbitant purge volumes of water at some well locations, due to the large volumes of water which were used for development because of the presence of fine silts and sands.

The purpose of well purging is to assure that any impacts to the aquifer immediately around the well screen, resulting from the process of installing and developing the well, have been mitigated by removal of water until it can reasonably be assumed that the water extracted from the well represents actual groundwater. This will occur naturally, given sufficient time, as the normal flow through the aquifer dissipates any impacts. Once well purging activities were underway, the time required to purge all wells, given the somewhat unusual circumstances and using the two criteria set forth above, would be significantly longer than could have been anticipated. In addition, at some well locations due to circumstances unique to the specific wells, it was not possible to remove the quantities of water required in any reasonable time frame. Therefore, not all wells were purged or purged according to the criteria set forth above.

In general, wells were purged, as required by the established criteria. However, in order to complete well purging, allow a minimum of 1-2 weeks between well purging and the collection of groundwater samples, and still complete the first groundwater sampling round in an acceptable time frame, it was impossible to purge all wells or to purge all wells of the volume of water required by the criteria. The discussions which follow provide the rationale for the field decisions made in circumstances where, as indicated on Table 2-11, well purging was not accomplished according to the criteria. These decisions were made cognizant of the need to assure that samples collected during the first groundwater sampling round were representative of the conditions within the aquifer. In general, two circumstances resulted in a decision to deviate from the criteria. First, wells for which development had been completed earlier in the field program were most likely to be the least impacted by reduced purging or no purging, because natural aquifer flow would have had sufficient time to mitigate the impacts of development. Second, some wells could not be purged of sufficiently high volumes because of minor installation problems or because of the characteristics of the geology at the particular location (i.e. fine silt and sands). The time between the first and second groundwater sampling rounds was approximately two months, ample time for stabilization of the aquifer. The close agreement of the analytical results from any of the wells discussed below, provides significant assurance that the rationale used to make the necessary field decisions was reasonable.

Well locations B101B and B120D were developed early in the field program and significant time had passed between development and the date of the first monitoring round, that the impacts of development could reasonably be expected to have been mitigated by natural aquifer flow. Therefore, the purging of these wells was either discontinued or not performed, so that available time could be devoted to purging other wells.

At well B109A, the pump rate was low (0.5 gpm) and sediment load was so heavy that it consistently plugged the purge pump and caused damage to the pump. Due to the early installation date of the well, low yield, and continual sediment damage to pumps, purging of this well was suspended.

At wells B102A, B102B, and B103B, attempts were made to withdraw purge water at sufficient volumes to meet the purge criteria. The yield from these wells, however, was low or unsustainable. It is highly likely that although the volume of return of development water during development was not recorded for these wells, the majority of development water introduced to the well was returned to the surface and that only a small volume of the total water introduced to these wells actually remained in the formation. These wells were developed early in the field program and significant time had passed between development and the date of the first monitoring round, such that the impacts of development could reasonably be expected to have been mitigated by natural aquifer flow. Therefore, purging at these wells was discontinued.

In an attempt to reduce the purge volumes of wells developed prior to recording water return, ESE used permeability data obtained during the 1991 field season to calculate the maximum volume of water absorbed by the surrounding formation at the time of development. The purge volume of well B112B was reduced, as a direct result of these calculations, from a volume of 2600 gallons to 537.5 gallons.

Well B114A could not be purged due to deformation of the riser pipe through inferred slumping of the DDA debris mass, presumably along the interface between the solid waste and the natural underlying soil. Curvature in the riser would not allow passage of a small submersible pump or piston pump.

Well B115B was installed through a boulder, and bridging of filter sand above the lower 5 ft. of well screen resulted in excessive silting of the well. Due to concern that the excessive silt load would damage submersible pumps and lock-up piston pumps, this well was not purged.

The well riser pipe in B103C was also severely curved to the point that all available pumps and standard bailers could not pass the obstruction. Only a small "pencil" bailer could pass the obstruction and would remove only approximately 120 ml. of water per bailer volume. Bailing the well with a 120 ml bailer was not a viable purging procedure. This well was repaired during Phase 1B and the curvature of the riser pipe was removed. However, since development occurred 12 months earlier, this well was not purged during Phase 1B.

Well B118A was partially purged before severe siltation combined with a falling water table thwarted purging attempts using small submersible pumps, piston pumps, and a field constructed inertial pump. In all subsequent attempts the groundwater level dropped below the bottom of the well screen and/or the pumps became clogged with silt. Purging of Phase 1B wells following development was not performed or required since the Phase 1B development procedure did not involve the introduction of tap water to the wells.

2.6.4 Sampling Program

<u>Rounds 1 and 2</u>

To determine groundwater quality in the Study Area, two groundwater sampling rounds were completed during the Phase 1A investigations. The first groundwater sampling round was begun on September 3, 1991 and was completed on September 10, 1991. Groundwater sampling began on wells purged early in the program and proceeded such that the wells purged last were sampled last. Wells were sampled no sooner than two weeks after purging. The second groundwater sampling round was smaller in scope and was begun on November 12, 1991 and completed on November 19, 1991.

Tables 2-12 and 2-13 present a list of the groundwater samples obtained during each of the sampling rounds as well as the analyses performed on each of the samples. The groundwater sampling program was completed using procedures set forth in the Phase 1A Work Plan. The groundwater sampling procedures involved determination of water level and standing volume of water in each well, purging of three or more well volumes prior to sampling, and acquisition of groundwater samples using stainless steel and/or teflon bailers. Water levels were measured with electronic water level indicators. All readings were referenced to a file mark/point mark or lock hasp on the top of the well casing. Purging was completed using small submersible pumps (TOR and intermediate wells), large submersible pumps (B120C, B126B and B131C), piston pumps (primarily bridging wells), centrifugal pumps (shallow wells), and bailers. All submersible and centrifugal pumps were connected to semi-rigid black plastic hose. Bailers were attached to white nylon rope. All rope was cut fresh immediately prior to sampling and was discarded immediately after each sample was obtained.

During each purging event, samples of the purged water were obtained after each well volume was removed. The purge water samples were field screened for pH, temperature, specific conductance, and turbidity. Purging of each well continued until all parameter readings stabilized to within 10 percent of the preceding set of readings. In no case were less than three standing well volumes removed form any well. Specific conductance readings and pH readings were obtained using a Pocket Pal DspH-3 pH and conductivity meter. Temperature readings were obtained using a partially encased pocket thermometer. Turbidity readings were obtained using a Monitek Portable Nephelometer Model 21PE. All electronic meters used to obtain the purging parameter readings were operated and calibrated in accordance with the manufacturers instructions.

Immediately prior to purging each bridging well, a clear, graduated, acrylic bailer was partially submerged into the water column to obtain a sample of the upper six inches of groundwater in the well to check for the presence of light non-aqueous phase liquids (LNAPL). During the second sampling round, semi-transparent teflon bailers were also lowered to the bottom of each TOR well immediately prior to purging to check for the presence of dense non-aqueous phase liquids (DNAPL).

Round 3

One round (Round 3) of groundwater samples were obtained from each of the existing groundwater monitoring wells and the Riverside School Supply Well (B120E) as part of the Phase 1B investigation. Table 2-14 presents a summary of the groundwater samples obtained during Sampling Round 3 and the analyses performed. The groundwater sampling was completed during the period July 13, 1992 through July 16, 1992. Due to schedule restrictions and dates of installation, well clusters B136 and B138 were sampled on July 29, 1992. All groundwater sampling was completed in accordance with the Phase 1A and Phase 1B Work Plans. The Phase 1B groundwater sampling procedures were the same as those for the Phase 1A sampling round with the exception that clear polyethylene hose was used with the 2-inch submersible pumps for purging prior to sampling rather than dedicated black plastic hose. The clear sampling hose was decontaminated with the submersible pump by steam-cleaning the outside of the pump and hose and then pumping copious volumes of soapy water (Alconox and tap water solution) and then tap water through the pump and house prior to inserting the pump and hose into another well. An ARCH air lift pump was also used to purge wells during the Phase 1B sampling round. Piston pumps were not used in any wells during the Phase 1B groundwater sampling round. All groundwater samples were obtained using stainless steel and/or teflon bailers. Clear acrylic bailers were not used for detection of LNAPL during Round 3 and preliminary checks for DNAPL in TOR wells were not performed in Round 3 due to the absence of high HNu readings from soil samples in the associated borings and the absence of visible or detectable DNAPL during Rounds 1 and 2. The results of the Round 3 (Phase 1B) groundwater analyses are discussed in Section 4.2.1.

Groundwater Sampling During Packer Testing of Selected Wells

Groundwater samples were obtained from two discrete zones within the bedrock corehole at B126B. The depth zones from which groundwater samples were obtained are 184-193 and 268-282.7 feet. Groundwater sampling was also attempted over four additional depth zones where fractures were encountered, but the bedrock formation did not yield groundwater. The groundwater samples were obtained by sealing-off the required depths with phuematic packers inflated with compressed nitrogen. A narrow diameter submersible pump suspended between the packers was used to purge three test zone volumes and sample the groundwater. The groundwater samples collected during the packer testing were submitted to Aquatec, Inc. and analyzed for TCL-VOC (DQO Level 3). Subsequent groundwater samples obtained during the groundwater sampling rounds were analyzed at DQO Level 4. The results of the groundwater analyses are discussed in Section 4.2.1.

A groundwater sample was obtained from a depth interval of 245 to 263.6 feet in the Riverside School Supply Well (B120E) by isolating the test zone with pneumatic packers and purging the test zone with a 2-inch submersible pump. Three test zone volumes plus the volume of water in the packer support pipe were purged prior to obtaining the sample. The groundwater sample was pumped directly into two 40 ml VOC vials, preserved with HCl, and submitted to Aquatec, Inc. for TCL-VOC analysis to DQO Level 3. Similar attempts were made to obtain groundwater samples from depth intervals of 190 to 200 feet, 170 to 180 feet, 145 to 155 feet and 115 to 125 feet, but in each case the test zone was pumped dry and a sample could not be obtained.

The same procedure was used to attempt to acquire groundwater samples from the Curran Well (B127D) at depth intervals of 97.2 to 108.3 feet, 52.9 to 64 feet, and 105.3 to 125.65 feet (bottom of well). The first two test zones were pumped dry and did not yield water; therefore, so no samples were obtained. A groundwater sample was obtained from the depth interval 105.3 to 125.65 feet and was pumped directly into two 40 ml VOC vials and submitted to Aquatec, Inc. to be analyzed for TCL-VOC to DQO Level 3.

A groundwater sample was obtained over a depth interval of 136 to 187 feet in B136C using a 2-inch submersible pump. A 10 foot thick bentonite and grout seal had been placed in the upper 10 feet of the bedrock prior to coring from 136 to 187 feet, it was assumed that this test zone was sealed from any nearby overburden influence, therefore a packer was not used to seal off the test zone. The submersible pump was placed at the bottom of the borehole and three well volumes were purged from the borehole prior to obtaining the sample. The sample was pumped directly into two 40 ml VOC vials and field screened with a gas chromatograph.

2.6.5 Local Hydrogeology

This section discusses the portions of the investigation designed to collect hydrogeologic data, including installation and testing of piezometers, water level measurement and groundwater flow, hydraulic conductivity testing, and pressure testing of bedrock.

2.6.5.1 Piezometers

As set forth in Section 7.3.3 of the Phase 1A Work Plan, eleven piezometers, identified as 301 through 311 on Figure 2-19, were installed 2.5 feet into the sediments of the unnamed stream on May 16 and 17, 1991 to determine the hydraulic characteristics of the stream and to evaluate the relationship between the groundwater and the stream. The piezometers, constructed of open ended iron pipe, were installed according to the methodology outlined in the Phase 1A Work Plan. During Phase 1B, three additional piezometers with staff gauges were installed at locations 312, 313 and 314 within the Passumpsic River to evaluate the relationship between the groundwater and the river. Previously installed piezometer 301 was destroyed in the Fall of 1991 during the extension of the municipal water main to Brown Farm Road. Piezometer 301 was replaced during Phase 1B.

Water level measurements from within the piezometer, and depth to surface water from the top of the piezometer casing, as well as water level measurements from all existing monitoring wells were recorded on seven different occasions between June 18 and November 11, 1991 and on four additional occasions between May 28 and September 10, 1992 to establish an understanding of hydrologic conditions over time. The top of casing elevation for each piezometer was surveyed by Truline. Falling head hydraulic conductivity tests were performed in each piezometer between June 29 and July 2, 1991 using either an electronic water level indicator (302, 303, and 306) or an electronic datalogger equipped with a pressure transducer (301, 304, 305, and 307 through 311), to record change in head induced by adding a known volume of water to the piezometer. Given the very slow rate of recovery observed in piezometers 301 through 311, either method was sufficiently accurate to resolve the rebound. As discussed above, piezometer 301 was destroyed during Parker and Son's installation of the new water main along Brown Farm Road in October 1991, prior to the final round of sampling and water level measurements. Falling head hydraulic conductivity tests were attempted in piezometers 312 through 314, but could not be completed because of extremely rapid recovery of water levels. Section 3.7.4 discusses the data collected from the piezometers.

2.6.5.2 Groundwater Flow

As set forth in Section 7.3.4 of the Phase 1A Work Plan, the groundwater flow directions in the overburden aquifer were evaluated by measuring the water levels in the monitoring wells, observation wells, and piezometers as well as two private supplies (B120E and B127D). The surface water levels in the unnamed stream and Passumpsic River were also recorded during each round to evaluate the interaction between surface water and groundwater. Five rounds of water level measurements were collected during the Phase IA field program prior to completion of the last Phase 1A monitoring well. Three complete rounds of water level measurements were collected from the wells and piezometers, after well development was completed, on September 3, September 30, and November 11, 1991. Three rounds of groundwater level measurements were collected during Phase 1B prior to completion of the last monitoring well (B136C). Two complete rounds of groundwater level measurements were obtained after the completion and stabilization of the last groundwater monitoring well. These readings were obtained on July 28 and September 10, 1992. Piezometric heads were calculated from the water level data and maps representing the piezometric groundwater surfaces on September 10, 1992. An evaluation of seasonal groundwater piezometric head variation over time was completed in selected locations by plotting piezometric head elevation versus location (distance in a given direction). These analyses and illustrations are presented in Section 3.

2.6.5.3 Hydraulic Conductivity of the Overburden

As set forth in the Work Plans, hydraulic conductivity tests (permeability tests) were attempted at each monitoring well, observation well, and piezometer. Three types of permeability tests, (constant flow test, rising head slug test, and falling head slug test), were employed depending on the conditions existing at each location. The constant flow test was employed preferentially over the other test methods as it more accurately measures the conditions existing in the aquifer around the monitoring well. Drawdown (change in aquifer pressure) at the monitoring well during the constant flow tests, due to steady pumping of water from the well casing, was recorded with an electronic data logger, equipped with a pressure transducer. Rising head slug tests were performed at wells in which it was (1) difficult to maintain pump prime during the constant flow test due to the low permeability of the formation at that location, (2) where the screen bridged the water table and a constant flow test was not possible due to restrictive pump clearance within the screen, or (3) in wells located where the unsaturated zone thickness prohibited constant flow testing (due to a combination of low to moderate permeability and pump lift constraints). Falling head tests were performed at locations where the other two test methods failed. Falling head tests were also performed in addition to the rising head or constant head test at several locations as a quality assurance measure.

Both rising head and falling head tests were completed using a slug consisting of a five or ten foot iron pipe sealed at either end and attached to a rope. The five foot slug was constructed of one-inch (outside diameter) black iron pipe with two-inch welded endcaps. The ten foot slug was constructed of 1.25-inch black iron pipe with welded endplugs threaded into the pipe.

Drawdown was recorded using an electronic data logger equipped with a pressure transducer. In wells that did not allow entry of the pump or slug, a water injection technique was used to perform a falling head test. This technique is only useful in situations where the screen is completely saturated and is not appropriate for wells which bridge the water table. This was the case at B103C. Permeability tests failed at two locations during Phase 1A: B118A and ERT1. Section 3.7.1 explains why the permeability tests failed. A list of the type of hydraulic conductivity test that was performed on each well is presented in Table 2-15.

Hydraulic conductivity from slug test data was computed using methods described by Bouwer and Rice (1976) using a verified computer program, Aqtesolv 1.1® (Geraghty & Miller, 1991). All solutions were checked for accuracy with an alternate method (Hvorslev, 1951) using a computer program developed at ESE. Hydraulic conductivity results from the constant flow tests were computed using the method outlined by (Hantush, 1964). Results of hydraulic conductivity measurements and data analysis are provided in detail in Section 3.

Testing of the aquifer at B137A and B138A was not completed due to the large thickness of the unsaturated zone (excess of 100 ft.) and the resulting stretching of the rope which precluded instantaneous removal of the slug. Constant flow testing at these locations was not feasible due to the nominal diameter of the wire wound screen which precluded insertion of a submersible pump. Slug testing at B137A initially resulted in jamming of the transducer wire and the slug within the well screen at a depth of 119 feet. Upon freeing the equipment from the well, additional hydraulic conductivity testing (slug testing) at B137A and B138A were cancelled due to the high potential risk of destroying the wells.

2.6.5.4 Hydraulic Conductivity of Bedrock

As discussed in the Phase 1A and Phase 1B Work Plans, in order to determine whether porous or fractured zones existed within the bedrock, packer testing was performed in open coreholes in the following borings: B102B, B107, B109C, B112B, B115B, B120D, B125B, B126B, B127C, B132, B136C and B139C, as well as the Curran Well (B127D) and the Riverside School Well (B120E). Approximately 10 to 15 feet of bedrock was cored in each location and the lower 10 feet of the open corehole was pressure tested with a single packer system. Sightly larger core runs and test zones were completed in the Phase 1B borings. Packer test data sheets summarizing the packer test conditions and results are provided in Appendix H. Approximately 175 feet of bedrock was cored at B126B. Specific test zone depths and dimensions are presented with the results in Section 3. In each bedrock test interval, water was injected into the corehole at a known pressure while measuring the inflow rate. Based on these measurements, calculations were performed to determine the capacity of the bedrock test zone for transmitting water.

Extensive packer testing was conducted at B126B in an attempt to locate discrete zones of potentially higher permeability. B126B extended approximately 275 feet below ground surface, approximately 175 feet into bedrock. The hole was originally cored with a 3-inch NX corebarrel and then widened with an air rotary drill bit which increased the corehole wall roughness. Six test zones were selected for pressure testing at B126B. The location and length of bedrock test zones in boring B126B were selected based on inspection of the rockcore: two test zones were intentionally placed in rock intervals that appeared to be competent (solid), while three of the tests were conducted in rock intervals that appeared fractured. These five tests were conducted using a double packer system, which seals the corehole below and above the test zone to allow discrete pressure testing of a given ten-foot section. The sixth test interval, the bottom 20 feet of the hole, was tested using a single packer.

Extensive packer testing of the Riverside School Well (B120E) and the Curran Well (B127D) were completed to determine the hydraulic conductivity of the bedrock, evaluate the integrity of the well seal, and investigate suspected casing breaks identified during the borehole geophysical logging. Eight test zones were packer tested in the Riverside School well and three test zones were packer tested in the Curran Well.

In order to calculate the hydraulic conductivity in each corehole test zone, two parameters were determined; (1) frictional head loss caused by pipe surface roughness and pipe length, and (2) total head on the test zone. Frictional head loss was computed using well established relationships for simple pipe flow (Streeter and Wylie, 1985). Hydraulic conductivity was estimated for each test zone using methods described by (Hantush, 1964) and (Bureau of Reclamation, 1974). Results of the packer testing and data analysis are discussed in detail in Section 3.

2.6.6 Post-Screening Field Investigation Test Borings

A total of eighteen test borings (B113C, B125B, B132B, B135C, B139I, B141, B142, B143, B203A1-4, B203B, B204A1-4, B204B) were completed by L. G. Cushing and Sons, Inc. of Lyndonville, Vermont between July 13, 1993 and August 24, 1993. As shown in Plate D thirteen of these borings were located within IWS 2. The remaining five borings were conducted at various locations surrounding the landfill. These borings were conducted in accordance with Sections 2.2 and 2.3 of the Post-Screening Field Investigation Work Plan dated May 21, 1993. Changes in drilling methods for certain borings (e.g. B203A-1 through B203A-4, and B204A-1 through B203A-4) were made in accordance with subsequent discussions with EPA.

The borings conducted during the Post-Screening Investigation were completed as either bedrock or overburden pumping wells or piezometers (depth to ground water monitoring points), to be used during subsequent bedrock and overburden pumping tests. With the exception of B139I, soil samples were not collected since these borings were located in areas (e.g. IWS 2) which have been extensively sampled during earlier investigations.

2.6.6.1 Bedrock Wells

Borings B113C, B125B, B132B, B135C, B141, B143, B203B, and B204B were completed as open bedrock wells to be used either as a pumping well or as piezometers (as discussed below, a well screen was eventually installed within the open bedrock borehole at well 203B). Each of these bedrock wells was completed using truck mounted, mud-rotary drilling rigs to advance and set 6 inch diameter steel casing through the overburden material and onto the top of bedrock.

At each bedrock well location, a 10 inch diameter roller bit and 4.5 inch diameter drill rod was used to drill (using mud) through the overburden to the top of bedrock. Once bedrock was encountered it's competency was confirmed by drilling a pilot hole into the bedrock with the roller bit until refusal (generally between 1 and 10 feet into the bedrock). Upon bedrock refusal, the roller bit and drill rods were withdrawn from the boring so that casing could be set.

Variable length sections of threaded and coupled, six inch diameter, #19 (i.e. 19 lbs/ft) steel well casing (equipped with a steel drive shoe) were assembled and lowered into the bore hole to the top of bedrock. Once assembled, the casing string was then driven into the bedrock pilot hole using an air hammer. The casing was then sealed to the bedrock surface by the emplacement of a cement/bentonite grout which was pumped to the bottom of the boring via tremie pipe. At most of these locations the tremie pipe was set in the annular space between the casing and the wall of the borehole with the discharge end of the tremie tube at the bottom of the boring. Partial collapse of the borehole and/or subsequent swelling of unsaturated overburden clay layers created borehole constrictions at several of the drilling locations. This condition prohibited the placement of tremie pipe outside the casing. In these instances, the tremie pipe was set at the bottom of the boring inside the casing. The casing was then suspended several feet above the bottom of the pilot hole while grout was pumped to the bottom of the boring, displacing the drilling mud upward.

Following placement of the grout in this manner, the interior of the casing was pressurized with water to force the grout out the bottom of the casing and up the annular space to ensure an adequate grout seal. The casing was then driven back to the bottom of the pilot hole to complete the seal. Approximately 3 feet of casing was left above the ground surface at all locations to provide above-grade access to the well.

After allowing the grout seal to harden (generally at least 48 hours) all drilling mud was flushed from the casing with fresh water. A 5 inch diameter, carbide studded, downhole air hammer was then lowered inside the casing to the top of bedrock to commence rock drilling. Generally, the rock drilling was conducted in ten foot intervals. After each interval the boring was blown with air (from the bottom) to purge the borehole and casing of drilling water and to assess the yield of the well. The estimated yield was based on the amount of formation water forced up and out of the casing by the injection the compressed air. When the well was judged by the on-site geologist to be producing adequate water for the purposes of conducting a pumping test, drilling was terminated. The use of compressed air to estimate the well's yield also served to develop the bedrock formation.

The Work Plan specified that well B141 be cored and then reamed to accommodate the eventual installation of a submersible pump. Since the water bearing capacity of the rock formation would be first estimated during the development of the well (using compressed air) and ultimately determined from pilot pumping tests, there was no advantage to coring and then reaming the rock hole. This change represents a deviation from the proposed Work Plan; however, it was considered the most effective and efficient use of time and equipment and did not adversely impact the program.

Attempts to develop well 203B using compressed air resulted in fine sand and silt infiltrating and filling the borehole to the approximate depth of the bottom of the casing. To control siltation, 30 feet of 4 inch diameter PVC wire wound screen (0.01 inch slot) was set at 190 feet below the ground surface (i.e. 1.5 feet above the bottom of the borehole). The top of the screen came to the bottom of the steel casing (160 feet below the ground surface or 3 feet below the top of the bedrock surface). A silica sand filter pack was installed to a depth of 167 feet below the ground surface so that 23 feet of screen remained exposed to the bedrock formation. A 10 foot thick hydrated bentonite seal was placed on top of the sand pack to seal the screen from the suspected source of siltation (believed to be fine sand and silt bearing fractures located within the top few feet of the bedrock). Following the installation of the screen and filter pack, well 203B was successfully redeveloped by surge-pumping and overpumping with a 3 inch diameter submersible pump.

Upon completion of each bedrock well, a concrete surface seal and a lockable steel cap was installed. Well construction diagrams for all bedrock wells are presented in Appendix G.

2.6.6.2 Overburden Wells

Borings B142 and B139I, and Piezometer clusters B203A1-4 and B204A1-4 were installed within the overburden. Boring B142 was completed as a four-inch diameter, fully penetrating overburden pumping well. The boring was completed using drive and wash drilling techniques. Due to the anticipated depth of this well (164') and the requirement to set a four inch diameter well (and associated sand pack) the boring was telescoped starting with a 12 inch diameter roller bit and fresh water as a drilling fluid. The 12 inch roller bit was initially advanced to 48 feet below grade level (BGL). At that point, 10 inch diameter, butt welded, steel casing was lowered into the boring and seated at a depth of 42 feet BGL. A 9.825 inch diameter roller bit and an under-reamer bit were then used inside the 10 inch casing to advance and set eight inch diameter, flush joint (threaded) casing at 106 feet BGL. Using the under-reamer bit, 6 inch diameter, flush joint (threaded) casing was then telescoped inside and advanced beyond the bottom of the 8 inch casing and set at a depth of 161 feet below the ground surface. An open hole was drilled to the top of bedrock (164 feet BGL) into which the well was subsequently set.

Well B142 was constructed using 150 feet of four inch diameter, wire-wound stainless steel screen (0.010 inch slot width) set at 164 feet BGL. A sufficient length of 4 inch diameter stainless steel riser pipe was attached to the screen to bring the top of the well to a height of approximately 3 feet above the ground surface. After assembling and setting the well at 164 feet

BGL, a filter pack consisting of #OON grade silica sand was placed inside the annulus between the screen and the casing. As the sand pack was installed (2 to 5 foot lifts) the casing was pulled up to expose the filter pack to the natural formation. After the sand pack was installed to a depth of 2 feet above the top of the screen, a 2.5 foot thick hydrated bentonite seal was placed in the annulus. All casing used to telescope the well was removed except for 10 feet of 10 inch casing which was cemented in place to serve as a protective casing for the well. Finally, the well was equipped with a lockable steel lid and a concrete surface seal/work pad was poured.

After allowing a post-installation stabilization period of approximately two weeks, well B142 was developed using compressed air. During development, all water and fine sediment removed from the well was containerized and screened with a PID prior to disposal. A well construction diagram for B142 is provided in Appendix G.

In order to monitor drawdown in the immediate vicinity of well B142 (the overburden pumping well) two clusters of overburden piezometers (B203A1-4 and B204A1-4) were installed approximately 10 feet northwest and 35 feet northeast of well B142, respectively. Each cluster consists of four separate one inch diameter piezometers installed at the corners of an approximate four foot square. This configuration represents a departure from the Work Plan, which specified that these sets of piezometers would be installed as a bundle within a single boring. As approved during subsequent discussions with the EPA, it was agreed that four separate piezometers installed (as described below) in separate borings within several feet of each other would: 1) serve the same function as four piezometers installed in the same boring, and 2) represent the most efficient use of time and materials.

Each overburden piezometer is constructed of 1 inch diameter, schedule 40, PVC screen and riser. The screens on all piezometers are 2 foot long with 0.01 inch machined slots. As shown in Figure 2-23, the four screened intervals within each cluster are evenly spaced from just above the top of the bedrock surface to approximately 10 feet below the groundwater surface. The piezometer label suffix number (1 through 4) indicates it's relative depth with "1" being the deepest and "4" being the most shallow.

The three deepest piezometers at each cluster were installed using mud-rotary drilling techniques to advance and set 4 inch diameter steel casing to within 10 feet of the anticipated screen depth. Once the casing was set and flushed clean of drilling mud, drive-and-wash drilling techniques (using fresh water) were used to wash out and advance the casing to the desired screen depth. The screen section was then installed at the desired depth (at the bottom of the casing) and a silica sand filter pack was installed around the screen. A minimum two foot thick hydrated bentonite seal was emplaced on top of the sand pack and the remainder of the borehole was grouted with a bentonite slurry. The construction of the two shallowest piezometers (number "4" at each cluster) was the same as that described for the deeper ones, however, the relatively shallow depths allowed these two piezometers to be installed using hollow-stem augers rather than casing. Well construction diagrams are provided in Appendix G.

In order to determine the influence of pumping (i.e. drawdown) in the distal sediment, an intermediate depth overburden monitoring well (B139I) was installed within the existing B139 cluster, approximately 400 feet northeast of IWS 2. In addition to allowing the installation of a monitoring well, this boring was also used to obtain a total of six undisturbed soil samples for eventual laboratory testing for shear strength.

Well B139I was installed using hollow stem augers and drive and wash drilling techniques to advance four inch diameter casing to the desired screen depth. Undisturbed soil samples were collected at six depth intervals during the course of the boring. The well was constructed using two inch diameter, schedule 40 PVC well materials, typical of many of the monitor wells previously installed at the site. A ten-foot long screen section (0.01 inch slot) was set at a depth of 70.1 feet below the ground surface. A silica sand filter pack was then emplaced to a height of approximately 4 feet above the top of the screen. A 2.7 foot thick hydrated bentonite seal was then installed above the filter pack and the remainder of the borehole annulus was grouted with portland cement. The well was furnished with a lockable, steel, protective casing and a concrete surface seal/work pad. The construction diagram for well B139I is shown in Appendix G.

Following an approximate two week stabilization period, well B139I was developed by overpumping with a pneumatic "arch" pump. All sediment and water removed from the well were screened with a PID prior to disposal.

2.7 AIR QUALITY

As discussed in Section 8 of the Phase 1A Work Plan, two rounds of air quality monitoring were performed as part of the Phase 1A Field Investigations. In addition, asbestos monitoring was conducted during the excavation of test pits and measurements of methane concentration were collected from combustible gas wells during Phase 1A. The first round of air quality monitoring was completed prior to the commencement of field activities. The second round was completed after all drilling activities had ceased. The results of the air quality surveys and combustible gas well measurements are presented in Section 4.1. The results of the asbestos monitoring during test pit excavation is presented in Section 2.7.3.

2.7.1 Air Quality Monitoring

Potential emissions were monitored using various field measurement instruments, which can detect methane, VOC, hydrogen sulfide, hydrogen cyanide, and respirable dust. In addition, 8-hour continuous sampling for VOC and asbestos was conducted at selected locations.

The surveys were conducted at a height of 3 to 6 inches above ground level utilizing visual observations and direct monitoring instruments (OVA, HNu/PID, specific continuous monitors for hydrogen sulfide, hydrogen cyanide, and respirable dust). The perimeters of IWS-1, IWS-2 and IWS 3, as well as the perimeter of the SWDA, were slowly walked while taking simultaneous readings. Additionally, readings were taken while slowly walking across the IWS Areas and non-active areas of the SWDA. These measurements were taken once in a north-south direction and, in addition for the IWS areas, once in an east-west direction. For the SWDA, measurements were taken four times, equally spaced along the SWDA in the east-west direction. Figure 2-20 shows the Monitoring Survey Paths for the continuous air monitoring surveys.

Given the nature of the potential contamination at the Landfill, the difference between the OVA reading and the HNu/PID reading, most likely, represents methane since the HNu/PID will not detect methane but will detect other VOC, and the OVA will detect both methane and other VOC. At selected locations, as described in the Phase 1A Work Plan, direct reading detector tubes for benzene and vinyl chloride were collected.

VOC 8-hour samples were collected as described in the Phase 1A Work Plan, using carbosieve 300 tubes, and submitted to the laboratory for analysis by EPA Method TO-2. High volume asbestos samples were also collected and submitted to the laboratory for analysis. Asbestos was sampled and analyzed as described in the Phase 1A Work Plan, according to the EPA Asbestos Hazard Emergency Response Act (AHERA) protocol. At IWS 1, IWS 2, and IWS 3, two samples were collected at the perimeter of each IWS Area. Two samples were collected at the north end of the SWDA, at the property line adjacent to the trailer park, spaced 500-800 feet apart. One sample was collected at the large leachate seep area located on the northeast side of the SWDA. Two samples were collected at the road on the south side of the SWDA, spaced 500-800 feet apart. A final sample was collected on the surface of the SWDA, approximately in the center. Figure 2-20 shows the air quality sampling locations indicated in green. In addition, at one location for asbestos and for VOC, co-located samples were collected and submitted to the laboratory for analysis for VOC and asbestos as described above.

Both the asbestos and VOC samples were collected using DuPont Alpha I sampling pumps. The flow rates for the TO-2 tubes were maintained with limiting orifices, to collect a sample volume of 6 to 7 liters during the approximate eight hour sampling period. The flow rate of each tube was checked at the beginning and end of the sampling period. Backup tubes were not used because of the anticipated low concentrations being sampled. Flow rates were set to protect against loss of the compound with the lowest retention volume (vinyl chloride). Duplicate tubes were collected for each VOC sample to provide analytical redundancy. The tubes with the largest air volumes were generally analyzed. The asbestos samples were collected at a flow rate of 3 to 4 liters per minute for approximately eight hours. The flow rate and sampling time was adjusted and maintained to collect the total sample volume of 1,200 to 1,800 liters as recommended by AHERA for TEM analysis. The sample air volumes for the VOC and asbestos sample tests are listed in Table 2-16.

The first round of sampling was completed on May 24, 1991 for VOC and on May 25, 1991 for asbestos. The second round of sampling was completed on September 5, 1991 for VOC and on September 6, 1991 for asbestos. However, the VOC samples exceeded the maximum holding times at the laboratory. The EPA was notified and the VOC sampling was repeated on October 29, 1991.

Meteorological conditions were measured on the days that air quality samples were collected. Each day ESE collected temperature, barometric pressure, and relative humidity data from the continuous-recording meteorological station. During the first round of sampling, the meteorological station at the Darling Hill Dump Superfund Site was used. During the second round of sampling, the meteorological data was collected at the Parker Site. Additionally, ESE installed, on the surface of the SWDA, a pole equipped with a wind ribbon and an analog wind direction and wind speed indicator. Measurements of wind speed and direction were recorded every 2 hours during air sampling events.

2.7.2 Combustible Gas Monitoring

Combustible gas (CG) monitoring wells were installed at locations B111 and B112 as shown on Plate D, as set forth in Section 8.4 of the Phase 1A Work Plan. The CG monitoring wells consisted of two-inch inside diameter flush joint schedule 40 PVC perforated screen with 0.25-inch perforations, threaded to riser pipe of similar manufacture and dimension. The screen and riser were installed above the groundwater table within an augured borehole. Screened intervals extend to depths of 25 ft., coincident with the anticipated bottom of the SWDA. At B112, a ten-foot screen (15-25 ft.) was installed. At B111, a large portion of the borehole passed through trash material. In an attempt to screen as much of the trash as possible, a screen was installed from 5-25 ft. A washed gravel filter pack (0.25-inch diameter) was placed in the annulus between the borehole and the well from the bottom of the well to a height of two feet above the screen. A two-foot thick bentonite seal was then placed immediately above the gravel pack. The remainder of the borehole was grouted with a bentonite and cement grout to the ground surface. At B111, where only 5 feet remained between the top of the screen and the surface, a bentonite seal was not installed and the borehole was grouted with bentonite and cement. Each CG monitoring well was protected at the ground surface with a cement pad and a locking steel guard pipe. The riser pipe of each well is equipped with a modified PVC slip cap. The PVC slip caps were modified by drilling a 3/8 inch hole in the center of the cap and installing a rubber "O"- ring and wooden dowel. Well construction details are shown on Combustible Gas Monitoring Well Installation Reports, provided in Appendix G.

Existing dry groundwater monitoring wells MW11, MW12, and VT1 were converted into additional CG monitoring wells by modifying their PVC slip caps as described above. Combustible gas readings were obtained from each CG monitoring well on July 19, 1991, July 25, 1991, and November 11, 1991, using a MSA Model 361 combined LEL, oxygen, and hydrogen sulfide meter. The results of this screening are presented in Section 4.1.1.

2.7.3 Asbestos Monitoring During Test Pits

During the excavation of test pits at IWS 1, 2, and 3, asbestos samples were collected using DuPont Alpha 1 pumps, 25 millimeter, pre-banded, 0.8-micron, mixed-cellulose ester (MCE) filter cassettes, and analyzed according to the NIOSH Method 7400. The analysis method determines total airborne fibers. Non-asbestos fibers, such as glass, cotton, and cellulose, would also be counted by this method and included in the total fiber count results.

Test pit excavation at each IWS area did not span an eight hour period as anticipated. To assure a detection limit of 0.01 fibers/cc, separate samples could not be taken for each four hour period as described in the Phase 1A Work Plan. However, a total of five samples were required and taken for each IWS area using separate pumps. The samples include two sets of area samples plus one personal sample attached to the ESE geologist conducting the test pit sampling. The area sample collection was conducted outside of the exclusion zone to monitor ambient airborne fiber concentrations. The monitoring results were used to determine the potential for exposure to the field team and to monitor and document any potential for off-site fiber migration. All samples were collected at breathing zone height about five feet above ground surface. The area samples included sampling locations down wind of the test pit area, as set forth in the Work Plan.

On May 22, 1991 at IWS 1, five area samples and one personal sample were collected. The total fiber concentrations of the six samples ranged between <0.01 to 0.03 fibers/cubic centimeter (f/cc) of air.

On May 23, 1991 at IWS 2, five area samples and one personal sample were collected. The total fiber concentrations of the six samples ranged between <0.01 to 0.02 f/cc of air. On May 24, 1991 at IWS 3, five area samples, and one personal sample were collected. The personal sample fell off of the geologist during the operation. The sample was assumed to be contaminated and discarded. The total fiber concentrations of the five area samples ranged between <0.01 to 0.02 f/cc of air.

The eight hour OSHA Permissible Exposure Limit (PEL) for asbestos is 0.2 f/cc. The OSHA Action Level (AL) for asbestos is 0.1 f/cc. The AL is the level that would trigger the requirement for an asbestos medical monitoring program. The highest total fiber level detected during this activity in the test pitting area was 0.03 f/cc. The highest result was less than one third of the AL. All personnel in the exclusion area wore Level B respiratory protection during test pitting.

The test pits were several hundred feet from the boundary of the Landfill and the substantial dilution capacity of wind as dust and possible fibers are transported make it unlikely that detectable quantities of fibers would exist off-site.

2.8 SURFACE WATER AND SEDIMENT INVESTIGATION

Samples of surface water and sediment were collected from the unnamed stream which crosses the eastern portion of the Study Area. Sampling locations are shown on Figure 2-21. Two rounds of sample collection were undertaken during Phase 1A. Collection and analysis of surface water and sediment samples were conducted as set forth in Section 9 of the Phase 1A Work Plan, unless a deviation is indicated below. Results of the surface water and sediment sampling rounds are provided in Section 4.3.

2.8.1 Round 1 Sample Collection

Surface water and sediment samples were collected between May 10 and 14, 1991, from the eleven locations shown on Figure 2-21 (400 series). Table 2-17 shows the samples collected and the analyses performed, and the percent solids measurements for sediment samples. Samples from Location 402 did not meet the 30% solids criteria set forth in the Phase 1A Work Plan. Location 402 has sediment very high in organic content (i.e., peat) and is extremely spongy. Reasonable attempts were made to collect a sample sufficiently free of water, despite the nature of the material. EPA was notified of the deviation, upon receipt of the laboratory data. All other sediment samples met the criteria.

As shown on Table 2-17, sediment samples were tested for a set of physical parameters, which included total organic carbon (TOC). Analysis for TOC was to be performed by the analytical laboratory. However, due to a laboratory miscommunication, TOC analysis was not performed. EPA was notified of this deviation.

2.8.2 Round 2 Sample Collection

Upon receipt of the validated data for the Round 1 analyses of surface water and sediment samples, ESE, on August 9, 1991, submitted a letter report to EPA presenting the results and recommending a scope of work for the second round sampling. By a letter dated August 23, 1991, EPA approved the second round sampling program. Surface water and sediment samples were collected on September 11, 1991, from sample locations 402, 405, 406, 407, and 408. Table 2-18 shows the samples collected and the analyses performed, and the percent solids measurements for sediment samples. As discussed above, sample location 402 presents significant problems relative to collection of a sediment sample which meets the 30% solids criteria. As can be seen on Table 2-18, the samples collected from Location 402 again failed to meet the 30% criteria. All other samples were well above the 30% solids requirement. Sediment samples were analyzed for physical parameters, including TOC and grain-size distribution.

2.9 ECOLOGICAL STUDIES

As discussed in Section 10 of the Work Plan, an ecological assessment was conducted to determine the adverse effects, if any, to biological receptors, resulting from the presence of the Landfill, or constituents therein. A wetlands study and delineation was performed as part of the LFI in the fall of 1990. A wetlands delineation was included in the Phase 1A Work Plan. A field survey of the wetland habitat was performed by an ESE environmental toxicologist in June of 1991 and a preliminary ecological assessment (Tier I) was completed. The purpose of the Phase IA preliminary ecological assessment (Tier I) was to perform a qualitative evaluation of the wetlands adjacent to the Parker Landfill and a quantitative evaluation of the physical and chemical data to determine if additional ecological field studies were necessary. The preliminary ecological assessment considered the data generated from the surface water/sediment sampling, as a measure of impacts on the ecology around and in the unnamed stream which flows through the study area. Similarly, the ecological investigation considered the results presented in the wetlands report.

Based upon the results of the first round of surface water and sediment sampling and the preliminary ecological assessment (Tier 1), it was recommended in the August 9, 1991 letter report (discussed above in Section 2.8), that further ecological field studies be limited to monitoring changes in water quality (pH, D.O., temperature, specific conductance, and surface water discharge measurements). EPA approved this approach in a letter dated August 23, 1991.

On August 20 and October 12, 1991, an ESE environmental toxicologist conducted a water quality and benthic macroinvertebrate study.

Water quality measurements were taken during the months of August and October. Dissolved oxygen (DO) and temperature were measured using a YSI Model 58 Dissolved Oxygen meter (calibrated to atmospheric oxygen as 100%). Conductivity was measured using a YSI 3000

Conductivity Meter (calibrated with standard solutions). pH was measured using an Orion SA-230 pH meter calibrated to standard buffer solutions. Oxidation/Reduction Potential (ORP) was measured using a Cole-Palmer pocket tester, calibrated using pH 4 and pH 7 buffer solutions saturated with quinhydrone (Δ 263 mV).

The evaluation of habitat, using USEPA Rapid Bioassessment Protocol (RBP), was initiated but subsequently abandoned because of the strong degree of similarity between habitat parameters for each station. For every station, flow, bottom substrate, embeddedness, poor riffle/run ratio, bank stability, and bank vegetation stability were identical. Only streamside cover varied, but only to a very small degree.

The evaluation of benthic macroinvertebrates was conducted using eight separate artificial substrate (rock basket) samplers. These were placed in Stream 1 (Figure 2-22) for a total of seven weeks. Three (BS-01, BS-02, and BS-03) were placed upstream of the confluence of Stream 1 and 2, and five (BS-04, BS-05, BS-06, BS-07, and BS-08) were placed downstream of the confluence (Figure 2-22). Care was taken to insure that each sampler was placed in a shallow depression to insure submergence should an unanticipated dry period occur. Each substrate was retrieved by moving it immediately into a wash bucket placed in a downstream position. The rocks were gently brushed and the resulting debris was screened, fixed in 70% ethanol/0.01% rose bengal, and placed in a pre-labelled Nalgene container. Each sample was then transported to the laboratory, split, and sorted. Subsamples were sorted under a dissecting microscope.

A WET II analysis was also performed for the Study Area and is discussed in detail in Section 4.4.5.

2.10 LONG-TERM MONITORING

As described in Section 13 of the Phase 1A Work Plan, a Long-Term Monitoring program was initiated to monitor residential drinking water sources which might be impacted by contaminants migrating from the Landfill. Ten selected residential drinking water sources were sampled and analyzed on a quarterly basis during the Phase 1A Field Investigations. Samples were collected from the residences identified on Table 2-19.

Two rounds of samples were collected from each residence during the Phase 1A field work. A set of samples was collected on June 26, 1991, and submitted for analysis, as set forth in the Phase 1A Work Plan. A second set of samples was collected on October 15, 1991. Collection of the second set of samples was delayed at EPA's request. Analysis of the samples from the second set was performed by a modified method. As discussed with EPA, these analyses were performed by a modified method, because of instrument problems encountered by the laboratory. The instrument calibrated and configured for analysis of samples by EPA Method 524.2 was not operational for an extended period. Because of this, the Long-Term Monitoring samples were not going to be analyzed within the required holding time. In order to avoid losing the data, ESE instructed the laboratory to proceed with the analysis using a modified Method 624. Analyses of samples R601C-I or R601D-I exceeded the required holding time.

Method 624 differs from 524.2 in that a different compound list is used, a larger purge volume is used, slightly different instrument conditions are used (i.e., a different column), and the detection limit is normally higher for Method 624. Both methods rely on GC/MS as the method of instrument detection and quantitation. Aquatec modified Method 624 by increasing the purge volume and thus lowering the detection limit to 1.0 ug/L. There are nine compounds on the Method 524.2 list which were not measured using the Method 624 instrument parameters. These were shown as NA (not analyzed) on the report sheets. None of these compounds has been detected in any previous residential well analyses. There are fifteen compounds for which the modified Method 624 does not include calibration standards. However, all of these compounds would be detected, if present, using the modified Method 624 instrument parameters. Only one of these compounds has been routinely detected in previous residential well sample analyses. Extra-peak searches were performed on all samples to determine if any of these compounds were present in the samples. When present, the concentration was estimated using a response factor of 1.0 and the sample result flagged. When not detected, the compound was shown as ND (not detected). All remaining compounds on the Method 524.2 compound list were quantitated and the value measured, or the detection limit, shown on the laboratory data sheets.

2.11 ACTIVE LANDFILL OPERATIONS

The Phase 1A Work Plan, in Section 8 of the Site Management Plan, sets forth a set of requirements for activities to be performed because of the continued operations of the SWDA during the Phase 1A Field Investigations. This section discusses the activities performed during Phase 1A to meet those requirements.

2.11.1 Security of RI/FS Investigations

Due to the ongoing activities at the SWDA, the Phase 1A Work Plan set forth requirements for protection of groundwater monitoring wells in and around the Landfill. Wells installed at the IWS Areas and around the perimeter of the SDWA during the RI were protected from accidental damage from vehicle or heavy equipment traffic by the installation of guard pipes and barriers. Guard pipes and barriers were constructed from six-inch well casing, welded and cemented into place to provide a substantial barricade.

2.11.2 Characterization of Incoming Wastes

ESE provided log-in forms to Respondent Ray O. Parker & Sons to allow for maintaining records of the nature of incoming wastes. ESE has questioned representatives of Ray O. Parker & Sons as to the use of the forms and requested that completed forms be sent to ESE. ESE has reviewed the forms and assured they were being used. However, to date, no forms have been submitted to ESE.

2.11.3 Delineation of Horizontal Extent of the SWDA

On April 2, 1991, representatives from EPA, VTDEC, and ESE met with Mr. Parker at the SWDA to discuss the appropriate location of monuments to delineate the horizontal boundaries of the SWDA. Based upon those discussions, ESE installed monuments at approximately 500 foot intervals around the perimeter of the SDWA. Monuments were constructed of ten-foot long, six-inch diameter steel well casing driven five feet below ground surface and filled with concrete. Monuments were painted with bright orange paint to increase visibility. The position of each monument has been surveyed relative to the Phase 1A survey grid system and are shown on Figure 2-4.

2.12 WELL INSTALLATION INFORMATION ON PRIVATE WELLS ON RED VILLAGE ROAD

At the request of EPA, ESE contacted ten homeowners having private drinking water supplies, located on Red Village Road southeast of the Curran residence, to gather information on private wells (Plate D). Responses were received from four of the property owners. Table 2-10 presents well construction data on six of the ten residences (Clark Sr., Burrington, Heywood, Tripp and the Red Village School) located in the area of interest. The Clark Sr. bedrock well also serves the Clark Jr. home. The Heywood well serves two residences owned by the

Heywood brothers. Repeated attempts to get information from the other three residences have been fruitless. Telephone discussions with the Vermont Department of Environmental Conservation did not reveal well construction data for these residences/businesses. Clark Sr. has indicated that a spring on his property supplies five additional residences. This information has not been confirmed, but if accurate would account for the final four of the ten residences (Sackett, Berry Tire, Houghton, and Berry). The five wells presented on Table 2-10 are bedrock wells. The following well yields were reported for the indicated wells:

Heywood	6 gpm
Burrington	30 gpm
Clark	8 gpm
Tripp	never measured
Red Village School	21 gpm

2.13 SOIL SAMPLING FOR GEOTECHNICAL EVALUATION

During the Post-Screening Field Investigations, soil samples were collected for geotechnical testing for two purposes: 1) to determine the strength characteristics of typical unconsolidated materials beneath the Landfill as pertains to support of a cap, and 2) to determine the permeability of the distal material as pertains to its suitability as cover material for the cap.

2.13.1 Strength Properties

A total of six undisturbed soil samples were collected from B139I, while the casing was being advanced, for testing for shear strength. These samples were collected in accordance with ASTM Method D 1587, wherein a thin walled tube (i.e. a Shelby tube) was pressed into undisturbed soil at the bottom of the boring. After waiting a suitable amount of time to allow the buildup of skin friction between the inside walls of the sampler and the soil, the tube was retrieved. Both ends of the tube were fitted with plastic caps and sealed with paraffin wax to preserve the natural moisture or pore water collected with the sample. Shelby tubes were collected at B139I from the following intervals (given in feet below the ground surface): 35-37; 50-52; 60-62.5; 62.5-65; 65-67.5; and, 71-73.5. All six tubes were sealed and shipped to ESE's Geotechnical Soils Laboratory located in Gainesville, Florida for shear strength testing in accordance with ASTM Method D 4767. These data were used in determining preliminary cap designs in the development of the FS and are discussed in the FS.

2.13.2 Soil Permeability

To determine the suitability of Study Area soils for potential use in the construction of a regulatory cap, bulk soil samples were collected and submitted to ESE's Geotechnical Soils Laboratory for determination of permeability in accordance with ASTM method D-5086. Additional tests performed on these samples included compaction testing (ASTM D-698), grain size analysis (ASTM D-422) and Atterberg limits tests (ASTM D-4318).

Composite soil samples (CS-1 through CS-3) were collected from three undisturbed areas located along the western perimeter of the SWDA. Two of these composite samples (CS-2 and CS-3) represent near surface soil collected from a maximum of 1.5 feet below the ground surface. Sample CS-1 is a composite derived from samples collected from the face of the cliff exposed from excavation activities and erosion. Each composite sample (approximately 55 pounds) was manually collected with a small hand shovel and stored and shipped in a sealed, five-gallon, plastic bucket. These data are discussed in, and were used during development of the FS.

3.0 PHYSICAL CHARACTERISTICS OF THE STUDY AREA

3.1 SURFICIAL GEOLOGY

3.1.1 Regional Physiography

To a large degree, the topography to the east of the Landfill is controlled by bedrock type. The more resistant Gile Mountain Formation forms the steep ridges which include Graves Hill and Shonya Hill (Figure 1-1). The Waits River Formation underlies a more subdued topography beneath and to the west and south of the Landfill. This area is characterized by more moderate relief where the lowest point is 680 ft. above mean sea level, at the Passumpsic River bed just south of Prospect Hill.

The highest point in the area is Shonya Hill, just northeast of the Landfill, with a summit elevation of 1,500 feet. Within the Passumpsic River Valley, two separate planar features exist. One, the Passumpsic River flood plain, which rises to several feet above the river, is located to the west of Lyndonville. The flood plain narrows to the south of the U.S. Route 5 bridge and then widens again just south of the intersection of Lily Pond Road and Red Village Road.

The second planar feature occurs at about 800 feet above mean sea level and stretches two miles from the confluence of the East and West Branches of the Passumpsic River, at its northern limit, southward to Brown Farm Road. This feature is not continuous, as it is deeply dissected at various points along its length. The Landfill is located within this feature. The areas around the Landfill, and east and southeast of the Landfill, are characterized as a hummocky terrain created through collapse of sediments as buried ice melted. Superimposed upon the natural topography are topographic lows created as a result of mining the glacial lacustrine sand deposits at the Landfill and surrounding area. Northeast of the Landfill is a gully that separates the hummocky terrain from the western flank of the ridge, underlain by the Gile Mountain Formation.

3.1.2 Surface Water Characteristics

The Passumpsic River is the major surface water feature in the Study Area. The river flows in a southerly direction. The East and West Branches of the Passumpsic River join just north of Lyndonville. The river has a wide flood plain as it meanders through Lyndonville. The flood plain narrows considerably, south of the U.S. Route 5 bridge. The Vail Power Dam lies just southwest of the junction of Lily Pond and Red Village Roads. The dam is seated into bedrock and is keyed into bedrock outcrops on both ends. The dam creates about a 20 foot drop in head, as the river continues south, where it ultimately discharges to the Connecticut River.

Lily Pond (Plate B), approximately three acres in area, is situated northwest of the Landfill. The pond has no perennial inlet or outlet. However, a small gully that captures local surface water runoff runs in a westerly direction from Lily Pond Road to Lily Pond. The pond, a kettle lake, is situated at a high elevation with respect to other nearby surface water bodies. A small potential wetland is located 900 feet to the northeast and about 63 feet lower in elevation. Three hundred and fifty feet southeast of Lily Pond is the headwater of an unnamed stream which is 24 feet lower in elevation than the pond. The difference in elevation suggests that Lily Pond is perched on an impermeable layer. Test boring data indicates the pond probably sits above a fine-grained, thinly bedded to thinly laminated glacial lacustrine silt/clay unit. This unit is discussed in detail in Section 3.1.4.

The unnamed stream discussed above is an intermittent stream which flows adjacent to the SWDA, IWS 3 and IWS 2 (as shown on Plate B). Piezometric head measurements from piezometers installed during the Phase 1A investigation indicate areas of the stream may be gaining or losing water from/to the groundwater table. The piezometer data are presented and discussed in Section 3.7.4.

To the south, this stream joins a larger stream as a tributary just south of IWS 2. During the Phase 1A and Phase 1B field programs, the unnamed stream was several inches deep north of the junction and consisted of a myriad of anastomosing streamlets contained within a 10- to 20-foot wide, flat bottomed stream bed. The southern stream drains the eastern uplands and was approximately one to two feet deep in April and May of 1991. The southern stream is contained within a narrow (three to five feet wide) incised channel. Further south, the combined stream joins a second stream. The second stream also drains the eastern uplands. This stream was observed to be approximately one to two feet deep in areas and contained within an incised channel approximately three feet in width. The surface water observed in both of the "upland" streams was clear, colorless, and free of sheens or odors. Conversely, the unnamed stream prior to the confluence contained water which was rust colored in places and showed a pleochroic sheen. Downstream from the confluence with the southernmost stream, the water in the combined stream was clear, colorless, and free of odors and sheens. The combined stream meanders in a southwesterly direction across the Riverside School property and discharges to the Passumpsic River at a point southwest of the Pine Knoll Nursing home.

3.1.3 Regional Surficial Geology

The surficial materials around the Landfill are predominantly of glacial origin and can be divided into four major classes; glacial till, glacial lacustrine sands and silts, esker sand and gravel, and recent alluvium. Plate E summarizes the current knowledge of surficial geologic conditions in the Study Area. Glacial till, characterized as an ablation till (MacClintock and Stuart, 1969) with a low percentage of fines (silt and clay), generally covers the upland areas and is commonly incorrectly referred to in the literature as Kame Terrace deposits. In the Study Area, surface exposures of the till deposits are limited to the higher elevations to the east of the landfill (generally above El. 850), where steep slopes are dominant. The planar area located between the eastern uplands and Lily Pond Road, in which the Landfill is located, is underlain by silty fine to medium sand of glacial lacustrine origin (MacClintock, open-file Report; Vermont Highway Department, 1966). The area west of Lily Pond Road is predominantly underlain by glacial lacustrine silt and sand, esker and/or eskerine deposits. Alluvium is limited to the flood plain of the Passumpsic River, immediate vicinity of streams, and small alluvial fans associated with intermittent drainage channels. Due to the close affinity of the alluvial deposits and the Proximal glacial lacustrine deposits, these two units are extremely difficult to distinguish in test boring soil samples. Therefore, alluvium and Upper Proximal glacial lacustrine deposits have been incorporated as one Proximal for the preparation of geologic cross-sections.

Published surficial geologic data indicate that the Passumpsic River Valley and Connecticut River Valley were occupied by Glacial Lake Connecticut and are predominantly underlain by glacial lacustrine deposits, bounded to the east and west by Ablation Till and/or Kame Terrace deposits. In the Lyndonville area, two glacial advances from the northwest (earlier) and northeast (later) eroded valleys in the bedrock and deposited glacial sediments. The last advance resulted in the formation of a parabolic-shaped terminal moraine just north of Lyndonville, referred to as the Lyndonville Moraine. In the Study Area, eskers formed along the river valley during the preceding glacial advance. One esker extends 25 miles from St. Johnsbury northward through Lyndonville to East Haven. Glacial melt water deposition in the Study Area resulted in the formation of glacial lake sediments within the Passumpsic River Valley. The glacial lacustrine deposits generally consist of well graded medium to fine sand to silty fine sand interbedded to interlaminated with silt and clay.

3.1.4 Local Surficial Geology

Four major surficial geologic deposits are of primary importance in the Study Area, as shown on Plate E. These deposits are esker deposits, an esker delta deposit, Proximal glacial lacustrine deposits, and Distal glacial lacustrine deposits. An esker is located just beyond the western limit of the Study Area. The esker extends in a general northerly direction from a point on the western side of the Passumpsic River immediately west of the Vail Dam and dives below the river bed and re-emerges on the eastern side of the river immediately northwest of the Pine Knoll Nursing Home.

From this point the esker extends in a northwesterly direction and climbs to a maximum elevation of approximately 920 feet at a location 2,000 feet due west of the Landfill. The esker deposits consist of coarse to medium sand, gravel, and cobbles in graded and cross-bedded imbricated channel deposits, bounded by cross-bedded coarse to medium sand. Flow direction indicators such as cross-bedding patterns, horizontal grading, and imbrication indicate flow direction of glacial melt waters was toward the southwest, south, and southeast. Melt water flow along the eastern flank of the esker was toward the southeast.

Proximal glacial lacustrine deposits abut the eastern flank of the esker and extend eastward to the bedrock cored uplands on the eastern side of the SWDA. The Proximal glacial lacustrine deposits, from hereon referred to as Proximal Deposits, consist of massively to thinly bedded medium to fine sand and silty fine sand. Coarser units of coarse to medium sand were encountered at several test boring locations. These deposits are massive to thinly bedded. Coarser units commonly exhibit fining upward sequences and cross-bedding.

The Proximal Deposits are extensive throughout the Study Area and underlie the SWDA and IWS Areas, as shown on Plates F through L. The locations of the geologic cross-sections presented on these plates are shown on Plate E. These deposits thicken toward the west and south and are generally indicative of deposition of glacial sediments within a moderately low energy lacustrine basin by melt water currents flowing in an easterly and southerly direction. Bedding planes within these deposits are exposed in cliff faces along the western boundary of the SWDA and appear to dip toward the southeast. These deposits apparently pinch out in an easterly direction against the underlying bedrock, which rises steeply toward the eastern highlands. The Proximal deposits are coarser (coarse to fine sand, variable gravel) in the vicinity of B119 and B120 due to their proximity to the esker. The grain size within the unit decreases in an easterly direction from Lily Pond Road and a northerly direction from Brown Farm Road. The Proximal deposits are interfingered with Distal Glacial Lacustrine Deposits, as shown on Plates F through L.

The distal glacial lacustrine deposits are overlain everywhere, except in excavated cliff faces, by proximal glacial lacustrine deposits and, therefore, are not shown on Plate E. Distal glacial lacustrine deposits consisting of thinly interbedded to thinly interlaminated very fine sand, silt, and clay overlie the basal Proximal and in turn are overlain by surficial (Upper) Proximal deposits. The Distal are varved at some test boring locations. These deposits are indicative of deposition of glacial sediments within a very low energy lacustrine environment. The low energy level of the depositional environment may have been the result of increasing water depth or simply increasing distance from the mouths of distributary channels extending eastward and southward from the esker. The interstratification of the Proximal and Distal immediately beneath the SWDA and IWS 2 suggest the latter interpretation is the case in the Study Area. As shown on Plates F through H, K, and L the Distal Deposit is interpreted to exhibit maximum thickness immediately beneath the SWDA and decreases in thickness radially away from the SWDA. The Distal deposits pinch out against bedrock along the eastern margin of the study area (Plates F and G). The Distal extends beyond the western boundary of the Landfill as indicated by its presence at B118 and the existence of Lily Pond. The existence of graded bedding strongly resembling turbity current deposits (incomplete Buoma Sequences) within the Distal, in borings within and adjacent to IWS 2, indicates proximity to a steeply dipping deposit of slightly coarser and less cohesive sediments such as Proximal deposits on the flank of an inferred esker delta deposit.

Where exposed at the ground surface, the Distal generally forms steep slopes and is highly cohesive. Thin interstratification of Proximal and Distal deposits near the northern boundary of the SWDA (Plate K and L) indicates the approximate northeasterly limit of the very low energy environment. Distal deposits are not seen at the surface or in test borings south of IWS 2 and boring B131.

A relatively narrow (250 feet) deposit of thickly to thinly cross-bedded coarse to fine sand and fine gravel in upward fining sequences extends in a general northwest to southeast direction from the vicinity of Lily Pond Road toward IWS 2 and B125, as shown on Plate E. This deposit is exposed in the cut face of a cliff bordering the southern limit of the SWDA. The deposit exhibits structural features indicative of deltaic deposits (i.e., topset, bottomset, and foreset beds) as well as aeolian-like features in the upper 10 to 15 feet of the unit. The unit appears to disrupt the Distal and likely provides an hydraulic connection between the Upper and Lower Proximal in this portion of the Study Area (Plates G and K). The northern contact between this unit and the Distal unit is exposed in a cliff wall immediately west of B113. The structural orientation of these two units indicates that the Distal unit pre-dates the inferred deltaic unit. This relationship and structural appearance of the deltaic unit suggests that this unit might represent an "Esker Delta Facies" as presented by Anderson(1989) and Thomas (1984).

The southern limit of the deltaic unit is not well defined but is interpreted to closely parallel the southern limit of a topographic high extending from Lily Pond Road to a point approximately 450 feet south of IWS 2, as shown on Plate E. The deltaic unit appears to pinch out against bedrock southeast of IWS 2. In the vicinity of IWS 2, the texture of the deltaic unit increasingly resembles the Lower Proximal unit.

The northwestern limit of this unit is not well understood but is interpreted to most likely extend in a northwesterly direction to the larger esker deposit, as shown on Plate E. At depth, this unit may extend as far southwest as B119.

A zone of regolith (extremely weathered bedrock that exhibits physical properties more akin to overburden deposits than to bedrock) was encountered immediately above the bedrock surface in borings B101, B104, B107, B115, B117, B123, B126, B127, and B135B (Figure 3-1). The regolith generally consists of coarse to fine sand, silt, little clay, and angular phyllitic gravel (locally derived from bedrock weathering) and generally occurs in downward coarsening units. The locations at which regolith was encountered generally fall along a line striking N54°E.

An ablation till was encountered in borings B103, B124 and B132 and generally consisted of coarse to fine silty sand with little to trace, gravel, and clay. Till is generally limited to the extreme eastern margin of the Study Area. Although similar in description to the "regolith", the ablation till exhibits a bonded texture, has less angular gravel fragments, and does not occur in coarsening downward units.

Historical information (VTDEC, 1985 and aerial photos dated 1962) indicates that sand deposits suitable for construction purposes (generally coarse to medium sand) were mined from the Landfill prior to its use as a solid waste disposal facility. Aerial photographs from 1962 indicate borrow operations were limited to a narrow area extending from the vicinity of B125 to a point immediately south of B138. This area is currently delineated by an access road extending from B125 northwesterly through B136 and terminating in the general vicinity of B138 (refer to Plate E). The borrow operations appear to have been concentrated within the "Deltaic". Borrow operations do not appear to have occurred in the immediate vicinity of the IWS Areas or SWDA prior to 1962. Borrow activities between 1962 and 1987 are not well understood or documented. However, based on the 1962 aerial photographs, borrow operations were most likely centered around generally northwest-southeast oriented melt water distributary channel deposits within the Proximal. Historical data indicated borrow activity in the immediate vicinity of the SWDA ceased when the coarser sand deposits were played out and nothing but silty fine sand, silt, and clay deposits remained. This information indicates the excavation preceding initiation of solid waste operations was most likely terminated in the locally extensive Distal, as shown on Plates F, G, and H. Aerial photographs from 1962 and discussions with Mr. Dean Parker indicate the area currently occupied by IWS 1, IWS 2, and the SWDA were previously characterized by natural hummocky terrain prior to initiation of the Landfill activities. Based on this data and casual observation of similar terrains north of the Study Area, surface erosion prior to landfill operations is likely to have eroded portions of the Distal beneath the Landfill and may have exposed windows of the Lower Proximal. A remnant of the Upper Proximal is located above the Distal along the entire length of the eastern access road, as shown on Plate F, G, H, J, and K.

3.2 BEDROCK GEOLOGY

The bedrock geology of the Study Area was extensively mapped during the 1950s and 1960s by Dennis (1956) and Woodland (1965). The bedrock mapping studies thoroughly addressed lithology, petrology, and structural geology of the Burke Quadrangle. A literature search did not reveal bedrock geologic study data since 1965.

Based upon the mappings, the Study Area is underlain by two formations interpreted to be late Silurian in age. The two formations are the Waits River Formation and the Gile Mountain Formation. The Waits River Formation consists of a quartzose limestone/phyllitic limestone member and an amphibolite member. The Gile Mountain Formation consists of a quartzose phyllite. The contact between the two formations is inferred to be gradational and located immediately east of the SWDA. The literature defines the contact as the point where the proportion of siliceous phyllite beds exceeds the proportion of calcareous phyllite beds. The contact is inferred to trend in a north-northeasterly direction (as shown on Figure 3-2). The Gile Mountain Formation is generally believed to be older than the Waits River Formation. On a regional scale, the geology remains uniformly the Waits River Formation to the west for nine miles. To the east, the geology is more complicated as the Gile Mountain Formation changes to a complex of Gile Mountain and granite.

Locally, two bedrock exposures of the Gile Mountain Formation are present: one along Brown Farm Road above elevation 920 and one at elevation 770 on the southwesterly flank of the ridge located northeast of the Landfill, approximately due east of B114. The Gile Mountain Formation is generally more resistant to weathering and erosion and generally underlies the topographically higher areas east of the Study Area, which are bedrock cored features. Siliceous phyllite inferred to be of the Gile Mountain Formation was encountered in borings B122, B125, B127 and B139 at elevations of 642, 638, and 607, and 655 feet respectively. An outcrop interpreted as Gile Mountain Formation is also located in the major bend of the Passumpsic River located south of B127 (El. 680). Inspection of outcrop exposures and bedrock cores from the Gile Mountain and Waits River Formations indicates that the Gile Mountain Formation is much more fractured than the Waits River Formation and may serve as a preferential migration pathway for groundwater.

Outcrops of the Waits River Formation (amphibolite member) were observed at an elevation of 800 feet along Brown Farm Road. Outcrops of the calcareous phyllite were observed along Red Village Road south of the junction of Red Village Road and Brown Farm Road (El. 707 to 733). Additional outcrops were observed along the Canadian Pacific Railroad easement and adjacent to the Vail Power Dam (El. 680 TO 690), as shown on Plate E. The Waits River Formation also outcrops west of the Pine Knoll Nursing Home on the west bank of the Passumpsic River and at the foot of Prospect Hill (El. 700). The less resistant Waits River Formation underlies the topographically subdued areas of the Study Area. Bedrock of the Waits River Formation was encountered in twenty test borings at elevations ranging from 561.9 to 723.39, as shown on Figure 3-4. Locations of borings where siliceous, calcareous, or a combination of both were encountered are shown on Figure 3-4. Siliceous phyllite was present overlying calcareous phyllite in boring B107 and was encountered in only one 10 foot interval of rock core of a 280 foot run in boring B126. Boring logs are provided in Appendix E.

Bedrock Structure

Published structural geologic data indicate the contact between the Gile Mountain Formation and Waits River Formation is complex in the Study Area and the bedrock in the Study Area is complexly folded with numerous major and minor folds (Woodland, 1965). At least two periods of deformation have resulted in the development of two fold structures in the Study Area. The trend of the major regional structural elements is generally within ± 10 degrees of north and is in general alignment with the strike of the bedding. The majority of minor folds in the Study Area trend approximately N20°E and plunge to the northeast at 23 degrees. The Study Area lies on the eastern limb of a north trending and plunging anticlinorium known as the Willoughby Arch.

Bedrock structural data obtained in the field during the LFI indicate that the bedding (where identifiable) in both formations generally strikes between N1°E and N10°E and dips toward the southeast at between 45 and 75 degrees. Published data and field data indicate that the dip of bedding in the major folds is primarily between 60 and 78 degrees to the southeast. However, shallower dips are observed in association with minor folds. Data gathered during the LFI indicate the development of two joint sets, discussed here as J_1 and J_2. J_1 generally strikes between N50°E and N60°E and dips to the northwest at 53 to 70 degrees. The trend of the occurrence of regolith, discussed previously, is coincident with the strike of the J_1 joint set and closely parallels the inferred contact between the Gile Mountain and Waits River Formations.

The J_2 joint set strikes between N50°W and N55°W and dips toward the southwest at 67 to 80 degrees. J_2 joints striking N75°W were observed along the railroad easement near the Vail Dam and may indicate local slumping or rotation of exposed bedrock following construction of the railroad. The J_2 joints are the most common and persistent joints in the Lyndonville and Burke quadrangles and are clearly visible as photoliners on air photographs.

The J_1 joints are commonly filled with calcite and quartz. However, some of the joints observed during the LFI were open, with separations ranging from less than a tenth of an inch to one inch in width. Published data for the Lyndonville Area (Dennis, 1956) indicate that on a regional scale the J_2 joints are commonly not filled.

Bedrock cored throughout the Study Area was generally fresh and sound with primarily closed, close to moderately close, moderately to steeply dipping joints. Some shallowly dipping joints were also encountered. Some joint surfaces exhibited slickensides indicating movement along the joint surfaces. Numerous joints were filled with 0.1 inch to four-inch wide veins of calcite, quartz, and pyrite. The majority of joints encountered during the test boring program were closed. Slightly to moderately weathered and fractured bedrock was encountered near the bedrock surface at boring locations B102, B103, B106, B107, B115, B120, B127, B136, and B139.

Seismic refraction profiling during Phase 1A identified a 1,600 ft. wide zone of low bedrock seismic velocity interpreted to be due to highly weathered or fractured bedrock extending southwestward from point H on Seismic Line H-H′ (between stations 0+00 and 11+00), as shown on Plate C. Bedrock seismic velocities along Line H-H′ spanned a broad range from 10,000 to 14,000 ft./sec. Seismic velocities of 10,000 to 12,000 ft./sec. were measured for the interpreted weathered/fractured zone. Bedrock seismic velocities outside this zone were typically 14,000 ft./sec. The lowest seismically determined bedrock elevation along this seismic line was coincident with the lowest bedrock velocities.

A sharp bedrock depression was identified on Seismic Line I-I′ between Stations 17+50 and 18+40. This bedrock topographic feature is located in the immediate vicinity of B132. The calculated seismic velocity for this portion of the Line was 11,000 to 12,000 ft./sec and was interpreted by Weston Geophysical Corporation to be indicative of a zone of highly weathered or fractured bedrock. A second pronounced bedrock depression was identified between Stations 21+00 and 22+5 (between B132 and B139) on Line I-I′. The seismic velocity for this portion of the line was determined to be 10,500 ft./sec. and was also interpreted to be indicative of highly weathered or fractured bedrock. Bedrock velocities for the remainder of this seismic line ranged between 15,000 and 16,000 ft./sec. and are generally interpreted to be indicative of sound bedrock.

A pronounced drop in bedrock elevation was detected between Stations 3+80 and 4+40 on Seismic Line L-L′ (immediately east of IWS 2). The location of this bedrock depression coincides with the trend of the depressions identified on Line I-I′. Ground surface topography precluded completion of off-set shots at locations sufficient to resolve the bedrock velocity along this portion of the line from Stations 3+50 and 6+00.

Low bedrock velocities ranging from 12,000 ft./sec to 13,000 ft/sec. and indicative of weathered or fractured bedrock were measured between Stations 0+00 and 3+00 on Line J-J′ and Stations -2+00 to 1+00 and 5+00 to 7+50 on Line K-K′. Bedrock velocities indicative of highly weathered or fractured bedrock were not encountered/measured along any other portions of seismic lines completed during Phase 1A or Phase 1B.

Test boring determined bedrock elevations in the Study Area ranged from 723.39 (B101) to 561.9 (B121). Contoured bedrock elevations, based upon outcrop, test boring, and seismic data, are presented on Figure 3-3. In the immediate vicinity of the Landfill, the bedrock surface generally dips gently toward the west. A northwest trending bedrock trough is located in the immediate vicinity of IWS 2 and extends northwest as far as B118. The trend of this bedrock feature is in general agreement with the strike of the regional J_2 joint set. A northwest trending bedrock low is located southwest of B131. A northeast trending bedrock low is located southwest of the Curran residence. An associated bedrock high is located immediately northwest of the Curran residence. The bedrock topographic pattern appears to be controlled or strongly influenced by the regional J_1 and J_2 joint sets.

Test boring and rock coring data indicate that the bedrock east of the SWDA and IWS 2 is comprised mainly of siliceous phyllite (Gile Mountain Formation) and is much more fractured than the calcareous phyllite bedrock (Waits River Formation) located to the west of the unnamed stream. The contact between the two bedrock formations is inferred to generally coincide with the location of the unnamed stream. Bedrock relief across the inferred contact is approximately 120 feet in the vicinity of B114 and 85 feet in the vicinity of IWS 2. Seismic data indicate the presence of a large swath of bedrock exhibiting bedrock seismic velocities between 10,500 to 12,000 ft./sec. This swath is generally 700 to 800 feet wide and extends in a northeasterly direction from B120 to B114 and IWS 3. The significance of this seismic feature is uncertain.

3.3 SEISMIC REFRACTION PROFILING

Phase 1A

The results of the seismic refraction survey are presented as profiles in the Weston Geophysical Corporation report provided in Appendix A. Refraction traverses D-D′ through H-H′ were designed to measure depths to groundwater, bedrock, and any identifiable overburden stratigraphy. Line D-D′ was located along the powerline easement south and east of the Landfill. Saturated thickness along this line is interpreted to range from 20 to 85 feet. Bedrock depth is interpreted to vary between 30 and 100 feet, and bedrock velocities of 13,000 to 18,000 ft./sec. were measured along this line. Bedrock velocities are less certain to the north of Line D-D′ Station 21+50, where the line crossed very irregular topography and landfilled materials. Elevations of the bedrock surface along Line D-D′ range between 645 feet and 710 feet, with the lowest bedrock elevations in the vicinity of Stations 12+00 and 19+50.

Line E-E′ was located on a hill south of the Landfill. A thick section of unsaturated overburden (100 to 130 feet) is interpreted to overlie the water table at this location. Saturated thickness was interpreted to be 85 to 150 feet, and bedrock depths to be 220 to 250 feet. The lowest interpreted bedrock elevation along this line was approximately 540 feet near Station 0+00.

Line F-F′ was located 2,000 feet south of the Landfill. Two to twenty feet of unsaturated overburden was interpreted to overlie the interpreted water table along this line. Interpreted saturated thickness along the line are 55 to 115 feet, with the greatest saturated thickness near Station -1+00. Bedrock velocities of 14,000 to 15,000 ft./sec. were measured along this line. Interpreted bedrock elevations range from 580 to 640 feet; the deepest bedrock was observed near Station -1+00.

Line G-G′ was located 2,000 to 3,000 feet south of the Landfill along Red Village Road. Ten to 25 feet of unsaturated overburden was interpreted to exist along this line. Maximum interpreted saturated thickness is approximately 100 feet near Station 9+00. The saturated overburden thickness is interpreted to decrease significantly to the north, and may pinch out near Station 14+50. Measured bedrock velocities along this line are relatively high (15,000 to 16,000 ft./sec.). The line profile indicates a prominent bedrock trough between Stations 4+50 and 10+50.

Line H-H′ was located approximately 1,500 feet south of the Landfill. The interpreted unsaturated overburden thickness along this line is ten to 25 feet, and the interpreted saturated thickness is 25 to 75 feet. Bedrock velocities along this line span a broad range from 10,000 to 14,000 ft./sec.. Velocities of 10,000 to 12,000 ft./sec. were measured between Stations 0+00 and 11+00. The lowest interpreted bedrock elevation of 615 feet is coincident with the lowest bedrock seismic velocities (10,000 ft./sec.).

Phase 1B

Seismic refraction Line I-I′ extended from boring B121 at Brown Farm Road to boring B104 near the IWS 3 area (Plate C). From boring B121 to Station 12+00, the line was positioned in open fields. At Station 12+00, the line turned to follow the northeast-trending stream valley towards the IWS 2 and IWS 3 areas. Offset shots extended the seismic interpretation to Stations -2+00 and 26+30.

A thick saturated section and deep bedrock was interpreted from Stations 0+00 to 9+00. Saturated thickness ranges from 70 to 130 feet; bedrock velocities range from 14,200 ft/sec to 17,500 ft./sec. From Stations 9+00 to 12+80, bedrock becomes shallower from approximate depths of 78 feet (Station 9+00) to four feet (Station 12+80). Very shallow bedrock (two to four feet deep) was interpreted between Stations 12+80 and 16+00; a bedrock outcrop was noted in the stream near Station 14+10. Seismic velocities in this shallow bedrock area (15,000 to 16,000) ft./sec) are indicative of relatively unweathered bedrock. Saturated thickness increases from two feet at Station 16+00 to 85 feet at Station 25+60, accompanied by generally deeper bedrock from elevations 716 feet (Station 16+00) to 656 feet (Station 25+60).

A distinct, localized bedrock depression was identified by the crossover distance and GRM interpretations between Station 17+50 and due southeast of IWS 2 (near B132) 18+40. GRM-computed seismic velocities ranged between 11,000 and 12,000 ft./sec, indicative of weathered/fractured bedrock. A broader bedrock depression was interpreted with the crossover distance technique between locations 21+00 and 22+50. A GRM-computed bedrock seismic velocity of 10,500 near this area suggests weathered/fractured bedrock.

Line J-J′ was positioned approximately 600 feet west of the IWS 2 area and trended south towards boring B122 at Brown Farm Road. The line ended approximately 50 feet short of boring B122, but the interpretation was extended beyond the boring using offset shots.

A thick saturated section (80 to 90 feet thick) was interpreted from Stations 0+00 to 3+70. The bedrock surface rises from approximate depths of 100 feet at Station 3+70 to 10 feet at Station 8+00. GRM-derived bedrock topography correlated to that of the crossover distance technique where GRM results could be computed (Stations 4+40 to 6+80). Relatively shallow bedrock (10 to 28 feet deep) was interpreted until Station 12+00; bedrock then dips to a depth of 70 feet at Station 16+00. Seismic velocities throughout Line J-J′ range from 13,000 to 17,000 ft./sec, indicative of slightly weathered to competent bedrock.

The southern end of Line K-K′ was located approximately 300 feet west of the IWS 2 area and trended north to Lily Pond Road ending near boring B118 and the gate to the Parker Landfill. Offset shots from Station 0+00 extended the seismic interpretation to Station -2+00. Thick unsaturated (50 to 120 feet thick) and saturated (90 to 150 feet thick) layers were interpreted along Line K-K′. Bedrock depths range from approximately 134 feet (Station -2+00) to 244 feet (Station 7+00). The bedrock surface appears to deepen from elevation 610 feet at Station 2+50 to elevation 550 feet at Station 12+25. Seismic velocity values indicate potentially weathered bedrock (12,000 to 13,000 ft./sec). Bedrock depths were not computed from Stations 7+50 to 12+00 due to extremely deep bedrock; the bedrock surface over this station interval was inferred using boring B118. Offset shots were not attempted across Lily Pond Road due to nearby residences. Highly irregular ground surface topography and loose fill materials (which rapidly attenuated seismic energy) prohibited offsets greater than 200 feet to the south of Station 8+00.

Line L-L' trended southeast from Station 8+00 through the IWS 2 area (Station 4+30 to 6+60), and turned to the east at Station 4+00. Unsaturated thickness is approximately 20 feet between Stations 0+00 to 3+00 and thins towards Station 4+00 at the stream bed. Between Stations 0+00 and 4+00, saturated thickness ranges from 30 to 70 feet and bedrock depths range from 44 to 94 feet. Bedrock velocities computed over this station range indicate competent rock (15,000 to 17,000 ft./sec).

A "sudden" drop in bedrock topography of approximately 50 feet was interpreted from Stations 3+80 to 4+40 on Seismic Line L-L'. Saturated thickness increases substantially from approximately 50 feet at Station 4+00 to approximately 184 feet at Station 8+00. Due to highly irregular surface topography and very loose near-surface soils, only one offset shot located at Station 3+20 was performed for the geophone array located between Stations 4+00 and 8+00. Consequently, deep bedrock was not resolved between these stations by either the crossover distance technique or GRM. The crossover distance technique was used to compute a bedrock velocity of approximately 17,500 ft./sec near Station 8+00 (indicative of competent bedrock) but rock velocity information was not discernible elsewhere. Boring results from borings B106, B107, and B108 correlate well and provide bedrock depth control between Stations 4+00 and 8+00.

3.4 COMPARISON OF TEST BORING AND SEISMIC RESULTS

The project design specifications for the accuracy of the seismic depth to bedrock data were plus or minus ten percent for bedrock depths outside the Landfill and plus or minus 20 percent within the Landfill. The Phase 1A test boring and seismic data were in agreement and met the design specifications of this investigation. Borings B105 and B107 were designed to serve as calibration points for Line A-A′. Seismic depths to bedrock in the vicinity of these borings deviated by less than one percent of the test boring data. Borings B111, B112, and B114 were designed as calibration points for Line B-B′. Seismic depths to bedrock in the vicinity of these borings deviated by less than six percent of the test boring data. Borings B104 and B118 were located near the end points of Line C-C′. Seismic depths to bedrock in the vicinity of these borings deviated by less than one percent of the test boring data. Borings B104, B115, and B124 were designed as calibration points for Line D-D′. The seismic depths to bedrock in the vicinity of these borings deviated by less than two percent at borings B115 and B124, and eight percent at boring B104. Boring B131 was designed as a calibration point for Line E-E′. The seismic depth to bedrock at this location deviated by less than seven percent of the test boring data. Boring B126 was designed to be the calibration point for Line F-F′. The seismic depth to bedrock deviated by less than three percent of the test boring data. Boring B123 was designed as the calibration point for Line H-H′. The seismic depth to bedrock at this location agreed with the test boring data. Borings B104 and B121 served as calibration points for Line I-I′. Seismic determined depth to bedrock for this line deviated by less than one percent of the test boring data. Borings B136 and B125 were calibration points for Line J-J′. Seismic determined depth to bedrock varied from the test boring data by -27% (B136) and +17% (B125). Test borings B113 and B118 served as calibration points for Line K-K′. The Seismic determined depth to bedrock varied by less than one percent of the test boring data. Borings B108, B107, B106, and B132 served as calibration points for Line L-L′. The seismic determined depths to bedrock for this line varied from the test boring data by +1.2% (B108), +1% (B107), +4% (B106), and +11.4% (B132). The seismic/test boring depth variation for Line L-L′ and B132 was -6.7 feet. However, B132 was located at an offset of 50 feet north of Line L-L′ and was located upslope from a seismically inferred bedrock trough.

3.5 LANDFILL INVESTIGATIONS

3.5.1 SWDA

3.5.1.1 Results of Geophysical Investigations

Seismic profiles for seismic lines which crossed the SWDA are presented in Appendix A. Seismically determined solid waste thickness of the SWDA during Phase 1A ranged from 0 feet along the perimeter of the SWDA to 60 feet along the axis of the SWDA. The average waste thickness along the axis of the SWDA (Line A-A′ on Plate H) was interpreted to be 55 feet in 1991. Due to the continued placement of solid waste between May 1991 and July 1992 (closure date) the average thickness of the waste along the axis of the SWDA is now estimated at 70 feet. As viewed in cross-section from north to south, the base of the landfill is interpreted to slope toward the south and the waste thickness remains relatively constant until the waste terminates just north of B105. As viewed in cross-section from west to east, the base of the solid waste mass generally slopes toward the east. The seismic data indicates the greatest waste thickness is located along the axis of the SWDA. Historical data indicate that waste could be in contact with groundwater across much of the SWDA. However, seismic and test boring data do not indicate that waste is in contact with groundwater at the specific locations surveyed or explored. Available test boring and seismic data suggest the bottom of the solid waste mass is within approximately five (B115) to 15 (B105) feet of the groundwater surface along the eastern margin of the SWDA, as observed during the drilling and groundwater sampling programs. Groundwater elevation data from borings B109 and B111 indicate a separation distance of approximately 60 to 100 feet between the solid waste and the groundwater surface along the western margin of the SWDA. Seismic data beneath the SWDA may be less accurate due to the thickness of the debris mass and signal attenuation. The seismic data does not provide conclusive data relative to the relation of solid waste to the groundwater table. Test boring data also indicates the base of the solid waste mass is located immediately above the Distal.

Magnetic data contoured on Figure 3-5 indicate that ferrous metal objects are present throughout the SWDA up to the survey limits, with the exception of the southern-most portion of the SWDA. Metallic objects appear to have shallower depth of burial and/or are more concentrated in the western portion of the SWDA, as evidenced by high amplitude and frequency magnetic anomaly patterns (vicinity of IWS 1). The high magnetic anomaly patterns shown in the north-central portion of the SWDA are most likely a result of the presence of numerous large dumpsters at this location during the survey period. Metallic objects are buried deeper or are less concentrated in the central portion of the SWDA, based on the relatively smooth low-amplitude magnetic contours. There generally does not appear to be any evidence of waste segregation within the SWDA.

3.5.1.2 Volume of Waste Mass

The volume of the waste mass was calculated using computer generated contours of the upper and lower surfaces of the SWDA. The lower surface of the waste mass was computer generated using seismic and geologic cross-section-based elevations of the bottom of the waste mass. The upper surface of the SWDA was contoured using survey data obtained by Trueline, Inc. during the Post Screening Field Investigation. The waste volume calculation was based on the computer generated contouring of the upper and lower surfaces of the waste mass using a software package called SURFER by GOLDEN SOFTWARE, INC. After generating contour maps for the top and bottom of the waste mass, SURFER is then able to determine the volume bounded by these two intersecting surfaces. The computer-calculated waste volume is approximately 1.4 million cubic yards. Using a density of 1.5 tons per cubic yard, 1.4 million cubic yards is equivalent to 2.1 million tons.

3.5.2 IWS 1

3.5.2.1 Results of the Geophysical and Test Pit Investigations

GPR and magnetic surveys of the disposal area and immediate vicinity determined the horizontal limits of the disposal area (waste) as shown on Figure 3-6. Magnetic data obtained in "background" areas of the Landfill (areas interpreted to be relatively free of ferrous metal) ranged from 54,600 to 54,800 gammas. Magnetic values measured in IWS 1, south of Line L, were typically more than 58,000 gammas. Contoured magnetic data are provided in Appendix A. These consistently high values are indicative of ferrous metal objects. The zone in which the steepest magnetic gradient was observed is interpreted to correspond to the maximum extent of buried metal fill. The greatest concentration of buried metal objects, interpreted from magnetic contour line density, is interpreted to be in the southern and western portion of IWS 1.

The GPR system was calibrated at a culvert (located three feet below the ground surface to the north of IWS 1) where "background" GPR soil velocities were anticipated. Interpreted magnetic and GPR results are summarized on Figure 3-6. Interpreted GPR results indicate objects are buried below grade. The region of disturbed soil (evidenced by lack of continuous soil structure and the presence of strong "point targets") corresponds well with the approximate fill boundary defined by magnetic results (see Appendix A). GPR data show that the greatest concentration of buried objects is in the southern and southwestern portion of IWS 1.

The majority of the point targets are interpreted to be metallic, because of their high amplitude reflections, and were detected at depths of approximately five to seven feet. Some targets were observed as deep as 11 feet below grade. The objects appear variable in size and irregularly shaped, as indicated by the lack of distinct parabolic GPR reflectors. In some instances, the approximate size and shape of the objects could not be defined because of overlapping reflections from multiple targets within the same area. The buried objects appear to be scattered throughout the disposal area. Segregation of wastes does not appear to have occurred.

GPR anomalies indicative of conductive soils and/or groundwater, evidenced by the severe attenuation of radar signals, were observed in three localized areas. These areas, shown on Figure 3-6, occur in the vicinity where concentrations of metal objects were observed at the ground surface and/or indicated by magnetic data.

Three test pits (P907, P908, and P909) were completed at the locations shown on Figure 3-6 to confirm the geophysical interpretations. The test pits ranged in depth from 7.2 to 11.0 ft. in depth. Waste consisting of brown medium to fine sand with abundant scrap metal, metal turnings, pipe, and 55-gallon drums was encountered to depths of 9.0 feet in test pits P908 and P909. The 55-gallon drums encountered in these test pits were open, crushed, and empty. No in-tact full drums were encountered during the test pit operations. Test pit P907 contained 5.5 feet of municipal solid waste beneath a 1.0 ft. veneer of metal shavings. Each test pit was terminated in the underlying Proximal lacustrine deposit. Large quantities of municipal solid waste were also exposed during the construction of the decontamination pad, indicating that portions of IWS 1 may overlie the footprint of the SWDA.

Test trench TT1-1 was excavated along the southern margin of the disposal area to confirm the geophysically interpreted disposal limits. The observed southern limit of waste in TT1-1 was in close agreement with the geophysical interpretation. Therefore, the limits of the disturbed soil as shown on Figure 3-6 are interpreted to accurately represent the footprint of IWS 1. Representative GPR traverse data is provided in Appendix A. Test pit/test trench logs are provided in Appendix C.

3.5.2.2 Volume of Debris Mass

GPR and test pit data indicate waste depths across IWS 1 range from approximately five to 16 feet with an average depth of approximately 11 feet with an average depth of approximately eleven feet. The disposal area covers a surface area of approximately 14,800 square feet (0.33

acres). The approximate volume of mixed wastes within IWS 1 is 6,030 cubic yards, which is approximately 9,045 tons of waste.

3.5.3 IWS 2

3.5.3.1 Results of Geophysical and Test Pits Investigations

The results of the geophysical surveys are provided in Appendix A. Magnetic and GPR surveys of IWS 2 indicate disposal of waste and ferrous material in three distinct locations. These geophysically determined disposal locations are shown on Figure 3-7. Ferrous materials are present in two roughly circular-shaped locations in the southern portion of IWS 2. One of these disposal locations is located on the western side of the access road which crosses IWS 2. This disposal location is the area historically referred to as IWS 2 by Parker and Son, Vermont AEC reports, and ERT reports. The second disposal location (Disposal Area 2) is located on the eastern side of the access road and has previously been referred to by Mr. Parker as the EHV Weidmann disposal area. This disposal location is comprised of industrial waste consisting of cardboard filter media and 55-gallon drums filled with a solid resin. The third location is also located east of the access road and immediately north of Disposal Area 2 and coincides with the location which yielded the greatest soil vapor reading during the soil vapor survey. This location appears as an area of GPR signal attenuation with few metal targets. Disposal Area 3 has only been identified by the soil vapor and geophysical surveys but has not been confirmed with soil/waste sampling.

Two test pits (P905 and P906) were completed within the first identified area, in the western portion of the disposal area (IWS 2), as shown on Figure 3-7. These test pits ranged in depth from 5.6 to 9.0 feet. Industrial waste fill consisting of brown to black, fine to coarse sand, with little silt, trace gravel, and metal wire, crushed buckets, metal turnings, wood, and crushed drums were encountered to depths of 3.5 to 7.5 feet. No intact drums were observed. Additionally, ERT completed nine test pits in the immediate vicinity of this disposal area. These test pits encountered similar wastes to depths of eight feet. Five of these test pits crossed the perimeter of the disposal area. The ERT-determined waste limits (ERT, 1987), although not surveyed and only shown on a sketch plan, generally confirm the geophysically determined waste limits. A test trench (TT2-1) was also completed immediately northwest of test pit P906 to confirm the GPR inferred waste limit. This test trench was simply a northwest-trending, three foot deep extension of P906. The boundary of the waste mass was encountered where predicted by the GPR results. Test boring B129 was completed through the main disposal area. The boring encountered six feet of industrial waste consisting of brown to black, medium to fine sand, with metal turnings.

Test pits were not completed within the second or third identified potential disposal areas. However, erosion and slumping of the waste mass in the Disposal Area 2 exposed numerous drums filled with fiber disks and solid resins. ERT completed test pits in this area in 1986 and encountered similar materials. The depth of the waste is interpreted to be on the order of eight feet. Test boring B106 was completed within Disposal Area 2 and encountered waste to a depth of six feet.

3.5.3.2 Volume of Debris Mass

The surface areas of the three identified potential waste areas were calculated to be approximately 3,500 square feet, 3,800 square feet and 400 square feet, respectively. The respective waste volumes are estimated at 1,040 cubic yards, 844 cubic yards, and 118 cubic yards. These volumes correspond to 1,555 tons, 1,266 tons, and 178 tons of waste, soil, and metal debris.

3.5.4 IWS 3

3.5.4.1 Results of Geophysical and Test Pits Investigations

GPR and magnetic survey results indicate the existence of three waste disposal areas at IWS 3, as shown on Figure 3-8. The majority of waste, is apparently located in the western portion of the IWS 3. GPR and magnetic surveys identified ferrous material in the northwestern and southwestern corners of IWS 3. Metal turnings and scrap metal were observed at the ground surface across the northwestern portion of IWS 3. The areal limit of the surficial waste coincides with a large area of GPR signal attenuation and disturbed soil.

Test pits P901, P902, and P904, and test boring B128 were completed within the disposal area in the northwestern corner of IWS 3 (Figure 3-8). The test pits ranged in depth to six feet. The test boring was completed to a depth of 56 feet. Boring B128 and test pits P901 and P902 encountered between 4.8 and 8.5 feet of industrial waste consisting of brown to black silty fine sand, to coarse to fine sand with gravel and metal cuttings, wood, plastic, and a crushed and empty drum (P902). Four attempts to drill B128 were aborted in the immediate vicinity of B128 due to refusal. Test pit 904 encountered an empty crushed drum in the northeastern corner of the pit, but only natural soils and no indication of fill material. No intact drums were encountered in any of the test pits conducted. Test trench TT3-4 was completed in a southwesterly direction from B128 to confirm the geophysically determined waste limits. In general, the trench data supported the geophysical interpretation.

TT3-1 was completed in the area of IWS 3, where geophysical data indicated ferrous materials. The test trench encountered 1.5 feet of granular fill consisting of gray-brown silty sand with rust staining in the northern portion of the trench. The transition from granular fill to natural soils coincided with the GPR inferred limit of disturbed soil.

Test pit P903 was near the southwestern corner of IWS 3 where GPR data indicated the presence of disturbed soil and potential ferrous material. The test pit extended to a depth of 4.2 feet and encountered granular fill consisting of brown to gray silty very fine sand. A two-inch thick iron oxide stained zone was observed at a depth of 2.6 feet. The pit was terminated in natural soil. This corner of IWS 3 is roughly circular in shape and is interpreted to have been a liquid disposal area. HNu screening of the soils indicate the presence of volatile organic compounds in the fill material (see Appendix D).

Test trench TT-2 was completed in an area in the center of IWS 3 indicated as free of waste materials based on geophysical data. The trench extended to a depth of 5.8 feet and encountered natural Proximal glacial lacustrine sediments to a depth of 4.5 feet. The trench was terminated in Distal lacustrine sediments.

TT3-3 was completed in an area identified as a potential disposal area by the VDEC on historical aerial photographs. The trench was terminated at a depth of 8.8 feet. The trench encountered 4.5 feet of miscellaneous granular fill underlain by 3.5 feet of waste. The granular fill consisted of brown very fine sand with little to trace silt. The waste consisted of black organic silt thinly interbedded with silty clay. This unit exhibited elevated HNu readings. This area is strikingly delineated at the ground surface by a dense growth of horsetails. The trench was terminated in natural soils.

Test trench TT3-5 was completed along the eastern boundary of IWS 3 to investigate a location where a high soil vapor reading was obtained during the soil vapor survey. The trench extended to a depth of 6.5 feet and encountered only natural soils with no elevated HNu readings.

Test pit data and test boring data from borings B101, B102, B103, and B128 indicate IWS 3 is immediately underlain by Proximal glacial lacustrine deposits which thin in an easterly direction.

3.5.4.2 Volume of Debris Mass

Three distinct waste disposal locations have been identified at IWS 3. The largest location is located in the northwestern corner of IWS 3 and is roughly triangular in shape with an interpreted average thickness of 13 feet. This location covers a surface area of approximately 6,000 square feet and contains a waste volume of approximately 1,292 cubic yards.

$$0.5 \times 155\ ft. \times 50\ ft. \times 9\ ft. \times \frac{1\ yd^3}{27\ ft^3} = 1{,}292\ yd^3$$

This correlates to approximately 1,938 tons of waste.

$$1{,}292\ yd^3 \times \frac{1.5\ tons}{yd^3}$$

The second waste disposal location is in the southwestern corner of the area and covers an area of approximately 961 square feet. The volume of waste within this location was estimated first by interpreting the disposal area as one-half of a sphere with a radius of 17.5 feet. This calculation yielded an estimated volume of 24 cubic yards.

$$4/3\ \pi\ r^2\ x\ 0.5 = 4/3\ x\ 3.14\ x\ (17.5\ ft)^2\ x\ 0.5\ x\ \frac{1\ yd^3}{27\ ft^3} = 24\ yd^3$$

The second volume calculation assumed the waste mass was approximately cylindrical in shape with a radius of 17.5 feet and a thickness (height) of 3 ft. This calculation yielded an estimated volume of 107 cubic yards.

$$\pi\ r^2\ h = 3.14\ x\ (17.5\ ft)^2\ x\ 3.0\ ft\ x\ \frac{1\ yd^3}{27\ ft^3} = 107\ yd^3$$

Applying a conversion factor of 1.5 tons per cubic yard indicates that this disposal area likely contains between 36 and 156 tons of waste.

The third waste disposal location is immediately north of the IWS 3 entrance gate. This disposal location is nearly circular in shape with a radius of 10 ft. and an interpreted thickness of 8 feet. The volume of waste within this area was estimated by interpreting the waste mass as cylindrical. The waste mass calculation yielded an estimate of the volume of waste of 93 cubic yards.

$$\pi\ r^2\ h = 3.14\ x\ (10\ ft)^2\ x\ 8\ ft\ x\ \frac{1\ yd^3}{27\ ft^3} = 93\ yd^3$$

Applying a conversion factor of 1.5 tons per cubic yard indicates that this disposal area contains approximately 140 tons of waste.

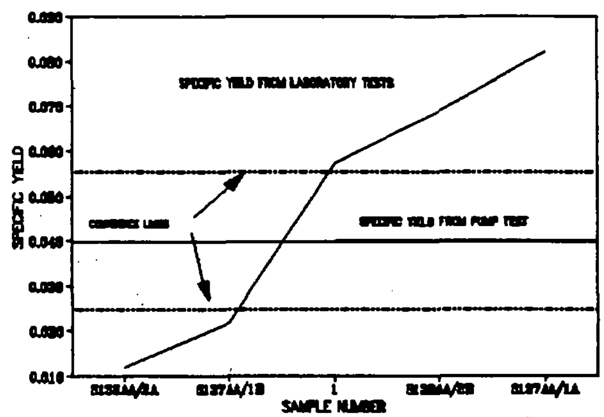
3.6 PHYSICAL CHARACTERIZATION OF NATURAL SOILS AND WASTE MATRICES IN THE STUDY AREA

The physical characteristics of soil samples from borings and test pits were determined by completing grain size analyses on a set of representative samples from different geographic and geologic locations in the Study Area. Based on the grain size analyses and geologic interpretations, composite soil samples were selected and analyzed for bulk dry density, total porosity, and effective (drainable) porosity. The result of these analyses are presented in Table 3-1. Total organic carbon was analyzed on selected samples and these data are summarized in Table 3-2. The raw results of the grain size analyses and physical testing are presented in Appendix F.

Composite sample Group 1 was comprised of selected borehole soil samples taken from the Proximal within the Study Area. Additional downhole samples of Proximal are given in the Table 3-1. Composite sample Group 2 was comprised of soil from the Distal taken from test pits near IWS 1. Borehole samples of Distal from Phase 1A were submitted to the laboratory for analysis; however, due to a laboratory error, most of these samples were not processed. One additional Distal sample from the unsaturated zone in B137 was tested during Phase 1B.

Bulk dry density results from the physical testing indicate that the Distal is significantly denser than the Proximal. Measurements of the bulk dry density of recompacted composite soil samples, originating from test pits or test borings, ranged from 1.56 gm/cm^3 for soil (Proximal) in the upper 12 feet at IWS 2 to 1.73 gm/cm^3 for soil (Distal) in the upper 12 feet at IWS 1. Total porosity values for Proximal ranged from 0.35 in the upper 12 feet of soil at IWS 3 to 0.41 in the upper 12 feet of soil at IWS 2. The mean porosity of Proximal sediments is approximately 0.37 (Table 3-3). The mean porosity of Distal sediments material is approximately 0.35.

Effective porosity measurements, which are approximately equal to specific yield, were determined in the lab for the composite samples and are summarized in Table 3-1. The mean effective porosity of the Proximal is approximately 0.048, while the mean effective porosity of the Distal is approximately 0.028. The specific yield of the Proximal, as calculated from a pump test, was 0.040 with confidence limits of 0.024 and 0.056. The laboratory data compare reasonably well with the pump test data as shown below:



Given the silt content of the soils analyzed, it is not unusual to expect the observed differences in porosity and effective porosity (specific yield). The methodology used to reproduce field density is a diligent and scientific effort to achieve field conditions (undisturbed). The effect of density on specific yield was demonstrated with groups 3A and 3B, which indicates a 42% decrease in specific yield (from 6.1 to 3.5, for a 4% increase in dry density). Additional discussion of physical characteristics is included in Section 5.

DRAFT

3.7 HYDROGEOLOGY

This section describes the hydrogeology of the Study Area, derived from geologic interpretations, water level measurements, and pumping test analyses. This information is fundamental in understanding the flow of contaminants and remedial alternatives available.

The natural groundwater flow in the Study Area is controlled primarily by the site geology and topography. Other natural factors that influence the hydrology of the site are precipitation, evapotranspiration and Passumpsic River stage fluctuations.

3.7.1 Geologic Considerations

The surface and groundwater flow patterns (hydrology and geohydrology) in and around the Landfill are affected by various geologic formations and features. Figure 3-9 shows a conceptual model of the IWS 2 Area pumping test location, based on the geologic cross sections. Some of the thickest overburden sediment occurs over an area where bedrock is the deepest. The overburden portion of the aquifer, therefore, does not have a uniform thickness. The unnamed stream shown in Figure 3-9 expresses some of the general flow of the shallow groundwater. The flow of shallow groundwater tends to mimic the ground surface topography, and generally flows south southwest.

In contrast, the flow of groundwater closer to the bedrock surface flows west. Figure 3-9 shows the bedrock surface topography is completely different from the ground surface topography, but that it slopes generally west in agreement with the groundwater flow data. The flow of water within the fractured bedrock aquifer is also significantly controlled by the orientation of fractures and where the main area of fracturing occurs. These areas are also shown in Figure 3-9.

The effects of distal and proximal sediments within the overburden portion of the aquifer, as shown in the geologic cross-sections, are also important, because distal layers frequently act as confining layers. Each of the geologic cross-sections (Plates F-L) depicts water levels measured on 8/25/93 at the different depths within the aquifer. Water levels are affected by the occurrences of less permeable sediments because water cannot percolate down as easily. As discussed in Section 3.8, during the pumping test these less permeable layers play a significant part in defining the aquifer for the overburden (142 pumped well) test and the bedrock (204B) test.

In order to better understand the flow of groundwater , the water level measurements have been presented as three different zones, dependent on depth and geology. These three zones are represented in the cross-sections by different water level elevations designated as shallow, medium or deep (denoted by the different line types).

The shallow well screens along the eastern edge of the SWDA (B114A, B115A, B117A, MW10, B117A, B133 and B139A) and at IWS 2 (MW13, B105I, B106A, B108A, B108I, ERT1, B134A, B134B, and B135A) are screened in Upper Proximal above the Distal. The deep well sets (B114B, B115B, B117B, B104, B107) are screened in Lower Proximal, regolith, and upper bedrock material. B106B is screened partially in the Upper Proximal and partially in the Distal on top of bedrock. B108B and B135B are screened on the top of bedrock within the lower portion of the Distal.

The saturated portions of the major soil and rock units within the Study Area can be grouped into three primary hydrogeologic units: the Upper Proximal, the Lower Proximal and Fractured Bedrock. Over most of the site the Lower Proximal and Fractured Bedrock are separated from the Upper Proximal by the Distal, which is a semi-confining unit. The transmissivity of the Lower Proximal is approximately two orders of magnitude greater than the transmissivity of the Fractured Bedrock, and the Upper Proximal is very limited in areal extent. Therefore, in terms of groundwater flow volume, the Lower Proximal is the principal water-bearing unit in the Study Area.

3.7.2 Hydraulic Conductivity

The natural rate at which groundwater can travel through a water bearing formation is a function of hydraulic conductivity, the hydraulic gradient, and the effective porosity of the formation. During Phase 1A, hydraulic conductivity (permeability) tests were attempted in 63 monitoring wells, 3 observation wells, and 11 piezometers. Permeability testing was not feasible in 3 of the 66 wells (ERT1, G118A, and HB1S) due to bends or constrictions in the well casing which prohibited pump and slug entry into the screened interval. During the Phase 1B field investigation, an additional 17 monitoring wells and one piezometer were successfully tested using constant flow and slug test methods. Data collected during hydraulic conductivity testing are presented in Appendix I.

3.7.2.1 Horizontal Hydraulic Conductivity

The horizonal hydraulic conductivity values are presented in Table 3-4. Hydraulic conductivity testing results for near-Landfill wells are also presented in Table 3-5, categorized according to the overburden geologic unit in which the well screen is located. Table 3-5 also shows the geometric means for each overburden unit. The results of constant flow tests are presented in Table 3-6. Results of hydraulic conductivity testing in wells in Other Area wells are summarized in Table 3-7 and 3-8.

At locations where more than one test was performed, the result from what was considered the more appropriate test, as discussed below, was used for statistical purposes. For example, the data from a constant flow test was considered to be more reliable than data from either of the slug test methods, as it is a small scale pump test; a pump test stresses a larger portion of the aquifer than a slug test. A slug test displaces water from a relatively small zone surrounding the well screen. In shallow bridging wells, the rising head test was considered to be more reliable than the falling head test because the upper portion of the screen is located in the unsaturated zone. Under these conditions, a "slug" of added pressure may cause water to rise in the casing and discharge to the unsaturated zone rather than inducing a significant pressure change in the saturated interval of the screen. The results of the hydraulic conductivity testing are summarized below:

- The horizontal hydraulic conductivity of the Upper Proximal in the vicinity of the Landfill ranges from 3.6×10^{-2} cm/sec (B107) to 3.8×10^{-5} cm/sec (MW10), with a geometric mean of 2.3×10^{-3} cm/sec. These values fall within the published range for silty sands and the lower range for clean sands (see Figure 3-10).

- The horizontal hydraulic conductivity of the Distal in the vicinity of the Landfill ranges from 1.1×10^{-3} cm/sec (B103A) to 1.7×10^{-5} cm/sec (B103B), with a geometric mean of 9.7×10^{-5} cm/sec. The Distal is saturated only north of IWS 2 and east of the SWDA. These values fall within the published range for silty sands and the lower range for clean sands (see Figure 3-10).

- In the vicinity of the Landfill, the Upper Proximal exhibits a mean horizontal hydraulic conductivity that is approximately 80 times greater than that of the Distal.

- The horizontal hydraulic conductivity of the Lower Proximal in the vicinity of the Landfill ranges from 8.1×10^{-3} cm/sec (B137B) to 7.1×10^{-5} cm/sec (B111R), with a geometric mean of 8.1×10^{-4} cm/sec. These values fall within the published range for silty sands and the lower range for clean sands (see Figure 3-10).

- The aquifer material beyond the immediate vicinity of the Landfill (west of B110 and south of B107) is comprised of slightly higher permeability Proximal sediments. The hydraulic conductivity of the Proximal sediments outside of the Landfill area range from 1.3×10^{-4} cm/sec (MW4A) to 3.4×10^{-2} cm/sec (HB6), with a mean of $3.7x10^{-3}$ cm/sec. These values fall within the published range for silty sands and the lower range for clean sands (see Figure 3-10).

- In general, the hydraulic conductivity within the Lower Proximal tends to increase with depth, and with distance from the Landfill toward the south and west (Tables 3-7 and 3-8). Those wells with hydraulic conductivity values greater than 10^{-2} cm/sec were typically measured in intermediate screens, top of the bedrock screens, or greater than approximately 1,500 feet south and west of the Landfill.

- A falling-head hydraulic conductivity test was conducted in B314, of the three 1-inch piezometers (B312, B313, and B314) located within the bed of the Passumpsic River. A pressure transducer was used to record recovery. The calculated hydraulic conductivity for piezometer B314 is $2.2x10^{-2}$ cm/sec. The fact that there was no measurable vertical hydraulic gradient between the Passumpsic and the underlying groundwater in this area is consistent with this relatively high stream bed hydraulic conductivity.

3.7.2.2 Vertical Hydraulic Conductivity

- There appears to be only a small difference between the vertical and horizontal hydraulic conductivities within the Proximal deposits, as measured near the Curran residence, using constant flow test data collected at B127B and B127C during Phase 1A. Constant flow tests were conducted at these wells with a pressure transducer measuring drawdown in each well during both tests. Vertical hydraulic conductivity was computed with equations formulated by Hantush (1964). Using a horizontal to vertical permeability ratio of 1.0, and permeability values given in Table 3-4, model results matched the field-measured drawdown.

It is also worth noting that downward vertical hydraulic gradient exist between the overburden and bedrock at this location.

- Based on field observations of horizontal structure and clay laminations characterizing the Distal, the vertical hydraulic conductivity of the Distal appears to be 45 times less than the horizontal hydraulic conductivity (approximately 1.5 orders of magnitude). Close inspection of the Distal strata located in the exposed excavation (cut) along the southwestern edge of the SWDA revealed extensive horizontal clay laminae and a high silt content as revealed by the grain size analyses in Table 3-1. Based on field observations of the deposits in the cut, the Distal sediments are cohesive and remain saturated for several days following precipitation events. In comparison, Proximal deposits in the wall appear well sorted and sandy with little to no small scale horizontal structure.

Two methods were used to evaluate the vertical hydraulic conductivity of the Distal: open borehole falling head tests and computed vertical hydraulic conductivity based on the observed bedding structure of the Distal.

ESE conducted open-borehole falling head tests within both units to attempt to quantify the vertical hydraulic conductivity. The test consisted of placing a large hydraulic head on the cased borehole during drilling. The casing was driven to the desired depth, then washed out and filled with water to the ground surface. A transducer was used to measure the drop of water level within the casing. The modified percolation test data are presented in Table 3-9. In general, results were inconclusive.

The second method of vertical hydraulic conductivity evaluation was based on the lithology of the Distal and the horizontal hydraulic conductivities determined from slug tests. As discussed above, the vertical hydraulic conductivity of the Distal is expected to be much lower than the horizontal value due to the observed bedding structure, such as clay laminae, which are readily observed in the deposits exposed west of B113. Horizontal hydraulic conductivities typically exceed vertical hydraulic conductivities by factors of at least 10 to 100 in stratified deposits. Furthermore, the measured vertical hydraulic gradients in this area, shown in Table 3-10, support this, with differences in piezometric head between shallow and deep wells along the eastern edge of the SWDA ranging from 14 feet at MW10/B104 to 37 feet at B114A/B114B. Differences in piezometric head between shallow and deep wells in the IWS 2 area range from zero at B106A/B106B to 32 feet at B108A/B108B, located approximately 100 feet west of B106. The Distal at B106 is only 9 feet thick, and the screen at G106B bridges Distal and Proximal, as the Distal terminates on the bedrock at this location.

The vertical hydraulic conductivity of the Distal was estimated using the formula of Domenico & Schwartz (Domenico & Schwartz, 1990; Bear, 1979).

$$K_v = \frac{\sum b_i}{\sum \left(\frac{b_i}{K_i}\right)}$$

K_v = effective vertical hydraulic conductivity of the entire interbedded sequence
b_i = thickness of each bed within the interbedded sequence
K_i = hydraulic conductivity of bed within the interbedded sequence

In contrast, the formula for effective horizontal hydraulic conductivity of a stratified deposit is:

$$K_h = \frac{\sum b_i K_i}{\sum b_i}$$

where, K_h is the effective horizontal permeability of the entire interbedded sequence and the other terms are as defined above.

Figure 3-11 is a representative 6-inch cross-section of the Distal determined from field observation of a sample taken from an exposed pit. Incorporating this stratigraphy in the above formulas gives:

$$K_{vert\ distal} = \frac{b_{distal}}{\left(\frac{b_{clay}}{K_{clay}}\right) + \left(\frac{b_{silt}}{k_{silt}}\right) + \left(\frac{b_{sand}}{k_{sand}}\right)}$$

$$K_{hor\ distal} = \frac{b_{clay}\ k_{clay} + b_{silt}\ k_{silt} + b_{sand}\ k_{sand}}{b_{distal}}$$

A representative model of the 6-inch Distal is comprised of the following laminae thicknesses and hydraulic conductivities:

Stratigraphic Unit i	b_i (cm)	K_i (cm/sec)
clay	3.0	$5x10^{-7}$
silt	6.5	$1x10^{-5}$
sand	5.5	$2.5x10^{-4}$
K_h (mean horizontal permeability of Distal from slug tests)		$9.7x10^{-5}$
K_v		$2.2x10^{-6}$
K_h/K_v		45

Since the horizontal hydraulic conductivity of the Distal (mean = 9.7×10^{-5} cm/sec.) is primarily associated with the higher-permeability sand layers (laminae), the hydraulic conductivity of the sand unit was back-calculated from the above equation with K_h set equal to the measured value of 9.7×10^{-5} cm/sec. The silt and clay laminae have negligible effect. The permeabilities of the clay and silt units were estimated from (1) literature values for these soil types (Freeze and Cherry, 1979; Bear, 1979; Domenico and Schwarz, 1990), using median to high-end values, and (2) typical minimum relative differences in permeabilities for clays, silts, and sands.

3.7.2.3 Bedrock Hydraulic Conductivity

The hydraulic conductivity of relatively competent bedrock was measured using Packer tests at 12 locations in the Study Area and within the cased and uncased portions of two former drinking water wells (B120E, Riverside School and B127D, Curran Residence). The nature of packer testing requires that the bedrock be relatively competent such that the inflatable rubber packers can seal off the borehole without being punctured or lodged in the corehole due to sluffing of bedrock from fractures. Due to the logistical problems involved with performing a packer test and installing a well in weathered or fractured bedrock, ESE was not able to test the hydraulic conductivity of the weathered/fractured portions of the bedrock. Accordingly, the results of the packer tests cannot be exclusively used to predict the hydraulic conductivity of the fracture zone, but may rather represent an average of the overall hydraulic conductivity of the entire bedrock matrix. The results of the packer testing from Phases 1A and 1B are presented in Table 3-11.

At B136C and B139C, constant flow tests were performed on sections of bedrock through unscreened and screened boreholes, respectively. The hydraulic conductivity of the bedrock at B139C, screened from three to 25 feet below the bedrock surface, appears to be extremely high (8×10^{-3} cm/sec) and compares with the value calculated from the packer test at B115, on the order of 0.01 cm/sec. Results of the packer test from B139C were two orders of magnitude lower. The difference between the packer and constant flow test results at B139C may be associated with the larger test interval for the constant flow test (97.2 to 122.2 feet below grade) compared to the packer test (109.0 to 122.8 feet below grade). A higher degree of fracturing may have been encountered in the constant flow test interval.

The results of bedrock hydraulic conductivity testing across the entire Study Area suggest that the hydraulic conductivity of the competent portion of the bedrock is on the order of approximately 1×10^{-5} cm/sec. Exceptions to this occurred at B115 and B139 where a highly weathered and fractured bedrock was encountered.

3.7.3 Groundwater Flow

Groundwater in an overburden aquifer flows through a porous medium comprised of soil grains containing voids which are completely filled with water (i.e., saturated). The combined effect of elevation and pressure at any point in the aquifer defines the piezometric head at that point, and the direction of groundwater movement in isotropic materials can be determined from differences in the piezometric head (water level), between monitoring wells. The horizontal hydraulic gradient between two points is defined as the difference in head between the two points divided by the distance between the two points. Accordingly, groundwater flows in the direction of lower piezometric head at a rate dependant upon the hydraulic gradient, effective porosity, and the hydraulic conductivity of the aquifer material.

Monitoring well water level measurements, equal to the piezometric head in the aquifer, were recorded on a monthly basis during Phase 1A between May 30 and November 11, 1991. Additional monthly measurements were recorded during Phase 1B between May 27 and September 10, 1992. Since the first five rounds of water level data from Phase 1A were collected prior to installation and development of the last well, only the last three rounds of water level data are complete. Similarly, only the last two rounds of data from Phase 1B are complete. During Post-Screening Investigations, two additional rounds of water level measurements were completed on August 25 and September 7, 1993. Water level data are presented in Table 3-12.

The long term water level measurements presented in Table 3-12 show seasonal variation. Because the water levels generally never varied by more than 1.5 feet in standard deviation, seasonal variation appears not to play a major role. The hydraulic gradient on-site is very large due to the great relief of the ground surface and bedrock surface. These large hydraulic gradients are the likely reason that the groundwater flow direction is not greatly affected by seasonal water level fluctuations.

3.7.3.1 Groundwater Flow

Upper Proximal

The Upper Proximal is unconfined. Groundwater enters the Upper Proximal as recharge from precipitation, seepage from the unnamed stream, and unsaturated flow at the top of the Distal. Groundwater leaves the Upper Proximal as discharge to the unnamed stream, as evapotranspiration in the wetlands and as underflow at the southwest boundary (IWS 2 Area). In this area, groundwater underflow from the Upper Proximal enters the Lower Proximal through a breach in the Distal (the Esker Delta Deposit). A head differential of up to 25 feet is observed between the Upper Proximal and the Lower Proximal at this location.

The shallow groundwater flow regime Upper Proximal is a function of the thickness and orientation of the Distal (leaky confining layer) and is therefore largely isolated from groundwater flow at depth through the Lower Proximal. The direction of groundwater flow in the shallow portion of the aquifer, above the Distal, is generally south-southwest toward IWS 2. Figure 3-12 presents the shallow well natural piezometric surface and the ground surface topography, with general stream lines.

Mounding of water in the Upper Proximal portion of the aquifer along the eastern edge of the SWDA is accentuated by the contribution of interflow (lateral subsurface flow in the unsaturated zone) from the SWDA and the eastern uplands near IWS 3. Observations of SWDA operations between April and November of 1991 indicate that the fill and cover practices on the SWDA produce a north-south trending ridge which results in easterly, southerly, and slight westerly sloping to horizontal bedding within the SWDA. Precipitation that occurs on the SWDA and infiltrates into the waste mass is, therefore, directed either easterly or southerly from the SWDA. During precipitation events, interflow (resulting from inclined alternating beds of soil fill and trash within the SWDA) has the effect of directing infiltration to the east and south, mounding groundwater along the eastern edge of the SWDA above the Distal. The additional infiltration, combined with the low permeability of the Distal, likely results in mounding of groundwater above the top of the Distal. Although there is a large downward vertical hydraulic gradient in this area, the groundwater in this Upper Proximal portion of the aquifer will tend to move horizontally to the south toward IWS 2 through the more permeable Upper Proximal, rather than vertically downward through the laminated, lower permeability sediments that comprise the Distal.

In summary, the groundwater flow in the Upper Proximal converges from the northwest (the SWDA area) and northeast (the valley wall) toward the center of the unit. The net shallow groundwater flow direction, and observed flow direction in the southwest third of the unit, is toward the southwest.

Lower Proximal

The Lower Proximal exists along the eastern perimeter of the SWDA and thickens to the south and west, becoming the primary overburden aquifer west and southwest of the SWDA. The Lower Proximal is generally unconfined. However, the potentiometric surface is above or within the Distal in wells at IWS 2 and in wells east of the SWDA (Plates F, G, H, J, K, and L). Accordingly, the Lower Proximal has varying degrees of confinedness. The water table drops below the Distal into the Lower Proximal beneath the western portion of the SWDA due to the southerly dip of the Distal and the Deltaic discussed in Section 3.5.

Precipitation recharges the Lower Proximal where the Distal is breached by the Esker Delta and in the southern third of Study Area where the Distal is missing. The Lower Proximal is also recharged by leakage from the Distal, losing reaches of the unnamed stream (as discussed in more detail in Section 3.7.5) and groundwater underflow. Groundwater leaves the Lower Proximal as discharge to the Passumpsic River, and as groundwater underflow to the regional groundwater system.

On the eastern side of the Study Area where the hydraulic conductivity is low, the Lower Proximal is thin, and runoff from the valley wall is high, the hydraulic gradient is in the range of 0.05 to 0.09. Groundwater flow in this area is to the west-northwest, approximately perpendicular to the bedrock valley wall. Under the SWDA, the hydraulic gradient decreases rapidly, and groundwater flow turns toward the southwest as the hydraulic conductivity and saturated thickness increase. Hydraulic gradients in the Lower Proximal between the SWDA and the Passumpsic River are in the range of 0.001 to 0.002. Figure 3-13 presents the medium well natural piezometric surface with general stream lines.

Fractured Bedrock

The northeast portion of the fractured bedrock zone, in the area of IWS 3, is semi-confined by the Distal, which lies directly above bedrock in this area. Over the remainder of the Study Area, the fractured bedrock is overlain by the Lower Proximal. Groundwater enters the fractured bedrock as groundwater underflow through bedrock and from the Lower Proximal. Groundwater exits the fractured bedrock as groundwater underflow through bedrock and possibly into the Lower Proximal.

The hydraulic gradient in the fractured bedrock, as measured in the IWS 2 Area, is on the order of 0.09. The direction of decreasing hydraulic gradient is west to west-northwest. Because of the southwest orientation of the fractured bedrock zone and anisotropy axis, the groundwater flow is not perpendicular to the hydraulic gradient contours, but is more toward the southwest, following the fracture zone. Figure 3-14 presents the bedrock natural piezometric surface with general stream lines. Wells (both bedrock and deep overburden wells) shown on Figure 3-14 were used to develop the figure. Deep wells were used in areas where a definite confining layer exists above the bedrock (i.e., Distal).

3.7.3.2 Natural Vertical Gradient

The natural vertical gradient was calculated from well clusters using differences in head and vertical distance between well screens between the medium and deep wells. The vertical gradient is represented on all of the geologic cross-sections by the water levels shown for each screened interval (shallow, medium and deep).

The vertical gradient between the medium and deep wells is shown in plan view in Figure 3-15. As shown, water flows downward, particularly in the IWS 2 area, where there is a natural groundwater sink. Water is also shown to then discharge vertically upwards nearer the Passumpsic River, which is hydrologically reasonable.

3.7.3.3 Summary of Regional Groundwater Flow

The Lower Proximal east of the SWDA becomes the sole aquifer south and west of the SWDA as the Distal pinches out to the south and becomes unsaturated to the north and west. This aquifer is in good hydraulic connection with the regolith and upper portion of the bedrock, and top of rock groundwater monitoring wells, as suggested by the fractured nature of the upper bedrock and analytical data obtained from bedrock.

As shown on Figure 3-13, flow is generally westerly with a relatively large hydraulic gradient as far west as the 693 piezometric head contour. The gradient then flattens, with an increase in the aquifer permeability (Table 3-7), and flow direction becomes southwest to south as the velocity field aligns with the flow direction of the Passumpsic River. The groundwater hydraulic gradient flattens due to recharge from surface water at the Vail Dam. The water level recorded in the Passumpsic River above the Vail Dam coincides with the elevations in a large majority of the wells located throughout the low lying area northeast of the Vail Dam. In summary, the piezometric head within the aquifer in the area between B201 and the Dam is relatively constant due to the strong hydraulic connection between the Passumpsic River and the aquifer, creating a flat water table in this area.

3.7.4 Groundwater-Surface Water Relationship

Falling head tests were performed on each of the eleven piezometers (refer to Figure 2-19 for locations) located in the unnamed stream. The computed permeability of the stream sediments, presented in Table 3-13, ranged from 6.3×10^{-3} cm/sec to 1.3×10^{-5} cm/sec. The geometric mean value for the stream sediments was 1.5×10^{-4} cm/sec. Water level data from the piezometers is presented in Table 3-12. Vertical hydraulic gradients observed in the piezometers are presented in Table 3-14 for seven dates beginning in late June and ending in early November.

A negative gradient in Table 3-14 indicates that the water level elevation inside the piezometer, which effectively measures groundwater piezometric head below the stream bed, is less than the water level (head) in the stream, resulting in a net loss of water from the stream (a "losing" reach of stream). Conversely, a positive gradient indicates there is a net addition of water to the stream via groundwater discharge (a "gaining" reach of stream). The unnamed stream exhibited a negative gradient near the northern extent of the Landfill, and alternated between losing and gaining stretches south through the IWS 2 area. As shown in Table 3-14, piezometers 305 and 309 indicate that these stretches of the stream alternate between gaining and losing over time. Stretches of the stream near 307 and 310 were dry during a majority of the summer, while stretches near 308 and 311 were consistently losing.

The surface water nearest the Landfill includes the unnamed stream, Lily Pond, and the Passumpsic River. The elevation of surface water measured in Lily Pond was surveyed to be 805.10 feet on 11/10/93. This water elevation falls within the natural progression of shallow water level elevation for groundwater in the Study Area. This indicates that groundwater probably flows from Lily Pond under Lily Pond Road to feed the unnamed stream. The unnamed stream then courses through the site to the Passumpsic River as shown in Plate R.

The groundwater-surface water interaction on-site, disregarding bank seepage from the landfill, is best characterized in Plate R by the stream piezometers installed throughout the length of the unnamed stream. Vertical flow direction is shown by up and down arrows for various measurement times before and during the pumping tests. Many stream piezometers could not be used at times because of a dry stream (surface water is necessary to obtain the vertical flow direction). However, precipitation occurred during the pumping tests (discussed in Section 3.8), so vertical direction of flow was obtained at that time.

Plate R shows that some piezometers, such as PZ-306 and PZ-303, showed a consistently losing stream (water flowing from the stream into the shallow aquifer), whereas just downstream, PZ-302 shows a mostly gaining stream.

Whether the unnamed stream is gaining or losing relative to the groundwater depends generally on topography (the location of the shallow groundwater surface). At PZ-306, the shallow groundwater is closer to the surface, than at PZ-311 where flow shows a consistently losing stream. In still other cases, the direction of vertical flow was more sensitive to variations in groundwater/surface water levels, and showed some variation (PZ-304, PZ-309).

A more detailed measurement program of stream piezometer PZ-306 was performed during the pumping tests, as shown in Figures 3-10, 3-17 and 3-18. These figures show the detailed effects of precipitation on surface and groundwater. Figure 3-16 for the 142 test shows a record at PZ-306 during a period with no precipitation, when the stream is gaining. Figures 3-17 and 3-18 show that during precipitation, a short term reversal in vertical flow occurs. This indicates that during a rain event the steam becomes a losing at PZ-306, while the aquifer is recharged with the surplus head in the stream, due to precipitation.

The surface water and shallow groundwater travel in the same general direction across the site in the vicinity of the unnamed stream. Surface water flows into and out of the ground depending on the reach of the unnamed stream (topography), and depending on precipitation. The unnamed stream then discharges into the Passumpsic River just after PZ-301, where water is generally recharging the aquifer (Plate R).

In summary, subsurface interflow of pore water, associated with precipitation and runoff from the SWDA and precipitation runoff from the eastern highlands, has an appreciable impact on the water levels observed in the piezometers and the stream. Runoff and lateral movement of moisture in the unsaturated zone, from the steep sides of the eastern embankment of the unnamed stream, and from the SWDA, are the primary contributors to stream and groundwater levels. Consequently, labeling portions of the unnamed stream as losing or gaining can be misleading. The gaining and losing condition of the stream at any point in time is highly dependant upon the precipitation occurring before and during times that water level data are recorded. Given the variable nature of the stream and the limited amount of water that occupies its channel, it is unlikely that the unnamed stream has a significant influence on the groundwater in the vicinity of the SWDA.

Based on a slug test of piezometer B314, the permeability of river bed sediments in the Passumpsic River is at least locally, similar in magnitude to the underlying aquifer. The permeability of 0.02 cm/sec measured in piezometer B314 is characteristic of the Proximal unit west and south of the Landfill. In addition, water level measurements from the piezometers indicate a complete hydraulic connection between the stream and the Aquifer, as there was no head difference between river and groundwater elevations during the first two measurements (6/25 and 7/28) of the 1992 field season, as shown in Table 3-14. The slight upward gradient observed within the river bed on the September 10 round suggests that the groundwater recharges the stream at this location, possibly as a function of seasonally lower flow in the river.

3.8 PUMPING TESTS

The Study Area hydrogeology, conceptualized in Figure 3-9, was further analyzed during two constant flow pumping tests. The geologic cross-sections show that there are generally two main aquifers beneath the IWS 2 area. The bedrock aquifer, which includes a regolith zone lying above the fractured bedrock, is effectively sealed by a Distal confining layer (the degree of confinedness decreases away from the IWS 2 area). The bedrock aquifer pumping test utilized 204B as the pumping well (bedrock pumping test). The remainder of the sediments to the shallow water table were tested using 142 as the pumping well (overburden pumping test).

The 142 pumping test was performed from August 25 to 27, 1993 (a 48 hour test), and the 204B test was performed twice, from August 31 to September 2 and from September 7 to 10 (a 72 hour test). Only the data from the second 204B test was analyzed for aquifer parameters.

3.8.1 Pumping Test Procedure

Each pumping test consisted of a pumping well (142 or 204B) pumped at a constant discharge rate for 48 and 72 hours, respectively. Measurements of the resulting change in water levels in surrounding monitor wells and piezometers were measured.

Prior to conducting the two 72 hour pump tests, a series of smaller duration step-pumping (pilot) tests were conducted on the intended overburden and bedrock pumping wells. A step-pumping test is a continuous test during which the pumping rate is deliberately and incrementally changed (stepped). The purpose of conducting the pilot tests was to predetermine the optimal pumping rates for the two 72 hour tests. Data obtained during the pilot tests was also used to select the appropriate pumps and water treatment equipment needed for the actual 72 hour tests.

Following it's development, a step pumping test was conducted on the intended overburden pumping well (B142). A submersible pump with a maximum output of approximately 30 gallons per minute (gpm) was temporarily installed near the bottom of the well. After measuring the initial static water level in the pumping well and in several adjacent overburden and bedrock wells, pumping was initiated at 20 gpm. After monitoring the drawdown in the pumping well and in the adjacent wells for approximately 2 hours the pumping rate was increased to approximately 30 gpm. The pump was allowed to run for approximately one more hour during which the drawdown was continually monitored and recorded. This drawdown data was analyzed as discussed in Section 3 of this report and an optimal pumping rate and associated equipment needs were determined for the eventual 72 hour overburden pumping test.

A step-pumping test was conducted at the originally intended bedrock pumping well (B141). However, data from this test indicated that the yield of this well would be inadequate for the purposes of conducting large scale bedrock pumping test. In an effort to identify an existing bedrock well best suited to conducting a 72 hour pumping test, step pumping tests were conducted at wells B203B and B204B. The analysis of data obtained from these step tests indicated that B204B was the bedrock well best suited for the test.

After the step pumping tests were completed and optimal pumping rates for both the overburden and bedrock wells were determined, it was possible to estimate the total volume of water which would be removed from the wells during the 72 hour tests. A pre-test estimate of the amount of water to be generated was necessary because: 1) the water had to be treated, and; 2) the water had to be transferred away from the vicinity of the pumping wells during the tests.

Since the groundwater at this site is known to contain certain amounts and types of contaminants and since a relatively large amount of groundwater (on the order of 500,000 gallons) would be generated during the pumping tests, it was necessary to devise a means to treat the groundwater extracted from the pumping wells prior to discharging it back to the ground surface. Based on chemical data obtained during previous groundwater sampling events at this site, a water treatment system was designed to remove the known organic contaminants prior to it's eventual discharge back to the ground surface.

The water treatment system designed for these pumping tests was comprised of a Carbonair STAT-30 portable air stripper, used to remove the bulk of the organic contaminants, followed by a series of Westport Environmental System LM-15 granular activated carbon (GAC) cells used as a final treatment. This treatment system, which has a capacity of 30 gpm, was installed inside the boundaries of IWS 2 within approximately 100 feet of the pumping wells.

Because it was not desirable to discharge large volumes of water to the ground surface in the vicinity of the pumping well during the pumping test, the extracted groundwater was to be transferred as far away as possible following it's treatment at the pumping well site. To accomplish this, a 2,000 gallon transfer tank was installed in close proximity to the treatment system and a retention pond, lined with polyethylene sheeting, was constructed approximately 900 feet northwest of IWS 2. Using this treatment and transfer system, water was pumped from the treatment system into the transfer tank and ultimately discharged into the retention pond, to allow a more controlled recharge back to the ground surface a considerable distance away from the pumping site.

Since the optimal pumping rate for the overburden pumping well (B142) exceeded the 30 gpm treatment capacity of the treatment system, an untreated groundwater holding cell was constructed adjacent to the treatment system west of IWS 2. This holding cell was lined with polyethylene sheeting and furnished with a sump so that untreated water could eventually be delivered to the treatment system. During the overburden pumping test, raw groundwater was pumped directly from the well and into the holding cell. From the holding cell the water was pumped into the treatment system and ultimately discharged into the retention pond via the transfer tank. The optimal pumping rate for the bedrock pumping test was less than 30 gpm, hence groundwater removed from the bedrock pumping well was delivered directly to the treatment system.

Due to an equipment failure, the first bedrock pumping test was aborted after approximately 32 hours. After allowing several days for the aquifer to stabilize a second bedrock pumping test was conducted for a full 72 hours.

Prior to the pump tests, two samples of groundwater were collected from the overburden pumping well for characterization purposes. These samples were submitted for laboratory analysis for VOC (EPA method OLMV): semi-volatile organic compounds (EPA method OLMS): CLP metals (EPA method ILM01): total cyanide (EPA method ILM01): biological oxygen demand (EPA Method 405.1): total organic carbon (EPA method 415.1): total dissolved solids (EPA method 160.1): chemical oxygen demand (EPA method 410.1): ammonia-nitrogen (EPA method 350.2): hexavalent chromium (EPA method 7196): and, total phenols (EPA method 420.1).

Analytical results for compounds detected for the pre-test groundwater characterization are provided in Table 3-15. At regular intervals during the pump tests, untreated groundwater samples were collected from the pumping well for analysis for VOC. Table 3-16 presents the analytical results for VOC for groundwater collected during the pumping tests.

Additionally, during the pump tests, samples of treated water were collected every four hours and analyzed in the field, for VOC by headspace analysis, using a Photovac 10550 field gas chromatograph, to assure that the treatment system was functioning properly.

Background water levels were collected during periods when no groundwater was being pumped, which allowed the evaluation of regional water level changes and natural aquifer characteristics. Atmospheric pressure was also monitored concurrently with the water levels using an absolute pressure transducer to determine its effect on the water levels. This information helped to determine the degree of confinedness of the aquifer, and consequently also helped to separate the wells into shallow, medium and deep designations.

Finally, aquifer parameters are calculated based on analyzing the water level changes induced by the pumping well (142 or 204B).

3.8.2 Pumping Rate

Pumping rate is an important variable in the calculation of Transmissivity (T). Pumping rate was generally measured using brass impeller-driven in-line flow meters. In the case of the 204B test, silt problems resulted in the additional use of measuring flow with two 6-gallon buckets. The average pumping rate for the 142 test was 76.6 gpm with a standard deviation of 1.4 gpm, while the pumping rate for the 204B test (near its maximum) was 14.3 gpm with a standard deviation of 0.7 gpm.

3.8.3 Pumping Test Data Processing

There are many natural and well induced factors to consider before the water level measurements from each pumping test can be analyzed. The primary natural influences on water level in the Study Area include precipitation, regional water level fluctuations, atmospheric pressure, and diurnal effects such as earth tides. Additional considerations include the partial penetration of pumping wells and observation wells, presence of a pumped well skin etc.

3.8.3.1 Partial Penetration Correction

Water level measurements should be corrected for the degree of penetration of the pumping well. This means that if a pumping well is screened in only half the aquifer being tested that water levels measured in nearby monitor wells must be corrected depending on the location of the respective well screens.

The 142 pumping well is fully screened throughout the overburden sediments, however, and therefore does not require a correction for partial penetration. Owing to the nature of the fractured bedrock aquifer, it would be difficult to assume a degree of penetration for pumped well 204B. However, since fracturing frequency is generally reduced with depth it can be assumed that for practical purposes 204B is fully penetrating within the bedrock aquifer.

3.8.3.2 Atmospheric Pressure Correction

Atmospheric pressure changes can easily alter the measured water levels during the pumping test. Atmospheric pressure was monitored throughout the testing, and is presented in Figure 3-19 relative to August 20, 1993. Figure 3-20 shows an example hydrograph of 109A, 109B and 109C for the 204B pumping test (9/7/93). Also presented on Figure 3-20, is the change in atmospheric pressure for the same period. The water levels show a virtual mirror image of the change in atmospheric pressure.

The firs step in reducing the data with respect to atmospheric pressure is to consider a possible time lag between change in atmospheric pressure and response of water level. This was examined using the linear correlation routine PEARS from Numerical Recipes (Press et al., 1989). No time lag was detected for wells screened at various depths at the Landfill, as can also be seen by examining Figure 3-20.

Next, a similar one-parameter correlation program using the method of least squares was written to correlate the atmospheric data to the water level data. The parameter provided a constant factor of the change in atmospheric pressure that could be subtracted from corresponding water levels. The result is the filtered data presented in Figure 3-20. Figure 3-20 shows that without atmospheric pressure the water levels in the 109 well cluster did not change during the 204B pumping test, and were therefore not significantly affected by the pumping.

Figure 3-20 is also a good example of how atmospheric pressure was used to determine whether a well was actually shallow (unconfined) or not (medium or deep wells). The more confined the screen location, the larger the affect by atmospheric pressure. Because 109A was significantly affected by atmospheric pressure, it was not included in the shallow water level piezometric surface of Figure 3-13.

Each well in the Study Area was examined in light of atmospheric pressure. The atmospheric pressure filter coefficients for all the wells are presented in Table 3-17. Hydrographs similar to Figure 3-20 for most wells are presented in Appendix N. In some cases, a filter coefficient had to be estimated based on the geologic cross-sections. Pumping test data were corrected for atmospheric pressure before analysis to obtain aquifer parameters.

3.8.3.3 Background Water Level Correction

Regional water levels can change during a pumping test independent of atmospheric pressure. Pressure transducers were placed in wells located far enough from the pumping wells as to not be influenced significantly by pumping. Background wells MW8 and 202OW were used for the 142 pumping test (1840 and 1480 feet from 142, respectively), and 112B was used for the 204B test (1410 feet from 204B).

The background water levels for the 142 test corrected for atmospheric pressure are shown in Figure 3-21. The sharp increase in water level shown at the beginning of the water level record is likely due to an on-site precipitation event. During the pumping test, MW8 continued to show water level decline from the precipitation event, but 202OW remained essentially constant. Because the water level changes were not consistent, and not large, this correction was not needed.

The background well for the 204B pumping test was 112B, and showed no water level trend after correction for atmospheric pressure as shown in Figure 3-22.

The small diurnal effects shown in the background water levels are probably due to earth tides. The magnitude of this effect was dependent on each well, but was not recognizable/significant in the data from most wells.

3.8.3.4 Additional Considerations

To insure that withdrawal of water would not potentially induce contaminant migration of water at well ERT-1, water level readings were collected at the well by hand. The ERT-1 hydrograph for the 142 pumping test is shown in Figure 3-23. No significant change in water level was observed during the test.

Figure 3-24 shows monitoring wells 113B and 113C hydrographs for the entire pumping test period (note the 3 different measurement periods). Monitor well 113C was screened in such impervious bedrock that it was still recovering from when it was drilled and flushed, as demonstrated in the calculations on Figure 3-24. Monitoring well 113C was not used in the analysis, but illustrates the discontinuous nature of the fractured bedrock aquifer.

3.8.4 Pumping Test Analysis Results

The 142 pumping test results for shallow, medium and deep wells are presented in Tables 3-18, 3-19, and 3-20. The results show water level elevation data before and just prior to the end of the pumping test, as well as uncorrected and corrected drawdown for each well. The corresponding results for the 204B test are presented in Tables 3-21, 3-22, and 3-23.

3.8.4.1 Drawdown Maps

The drawdown plots shown in Figures 3-25 and 3-26 were obtained from subtracting corrected water levels before and just prior to the end of each test. The drawdown map shows the extent and magnitude of influence of the pumping well.

The contrast between the corrected drawdown induced by pumping tests 142 and 204B is striking. The zone of drawdown for the 142 test shown in Figure 3-25 appears to be a fairly uniform cone of depression, detectable to only 300 feet from the pumped well. This indicates a high transmissivity and storage for the overburden aquifer.

In contrast, the zone of drawdown shown in Figure 3-26 for both 204B pumping tests (8/31/93 and 9/7/93) shows a strong anisotropy. The direction of the primary transmissivity of the anisotropy is drawn in Figure 3-26 as north 45 degrees east along the axis of the elongated drawdown. The direction of anisotropy is consistent with the conceptual model for the bedrock aquifer shown in Figure 3-9.

The zone of influence from the 204B pumping test (9/7/93) was detectable over 1000 feet from the pumping well despite a pumping rate more than five times less than that of the 142 pumping test.

3.8.4.2 Piezometric Surfaces and Vertical Gradient

The maximum impact of drawdown for the 142 pumping test was seen in the medium water levels. Very little change in the medium well potentiometric surface was observed, as shown in Figure 3-27, however, despite the 76 gpm pumping rate. This is an indication of the high transmissivity and storage of the proximal sediments.

A dramatic change in the bedrock piezometric surface was induced with only a 14 gpm pumping rate, however, as shown in Figure 3-28. This is due to the low storage and higher degree of confinedness of the fractured bedrock aquifer.

In contrast to the natural vertical gradient shown in Figure 3-15, the increased vertical gradient between the shallow and deep wells for the 204B pumping test (9/7/93) is shown in Figure 3-29.

This vertical gradient is what causes the leakage of water into the fractured bedrock aquifer, as represented by the leakance coefficient (L).

3.8.4.3 Cooper-Jacob Parameter Analysis

The transient portion of the water level data was analyzed using the Cooper-Jacob (or modified Theis) method. The Cooper-Jacob method is strictly only applicable when the Theis $u < .05$:

$$u = \frac{1.87 S r^2}{T t}$$

where:

T = tranmissivity (gpd/ft)
r = radial distance from pumping well
S = storage coefficient
t = time since pumping started (days)

The Cooper-Jacob method of analysis is a function of the transmissivity of material in the front of the cone of depression caused by the pumping test. The transmissivity calculation is independent of the material between the radius of the cone front and the pumping well when the Cooper-Jacob method is used.

The Cooper-Jacob method therefore has the advantage of being independent of a well skin or any well losses (Butler, 1990). A sample Cooper-Jacob drawdown versus time graph is shown in Figure 3-30 for monitoring well 108I, along with the calculations for T and S.

The transmissivities analyzed in this way are shown in Table 3-24 for the 142 pumping test, and in Table 3-25 for the 204B pumping test. The remaining Cooper-Jacob plots and calculations are presented in Appendix O.

3.8.4.4 SUPRPUMP Analysis

The program SUPRPUMP (Bohling et al, 1992) was used to analyze the pumping test data. SUPRPUMP uses the Gauss-Newton, or linearization, method to solve the nonlinear parameter estimation problem for pumping test analysis. SUPRPUMP analyzes multiple observation wells to obtain aquifer parameters that represent the whole data set. The methodology employs a matrix of sensitivities of the calculated drawdown at all observation points and times to the pumping test function parameters. This allows for the analysis of several observation wells at once.

The 142 test provided well hydrographs used in the SUPRPUMP analysis as far from the pumping well as 139C and 103C. Various wells were tried in the analysis, without much change in the result. This could be because the data tended to follow the Theis curve throughout the tests (Appendix O). Wells 139C and 103C were also influenced by the 204B pumping test, showing that there are degrees of interconnection between the two tests.

The 142 test was performed in a locally confined area, though 139C and 103C are screened in a confined zone. In addition, the aquifer thickness was extremely variable, and taken as a whole very difficult to establish. The 204B test was performed using the anisotropy found from the drawdown map shown in Figure 3-26. The anisotropy orientation was used in SUPRPUMP to obtain the primary and secondary transmissivity, storage coefficient and leakance of the confining layer. A sample SUPRPUMP output is provided in Appendix P. The SUPRPUMP results are summarized in Tables 3-24 and 3-25 for the 142 and 204B pumping tests, respectively.

4.0 NATURE AND EXTENT OF CONTAMINATION

This section presents the results of the environmental sampling and analysis performed during the RI. Section 4.1 discusses results of the contaminant source investigation. Section 4.2 discusses the results of the groundwater investigations. Section 4.3 discusses the results of the surface water/sediment investigations. Section 4.4 discusses the results of the ecological investigation. Summary tables generally are referred to herein and used for discussion of the data. Complete data report sheets are provided in Appendix J.

Data validation was performed on all Level 4 data, according to the requirements of EPA Region I Laboratory Data Validation Functional Guidelines for Evaluating Organic Analyses and Inorganic Analyses. Data tables presented in Appendix J include qualifiers generated during the data validation process. The final data qualifiers, indicated on the analytical data tables, have the following meanings:

- U Undetected
- J Estimated concentration
- R Value rejected
- B Below Contract Required Detection Limit (CRDL), but above the Instrument Detection Limit (IDL) (metals only)
- Y Below Contract Required Quantitation Limit (CRQL), (pesticides/PCB only)
- E Concentration in sample exceeded range of calibration curve

Summaries of the data validation results are presented in Appendix K.

Much of the data was generated from Contract Laboratory Program (CLP) methods for organics and inorganics. Organics analyses included TCL-VOC, TCL-A/BN, and TCL-Pesticides/PCB, with analyses conducted pursuant to the requirements of the CLP Statement of Work for Organics, dated February 1988. TCL-VOC and TCL- A/BN analyses include a mass spectral search for additional compounds, identified as Tentatively Identified Compounds (TICs).

Laboratory report sheets for TICs are provided in Appendix L. Inorganic analyses included TAL-Metals and cyanide, with analyses conducted pursuant to the requirements of the CLP Statement of Work for Inorganics, dated July 1988.

4.1 CONTAMINANT SOURCE INVESTIGATION

This section presents the results of the environmental sampling and analysis conducted within the Landfill (SWDA and IWS Areas).

4.1.1 Air Quality Investigation

4.1.1.1 Air Quality Monitoring Surveys

Meteorological measurements were taken during both rounds of air quality monitoring surveys. On May 24, 1991 (Round 1 VOC sampling), the barometric pressure measured 29.5 inches of mercury. The wind velocity ranged from 0 mph (with occasional gusts to 10 mph) between 0700 hours and noon, to 7 mph through the afternoon until sampling ended at 1700 hours. Wind was from the WSW at 1300 hours, SSE at 1500 hours, and NNW at 1700 hours. Air temperature was 64°F at the start of the sampling, rising to a high of 72°F at midday. On May 25, 1991 (Round 1 asbestos sampling), the wind was from the SW at 0900 hours through noon, SSW through 1500 hours, and SW at 1700 hours. Wind velocities varied from 5-15 mph throughout the sampling period. Air temperature was 55°F at the start of sampling, reaching a high of 60°F. The Round 1 air sampling events were conducted prior to any intrusive field investigations. The SWDA was in active operation during the Round 1 air sampling events.

On September 6, 1991 (Round 2 asbestos sampling), wind velocities were less than 5 mph throughout the sampling period. Air temperature was 46°F at the start of sampling, reaching a high of 76°F. On October 29, 1991 (Round 2 VOC sampling), wind velocities were less than 5 mph throughout the sampling period. Barometric pressure was 29.97 inches of mercury. Air temperature was 23°F at the start of sampling, reaching a high of 44°F. The Round 2 air sampling events were conducted after the completion of intrusive field activities. The SWDA was in active operation during the Round 2 air sampling events.

As discussed below, the results for both rounds of air quality monitoring were similar, with neither round measuring contaminant concentrations much above the instrument detection limits. Furthermore, the meteorological conditions measured during the air quality sampling events were not extreme, either in temperature, wind speed, or barometric pressure. The impact of meteorological conditions on the results of the air quality monitoring appears, therefore, to be minimal.

During the Round 1 air quality survey, air emissions were measured from non-detect to 30 ppm with the flame ionization detector, up to 2.7 ppm with the photoionization detector, up to 0.3 ppm with the hydrogen sulfide monitor, up to 0.05 ppm with the hydrogen cyanide monitor, and between 0.1 to 0.3 mg/cubic meter with the dust monitor.

During the Round 2 air quality survey, air emissions were measured from non-detect to 15 ppm with the flame ionization detector, up to 1.0 ppm with the photoionization detector, up to 0.1 ppm with the hydrogen sulfide monitor, up to 0.02 ppm with the hydrogen cyanide monitor, and between 0.1 to 2.13 mg/cubic meter with the dust monitor (a single reading while walking through fine dust on the SWDA).

Both the hydrogen sulfide and the hydrogen cyanide instruments are subject to drift and interferences from, for example, truck diesel emissions from operations on the active SWDA. At locations where VOC were detected with the flame ionization detector, low photoionization results were observed, suggesting that the organic compounds detected were largely methane. Benzene and vinyl chloride were not detected, using direct reading detector tubes, at any sampling location. Positive readings were generally random across the Landfill and do not appear to be related directly to location within the Landfill.

Non-detectable results have the following specific detection limits:

INSTRUMENT	DETECTION LIMIT
Flame ionization detector (detects most VOC, including methane)	1 part per million (ppm)
Photoionization Detector (detects most VOC, but does not respond to methane)	0.5 ppm
Hydrogen Cyanide Monitor (detects gaseous hydrogen cyanide)	0.01 ppm
Hydrogen Sulfide Monitor (detects gaseous hydrogen sulfide)	0.1 ppm
Aerosol Dust Monitor (detects respirable dust)	0.01 mg/cubic meter

The high volume asbestos samples collected during both rounds had the following results. Only 3 out of the 27 samples collected contained any detectable asbestos fibers (Sample location 507 during Round 1 and sample locations 510 and 512 during Round 2). Each of the three positive samples had only a single asbestos fiber detected in the over 1,200 liters of air collected, which calculates to 0.002 asbestos f/cc of air. These results are 100 times less than the OSHA PEL of 0.2 f/cc.

Complete analytical results for Round 1 and Round 2 volatiles in air, are provided in Appendix J, on Tables J-1 and J-2, respectively. Table 4-1 summarizes compounds detected in the TO2 VOC analyses for Round 1 and Round 2 air samples. Only benzene, methylene chloride, 1,1,1-trichloroethane, and trichloroethene were detected.

Concentrations of benzene measured during Round 1 ranged between none detected to 0.00074 parts per million, volume/volume (ppmv). The calculation for converting ppmv to mg/m³ is as follows:

$$ppmv = mg/m^3 \; X \; \frac{24.45}{MW}$$

MW = molecular weight of compound

Benzene was detected at sampling locations 501 and 502 (IWS 1), 505 and 506 (IWS 3), 510 (western perimeter of the SWDA) and 512 (on the SWDA; this was the location with highest detected concentration). Benzene was detected in the replicate, but not the initial sample at location 509.

Concentrations of methylene chloride were measured during Round 1 and ranged between none detected and 0.00034 ppmv, estimated concentration. The compound was detected at sampling location 503 and 504 (IWS 2). Estimated concentrations were reported for 505 and 506 (IWS 3; the estimated concentration at 505 is the highest reported), and at 509 of the SDWA). Locations 510 and 511 had detectable levels of methylene chloride, while the finding in sample 512 was rejected in the data validation process.

Concentrations of 1,1,1-trichloroethane were measured during Round 1 and ranged between none detected to 0.00061 ppmv (estimated concentration). The compound was detected at sampling location 502 (IWS 1) and locations 503 and 504 (IWS 2; an estimated concentration in 504). An estimated concentration was reported at location 508 and detectable levels were observed at 511 (SDWA). 1,1,1-trichloroethane was detected in the replicate but not the initial sample taken at 509.

Concentrations of trichloroethene were measured during Round 2 in sample 503 at 0.0006 ppmv.

The air sampling locations closest to the nearest receptors, the trailer park contiguous with the SDWA, are 507 and 508. No VOC were detected at location 507, while only 1,1,1-trichloroethane (at an estimated concentration of 0.0006 ppm) was observed in sample 508.

The air quality survey suggests that most of the detectable organic vapors at the Study Area are methane. The concentrations of VOC detected in TO-2 air samples, collected at a height of three to six inches from the ground, do not indicate a significant source for VOC emissions. The photoionization results were well below a value of 15 ppm, established in the Work Plan as the criteria for going to an off-site survey. The detected concentrations are low and significantly below their respective permissible exposure limits (established in the Work Plan as additional criteria for going to off-site sampling), and the substantial dilution capacity of wind as compounds are transported make it unlikely that detectable concentrations of chemicals would exist off-site.

4.1.1.2 Air Quality Monitoring During Intrusive Activities

Air quality monitoring was routinely performed during drilling and test pit excavation, within the IWS Areas. This monitoring included: PID measurements, HCN measurements, and H_2S measurements at the perimeter of the exclusion zone during completion of borings B128, B129, and B130 (borings installed through each IWS Area); PID measurements at the perimeter of the exclusion zone during test pit excavation; and PID measurements, HCN measurements, H_2S measurements, respirable dust measurements, and % LEL measurements inside the exclusion zone (adjacent to the test pit) during test pit excavation.

Measurements taken within the exclusion zone during test pit excavation were recorded. Table 4-2 presents the ranges of values measured for each parameter at each test pit location. Measurements were not routinely recorded when taken at the borehole or at the perimeter of the exclusion zone, unless a PID reading in excess of 5 ppm (the action criteria for upgrade to Level

C protection established in the Health and Safety Plan) was measured, or if HCN or H_2S was detected.

During test pit excavation, no PID measurements taken at the perimeter of the exclusion were recorded as being in excess of 5 ppm. During the drilling of test borings B128, B129, and B130, no PID measurements taken at the perimeter of the exclusion zone were recorded as being in excess of 5 ppm, nor were HCN or H_2S detected.

Based on these measurements, it appears that intrusive work during remediation can be accomplished using care in the establishment of exclusion zones around intrusive activities and performing field air quality monitoring to assure compliance with air quality requirements.

4.1.1.3 Combustible Gas Well Measurements

The results of combustible gas measurements are shown below:

Location	7/19/91	7/25/91	11/11/91
111CG	95% LEL	267% LEL	286% LEL
112CG	0% LEL	1% LEL	8% LEL
MW11	0% LEL	1% LEL	282% LEL
MW12	0% LEL	1% LEL	48% LEL
VT1	0% LEL	3% LEL	34% LEL

Locations MW11 and MW12 are monitoring wells abandoned above the current water table. They are located near IWS 1, west of the SWDA and provide an indication of the methane levels at depth on the western boundary of the debris mass. VT-1 is a State-installed well, screened above groundwater, located north of IWS 1 near the northern boundary of the Landfill. Likewise, 111CG is located within the SWDA at the northern boundary, adjacent to the trailer park. These four locations confirm that, in areas associated with SWDA debris mass, elevated methane levels are present.

Location 112CG is located within the trailer park, adjacent to the northern boundary of the SWDA. It is not in the debris mass, but is in natural soil outside the SWDA. The low levels of methane detected in this well indicate that significant migration of methane has not occurred from the SWDA debris mass into natural soils north of the SWDA, and underlying the trailer park.

4.1.2 SWDA

This section discusses the environmental sampling and analysis conducted around the perimeter of the active SWDA. As outlined in the Work Plans, no intrusive sampling of the SWDA was performed during the RI.

4.1.2.1 Surficial Soil Sampling Results

Surficial soil samples were collected from areas where leachate flow from the SWDA had left visibly stained soil (Figure 2-5). In addition, a background surface soil sample (sample designation U101) was collected from the area around boring location B101. Sample locations 701, 702, 703, 704, 705, and 706 were collected along the eastern perimeter of the SWDA. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J, Tables J-3, J-4, and J-5 respectively. Table 4-3 presents a summary of the concentrations of compounds detected in any of the samples. As shown on Table 4-3:

- No VOC were detected in any of the samples, above the CRQL.
- No PCB or pesticides were detected in any of the samples, above the CRQL;

- Phthalates were detected at sample locations U703, U704, and U705, and benzoic acid was detected at sample location U703. No other acid/base neutral extractables were detected above the CRQL in any of the samples.

- Metals were detected above and below background concentrations (U101). Beryllium and cobalt were present in samples but not in the background sample. Arsenic at U705 and U706 and nickel at U706 were present at greater than three times background.

4.1.2.2 Leachate Sampling Results

Leachate samples were collected from three leachate flows along the eastern perimeter of the SWDA, at sample locations 801, 802, and 804 (Figure 2-5). The complete analytical results are presented for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses in Appendix J, on Tables J-6, J-7, and J-8, respectively. Table 4-4 provides a summary of the concentrations of compounds detected in any sample. As shown on Table 4-4:

- No pesticides or PCB were detected in any of the samples.

- Low levels of benzoic acid were detected at sample location 801, phenolic compounds were detected at sample location 802, and naphthalene was detected at sample location 804. No other acid/base neutral compounds were detected above the CRQL in any of the samples.

- No chlorinated VOC were detected in any of the samples, above the CRQL.

- A variety of non-chlorinated VOC (ketones, ethyl benzene, toluene, and xylenes) were detected at all three sample locations. The highest levels of non-chlorinated VOC were detected at sample location 802. No other VOC were detected in any of the samples, above the CRQL.

- Metals were detected above and below background concentrations. Background concentrations were determined from analyses of groundwater at monitoring well G101B. Arsenic and copper were detected in leachate samples, but not in the background well. Sample W801R, the replicate of W801, is significantly higher in all metals, than W801. This is potentially due to increased sediment in the replicate sample. Except for W801R, results for samples are generally within three times background concentrations.

- No direct correlation is apparent between the compounds measured in the leachate samples and those measured in associated surface soil samples. Significantly fewer organics were detected in surface soil samples, as compared to the leachates.

4.1.2.3 Test Borings

Soil samples were collected from four borings installed on the perimeter of the SWDA (samples S113I-A, S114I-A, S115I-A, and S117I-A) and analyzed for Full TCL/TAL compounds (Plate D). In addition, the soil sample from test boring S101I was designated as a background subsurface soil sample. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J in Tables J-9, J-10, and J-11, respectively. Table 4-5 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-5:

- Non-chlorinated VOC were detected above the CRQL in only one sample (S114I-A);

- Chlorinated VOC (TCE and DCE) were detected above the CRQL only in one sample (S113I-A);

- No pesticides or PCB were detected in any sample;

- Only one acid/base neutral compound was detected above the CRQL in one sample; benzyl butylphthalate in S115I-A;

- Non-detected results for acid extractable compounds were rejected in sample S117I-A, during data validation, because of low matrix spike recoveries;

- Metals were detected above and below background concentrations (S101I). Selenium was detected at S115, but not in the background sample. No other metals were measured in samples at levels exceeding three times background concentrations.

4.1.3 IWS 1

This section discusses the environmental sampling and analyses conducted in and around IWS 1.

4.1.3.1 Soil Vapor Survey

The results of the soil vapor survey conducted at IWS 1 are presented on Table 4-6. The data obtained from the soil gas survey was used, in conjunction with geophysical measurements, to identify test pit and boring locations at IWS 1, and was presented to EPA in the May 13, 1991 interim letter report. Figure 4-1 shows the concentration contours for total VOC tested, for IWS 1. VOC were measured in soil gas from primarily one area on the northeast corner of IWS 1, near and beneath the landfill access road. This is outside the delineated disturbed area for IWS 1 (as delineated on Figure 2-15). Boring B130 was installed near this area and no chlorinated VOC were detected in soil samples collected from that boring.

4.1.3.2 Surficial Soil Sampling Results

Two surficial soil samples (U713I and U714I) were collected on IWS 1 (as shown on Figure 2-5) and submitted to the laboratory for analysis for Full TCL/TAL Compounds. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J, on Tables J-3, J-4, and J-5, respectively. Table 4-7 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-7:

- No VOC were detected in either sample, above the CRQL;
- No PCB or pesticides were detected in either sample, above the CRQL;
- Low levels three PAH compounds (fluoranthene, phenanthrene, and pyrene) were detected in U713I, but no other acid/base neutral extractables were detected above the CRQL in either sample;
- Metals were detected above and below background concentrations (U101). Antimony, beryllium, and cadmium were detected in samples, but not in the background sample. Chromium, copper, and lead were measured in U713 at levels higher than three times background. Copper, iron, lead, nickel, and vanadium were measured in U714 at levels higher than three times background.

4.1.3.3 Test Pits Sampling Results

Six total samples, as shown on Figure 2-15 (P907I-A&B, P908I-A&B, and P909I-A&B), were collected, one from the fill and one from the natural soil below the fill, from three test pits at IWS 1, and submitted to the laboratory for analysis for Full TCL/TAL Compounds. In addition, the three fill samples were analyzed for a set of Waste Characteristics and RCRA Characteristics. The soil boring sample from S101I was designated as the background soil for these analyses. Table 4-8 presents the results of the analysis for Waste Characteristics and RCRA Characteristics as outlined in Section 2.5.1. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-12, J-13, and J-14, respectively. Table 4-9 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-9:

- Fill from all three test pits tested below the regulatory limit for RCRA characteristics, including TCLP;

- In general, the three samples exhibited elevated levels for waste characteristics tested. P908I-A showed high COD and TPH, and higher chloride than the other two fill samples.

- No pesticides or PCB were detected in any of the six samples;

- PAH were detected in P908I-A and P909I-B, pentachlorophenol was detected in P909I-B, and di-n-butyl phthalate was detected in P907I-A. No other acid/base neutral compounds were detected above the CRQL in any of the six samples;

- A variety of chlorinated VOC were detected in P908I-A. Trace levels of chlorinated VOC were detected in P907I-A and P908I-B. Trace levels of non-chlorinated VOC were detected in P908I-A. No other VOC were detected above the CRQL in any of the six samples.

- Metals were detected above and below background concentrations (S101I). Cyanide was measured in samples P908A and B. Cadmium and mercury were measured in P907A, and silver was measured in P909A, but not in the background sample. Barium was generally measured in samples at levels higher than three times background. Results for P908A generally exceeded three times background. Results for other metals in other samples generally were within three times background.

4.1.3.4 Test Borings

Eight soil samples were collected from four borings installed in and around IWS 1. Samples S109I-A, S109I-B, S110I-A, S111I, S130I-B, and S130I-C were analyzed for Full TCL/TAL

Compounds. In addition replicates at S109I-A (collected 5-21-91) and S130I-A were analyzed for TCL-VOC. The soil sample from boring location S101 was designated as the background sample for these analyses. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-9, J-10, and J-11, respectively. Table 4-10 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-10:

- Chlorinated VOC were detected at S109I-A, S130I-A, and S130I-B. No VOC were detected in S130I-C;

- Non-chlorinated VOC were detected in S130I-A and S130I-B. The non-chlorinated compounds included a variety of ketones, benzene, ethyl benzene, toluene, and xylenes;

- No other VOC were detected above the CRQL in any of the eight soil samples;

- No pesticides or PCB were detected in any of the eight samples;

- Acid/base neutral compounds (A/BN) were not detected above the CRQL in any of the eight samples, except S130I-B;

- A variety of PAH and 1,2-dichlorobenzene were detected in S130I-B.

- Metals were detected above and below background concentrations (S101I). Beryllium and cadmium were detected in sample S130-B, but not in the background sample. Arsenic, barium, and chromium were measured in S130-B, and zinc in S110-A, at levels exceeding three times background. Other metals in other samples were generally within three times background.

4.1.4 IWS 2

This section discusses the environmental sampling and analyses conducted in and around IWS 2.

4.1.4.1 Soil Vapor Survey

The results of the soil vapor survey conducted at IWS 2 are presented on Table 4-11. The data obtained from the soil gas survey was used, in conjunction with geophysical measurements, to identify test pit and boring locations at IWS 2, and was presented to EPA in the May 13, 1991 interim letter report. Figure 4-2 shows the concentration contours for total VOC, for IWS 2. As shown on Figure 4-2, VOC in soil gas were measured throughout a major portion of IWS 2, but primarily centered within Disposal Area 1 (as delineated on Figure 2-16). The results are consistent with the results obtained from chlorinated VOC analyses of soil samples from test pits excavated throughout IWS 2 (see Section 4.1.4.3). Soil samples from test borings installed in the area of highest soil gas concentrations (B107 and B129) exhibited elevated levels of chlorinated VOC, as discussed in Section 4.1.4.4.

4.1.4.2 Surficial Soil Sampling Results

Three surficial soil samples (U710I, U711I, and U712I) were collected on IWS 2, as shown on Figure 2-5, and submitted to the laboratory for analysis for Full TCL/TAL Compounds. The surface soil sample (U101) from the area around boring S101 was designated as the background sample. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-3, J-4 and J-5, respectively. Table 4-12 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-12:

- No VOC were detected in any of the three samples, above the CRQL;

- No PCB or pesticides were detected in any of the three samples, above the CRQL;

- No acid/base neutral compounds were detected in any of the three samples, with the exception of bis(2-ethylhexyl) phthalate in U711I;

- Metals were detected above and below background concentrations (U101). Metals measured in sample U710 generally exceeded three times background. Metals measured in other samples were generally within three times background.

4.1.4.3 Test Pits Sampling Results

Four samples, as shown on Figure 2-17 (P905I-A&B, and P906I-A&B), were collected, one from the fill and one from the natural soil below the fill, from two test pits at IWS 2, and submitted to the laboratory for analysis for Full TCL/TAL Compounds. The soil boring sample from location S101 was designated as the background sample. In addition, the two fill samples were analyzed for a set of Waste Characteristics and RCRA Characteristics. Table 4-13 presents the results of the analysis for Waste Characteristics and RCRA Characteristics. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-12, J-13, and J-14, respectively. Table 4-14 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-14:

- Fill from both test pits tested below the regulatory limit for RCRA characteristics, including TCLP, with the exception of barium for P906I-A;

- In general, the two fill samples exhibited elevated levels for waste characteristics tested. Both samples exhibited high COD and TPH;

- No pesticides or PCB were detected in any of the four samples;

- A variety of PAH were detected in all four samples and dibenzofuran was detected in both fill samples. No other acid/base neutral compounds were detected above the CRQL in any of the four samples;

- A variety of chlorinated VOC were detected in all four samples. Non-chlorinated VOC (benzene, ethyl benzene, toluene, and xylenes) were detected in P906I-A, and xylenes were detected in P906I-B. In general, VOC concentrations were higher in the native soil sample (P906I-B). No other VOC were detected above the CRQL in any of the four samples.

- Metals were detected above and below background concentrations (S101I). Cyanide was measured in all four samples. Selenium and silver were measured in samples P905B and P906A and B, but not in the background. Metals were generally measured in samples P905A and P906A at levels higher than three times background. Metals measured in other samples were generally within three times background.

4.1.4.4 Test Borings

Eight soil samples were collected from four borings installed in and around IWS 2. Samples S105I-A, S106I-A, S107I-A, S129I-A, and S129I-C were analyzed for Full TCL/TAL Compounds. Sample S134I-A was analyzed for TCL-VOC, TCL-A/BN, and TAL-Metals. In addition S107I-C and S129I-B were analyzed for TCL-VOC. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-9, J-10, and J-11, respectively. Table 4-15 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-15:

- No chlorinated VOC were detected above the CRQL in S105I-A or S106I-A. Trace levels of chlorinated VOC were detected in S107I-C. Elevated levels of chlorinated VOC were detected in S107I-A, S129I-A, S129I-B, and S129I-C;

- Non-chlorinated VOC were detected in S105I-A, S107I-A, S107I-C, S129I-A, and S129I-C. The non-chlorinated compounds included a variety of ketones, ethyl benzene, toluene, and xylenes;

- No other VOC were detected above the CRQL in any of the eight soil samples;

- No pesticides or PCB were detected in any of the eight samples;

- The re-analysis of S129I-C (S129I-CRE) was used in the database, as directed by the data validation.

- A variety of PAH were detected in S107I-A, S129I-A, and S129-CRE, methyl phenol was detected in S105I-A, and bis (2-ethyl hexyl) phthalate was detected in S107I-A. No other acid/base neutrals were detected above the CRQL in any of the eight samples;

- Metals were detected above and below background concentrations (S101I). Cyanide was measured in sample S129-A. Beryllium and cadmium were measured in S134-A, and beryllium in S105-A, but not in the background. Barium was measured in S107-A and S129-A, chromium was measured in S129-A, and zinc was measured in S106-A, at levels exceeding three times the background. Other metals in other samples were generally measured at levels within three times background.

4.1.5 IWS 3

This section discusses the environmental sampling and analyses conducted in and around IWS 3.

4.1.5.1 Soil Vapor Survey

The results of the soil vapor survey conducted at IWS 3 are presented on Table 4-16. The data obtained from the soil gas survey was used, in conjunction with geophysical measurements, to identify test pit and boring locations at IWS 3, and was presented to EPA in the May 13, 1991 interim letter report. Figure 4-3 shows the concentration contours for total VOC, for IWS 3. Soil gas VOC concentrations were generally low across the entire IWS 3 area. Two isolated areas of increased VOC concentrations were measured, one at the eastern edge of the IWS 3 (1-2 units) and in the center of IWS 3 (4-5 units). These levels are significantly lower than those measured in either IWS 1 or 2. The area on the eastern edge is far outside any delineated disturbed areas. A test pit installed in this area (TT3-5) indicated essentially natural material. Soil samples from test pits within IWS 3 contained generally low levels of chlorinated VOC, with the exception of TP902 (330 mg/kg TCE), as discussed in Section 4.1.5.3. TP902 is in a location which had little or no measured VOC in soil gas. Soil samples collected from boring B128, installed within the area of the soil gas survey, detected only trace levels of chlorinated VOC.

4.1.5.2 Surficial Soil Sampling Results

Three surficial soil samples (U707I, U708I, and U709I) were collected at or near IWS 3 and submitted to the laboratory for analysis for Full TCL/TAL Compounds. The surface soil sample (U101) collected from boring location S101 was designated as the background sample. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on Tables J-3, J-4 and J-5, respectively. Table 4-17 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-17:

- No VOC were detected in U707I or U708I, above the CRQL. Chlorinated VOC were detected in U709I;

- Non-chlorinated VOC (carbon disulfide, ethyl benzene, toluene, and xylenes) were detected in U709I;

- No PCB or pesticides were detected in any of the three samples, above the CRQL;

- No acid/base neutral compounds were detected above the CRQL in any of the three samples, with the exception of pyrene in U708I;

- Metals were detected above and below background concentrations (U101). Cyanide was measured in samples U708 and U709. Metal results in samples generally exceeded three times background for arsenic, barium, chromium, cobalt, copper, iron, lead, nickel, and vanadium.

4.1.5.3 Test Pits Sampling Results

Six samples, as shown on Figure 2-17 (P901I-A&B, P902I-A&B, and P903I-A&B), were collected, one from the fill and one from the natural soil below the fill, from three test pits at IWS 3, and submitted to the laboratory for analysis for Full TCL/TAL Compounds. In addition, the three fill samples were analyzed for a set of Waste Characteristics and RCRA Characteristics. Table 4-18 presents the results of the analysis for Waste Characteristics and RCRA Characteristics. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL- Metals analyses are presented in Appendix J on Tables J-12, J-13, and J-14, respectively. Table 4-19 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-19:

- Fill from all three test pits tested below the regulatory limit for RCRA characteristics, including TCLP;

- In general, the three samples exhibited elevated levels for waste characteristics tested. All three samples exhibited high COD and TPH.

- No pesticides or PCB were detected in any of the six samples;

- A variety of PAH were detected in P901I-A, methyl naphthalene was detected in P901I-B, bis (2-ethyl hexyl) phthalate and di-n-butyl phthalate were detected in P902I-A. No other acid/base neutral compounds were detected above the CRQL in any of the six samples;

- A variety of chlorinated VOC were detected in five of the six samples (no VOC were detected in P903I-B). Non-chlorinated VOC (various ketones, benzene, ethyl benzene, toluene, and xylenes) were detected in P901I-A, P901I-B, and P902I-A. No other VOC were detected above the CRQL in any of the six samples.

- Metals were detected above and below background concentrations (S101I). Cyanide was measured in all test pit samples. Sample results for metals in samples P901-A and P902-A and B, generally exceeded three times background. Sample results for P901-B and P903-B generally were within three times background.

4.1.5.4 Test Borings

Six soil samples were collected from three borings installed in and around IWS 3. Samples S101I (background), S103I-A, S128I-A (6/7), and S128I-B (6/10) were analyzed for Full TCL/TAL Compounds. The sample from S101 was designated as the soil boring background sample. An additional shallow sample at S128I-A (collected 5-22-91) and at S128I-B (collected 5-22-91) were analyzed for TCL-VOC. The complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals analyses are presented in Appendix J on

Tables J-9, J-10, and J-11, respectively. Table 4-20 presents a summary of the concentrations of compounds detected in any sample. As shown on Table 4-20:

- No chlorinated VOC were detected above the CRQL in S103I-A. Trace levels of chlorinated VOC were detected in S128I-B (6/10). Elevated levels of chlorinated VOC were detected in S128I-A (5/22), S128I-A (6/7), and S128I-B (5/22);

- Non-chlorinated VOC were detected in S128I-A (5/22), S128I-A (6/7), and S128I-B (6/10). The non- chlorinated compounds included a variety of ketones, benzene, ethyl benzene, toluene, and xylenes;

- No other VOC were detected above the CRQL in any of the six soil samples;

- No pesticides or PCB were detected in any of the six samples;

- A variety of PAH were detected in S128I-A and naphthalene was detected in S103I-A. No other acid/base neutrals were detected above the CRQL in any of the six samples;

- Metals were detected above and below background concentrations (S101I). Cyanide was detected in sample S128-A. Barium, chromium, and vanadium were measured in S128-A at levels exceeding three times background. Other metals and other samples were generally measured at levels within three times background.

4.1.6 Summary of Contaminant Source Analytical Results

Surface and subsurface soil testing confirmed the presence of three potential source areas at or near the previously identified IWS 1, 2, and 3 Areas. Plates M, N, and O provide cross-sections of each IWS area with the corresponding analytical data. Analytical data is derived from test pit samples and boring samples collected within, or just below, the confines of each IWS area.

4.2 GROUNDWATER

This section discusses the nature and extent of contaminants in groundwater throughout the Study Area. Because of the large number of monitoring wells and multiple groundwater sampling events, there is a very large analytical database for groundwater. To assist in understanding what that database indicates in terms of the presence of contaminants in groundwater, ESE has 1) grouped the monitoring wells into areas for discussion purposes, and 2) developed a set of indicator parameters.

The discussion of groundwater quality is presented for five areas: wells associated with the SWDA (Section 4.2.1.1), wells associated with IWS 1 (Section 4.2.1.2), wells associated with IWS 2 (Section 4.2.1.3), wells associated with IWS 3 (Section 4.2.1.4), and wells in other areas of the Study Area (Section 4.2.1.5). Section 4.2.2 provides a summary of groundwater quality and presents data in a Study Area-wide fashion and discusses relevant groundwater quality standards (Federal MCLs or Vermont Enforcement Standards (VES)).

Analytical data is presented, in some instances, as total non-chlorinated VOC, total chlorinated VOC, total phenolics, total other SVOC, total iron/manganese/aluminum, and total heavy metals. VOC have been separated into chlorinated and non-chlorinated because of the nature and history of the Landfill. The RI has shown that chlorinated VOC are generally associated with the IWS areas and that non-chlorinated VOC are generally associated with the SWDA. SVOC have been separated for the purpose of understanding the distribution of phenolics (associated with the SWDA), differentiated from other SVOC which might be associated with the IWS areas. Metals have been separated to distinguish between high levels of iron, manganese and aluminum (all associated with the operation of the SWDA) and the significantly lower levels of heavy metals, which, if present, pose the greater health risk. Cyanide has been included in the heavy metals calculation.

Within these general groups, specific compounds were selected to calculate the totals. Only compounds identified by the Risk Assessment as constituents of concern were included. Within that list generally only compounds which have an MCL or VES were included in the total. Any phenolic compounds detected were included in the total phenolic calculation even though they had no groundwater enforcement standard. Based on this selection process the following groups of compounds were used:

(A) total non-chlorinated VOC:

acetone	2-methyl-4-pentanone
benzene	toluene
2-butanone	xylenes
ethyl benzene	

(B) total chlorinated VOC:

chloroform	1,2-dichloropropane
dichlorodifluoromethane	tetrachloroethene
1,1-dichloroethane	trichloroethene
1,1-dichloroethene	1,1,1-trichloroethane
1,2-dichloroethene	vinyl chloride

(C) total phenolics:

any detected phenolic SVOC

(D) total other SVOC:

bis(2-ethyl hexyl)phthalate
diethyl phthalate

(E) total Fe/Mn/Al:

iron	aluminum
manganese	

(F) total heavy metals:

antimony	copper
arsenic	cyanide
barium	lead
beryllium	nickel
cadmium	selenium
chromium	

The concentrations calculated for these groups are based on the highest concentration measured for each analyte in any sampling round.

Plates F through L present groundwater analyte concentrations, for total non-chlorinated VOC, total chlorinated VOC, total phenolics, total other SVOC, total Fe/Mn/A1, and total heavy metals, on the geologic cross-sections. These plates are referred to throughout the discussion which follows. Likewise, these groupings are used in plan-view figures discussed throughout this section.

4.2.1 Groundwater Monitoring Wells

Groundwater monitoring during the RI included new and existing wells in the following areas: SWDA, IWS 1, IWS 2, IWS 3, and Other Areas. Three rounds of groundwater sampling were performed. This section presents the results of laboratory analyses conducted on groundwater during the RI. Not all wells were analyzed for the same analyte list in all rounds, dependent upon the recommendations made in the interim letter report to EPA, dated November 1, 1991, presenting Phase 1A Round 1 analytical results and proposing a Round 2 scope of work, and the

Scope of Work for Phase 1B. No pesticides/PCB analyses were performed during Phase 1A Round 2 or Phase 1B.

4.2.1.1 SWDA

Wells B112B, B113A, B113B, B114A, B114B, B115A, B115B, B117A, B117B, B137A, B137B, B138A, B138B, B139A, B139B, and B139C were installed around the perimeter of the SWDA. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals are provided in Appendix J in Tables J-15, J-16, and J-17, respectively. A zero in the data field indicates that the analyte was not measured on that sample.

Table 4-21 provides a summary of compounds detected in groundwater in SWDA wells. A blank indicates that the compound was not detected in that well in any sampling round. If a compound was detected only in one round in a well, that value is presented. If a compound was measured in more than one round, a range is provided.

Figures 4-4 and 4-5 present non-chlorinated and chlorinated VOC concentration ranges, respectively, in plan view for SWDA wells. The highest levels of non-chlorinated VOC were measured at wells B114A (5.4 mg/l total) and B115A (2.0 mg/l total) and at wells B114B (0.076 mg/l total) and B115B (0.26 mg/l total). As shown on Plate K, cross-section 8-8', both B114A and B115A are screened in the Upper Proximal, while their deep counterparts are screened in the Lower Proximal. Concentrations of non-chlorinated VOC are 1-2 orders of magnitude higher in the Upper Proximal than in the Lower Proximal. The highest concentrations of chlorinated VOC were measured at well B139A (9.0 mg/l total) and B138B (0.24 mg/l). Well B139A is on top of Distal, in the path of contaminants moving on Distal between IWS 3 and IWS 2, and likely impacted by contaminants from IWS 3 rather than from the SWDA. Concentrations of chlorinated VOC in the deeper screened well B139B (screened in the distal, as shown on cross-section 7-7', Plate J), and the bedrock well (B139C), are near the detection limit.

Figures 4-6 and 4-7 present total phenolics and total other SVOC concentration ranges, respectively, in plan view for SWDA wells. Concentrations of phenolic compounds were generally low, the highest concentration being measured at well B115A (0.65 mg/l total phenolics). Concentrations of other SVOC were generally low in all SWDA wells, the highest concentration measured being at well B1112B (0.064 mg/l total).

Figures 4-8 and 4-9 present total iron, manganese, and aluminum concentration ranges and total heavy metals concentration ranges, respectively, in plan view for SWDA wells. The highest metals concentrations were measured in wells B115A (198 mg/l total Fe, Mn, Al; 1.14 mg/l total heavy metals), B137A (117 mg/l total Fe, Mn, Al; 0.68 mg/l total heavy metals), and B138A (152 mg/l total Fe, Mn, Al; 0.95 mg/l total heavy metals).

4.2.1.2 IWS 1

Wells B109A, B109B, B109C, B110A, B110B, B111R were installed around IWS 1. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals, are provided in Appendix J in Tables J-15, J-16, and J-17 respectively. A zero in the data field indicates that the analyte was not measured on that sample.

Table 4-22 provides a summary of compounds detected in groundwater in IWS 1 wells. A blank indicates that the compound was not detected in that well in any sampling round. If a compound was detected only in one round in a well, that value is presented. If a compound was measured in more than one round, a range is provided.

Figures 4-10 and 4-11 present non-chlorinated and chlorinated VOC concentration ranges, respectively, in plan view for IWS 1 wells. The highest levels of non-chlorinated VOC were measured at wells B109B (3.0 mg/l total) and B109C (5.2 mg/l total). The highest levels of chlorinated VOC were measured at wells B109A (3.9 mg/l total) and B109C (0.85 mg/l total).

Figures 4-12 and 4-13 present total phenolics and total other SVOC concentration ranges, respectively, in plan view for IWS 1 wells. Concentrations of phenolic compounds were generally low, the highest concentration being measured at wells B109B (4.0 mg/l total) and B109C (2.0 mg/l total). Concentrations of other SVOC were generally low in all IWS 1 wells, the highest concentrations measured at wells B109B (0.21 mg/l total) and B109C (0.17 mg/l total).

Figures 4-14 and 4-15 present total iron, manganese, and aluminum concentration ranges and total heavy metals concentration ranges, respectively, in plan view for IWS 1 wells. The highest metals concentrations were measured in wells B109A (22 mg/l total Fe, Mn, Al; 0.26 mg/l total heavy metals), B109B (89 mg/l total Fe, Mn, Al; 0.72 mg/l total heavy metals), and B109C (64 mg/l total Fe, Mn, Al; 0.96 mg/l total heavy metals).

4.2.1.3 IWS 2

Wells B105, B106A, B106B, B107, B108A, B108B, B132, B134A, B134B, B135A, B135B, B105I, and B108I were installed around IWS 2. In addition, existing wells MW13 and ERT1 were incorporated into the study of IWS 2. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals are provided in Appendix J on Tables J-15, J-16, and J-17, respectively. A zero in the data field indicates that the analyte was not measured on that sample.

Table 4-23 provides a summary of compounds detected in groundwater at IWS 2. A blank indicates that the compound was not detected in that well in any sampling round. If a compound was detected only in one round in a well, that value is presented. If a compound was measured in more than one round, a range is provided.

Figures 4-16 and 4-17 present non-chlorinated and chlorinated VOC concentration ranges, respectively, in plan view for IWS 2 wells. Non-chlorinated VOC were generally detected throughout the IWS 2 area, with the exception of wells B106A, B108A&B, and B132. The highest levels of non-chlorinated VOC were measured at wells ERT 1 (19 mg/l total), and B106B (18 mg/l total). The two deeper companion wells to ERT 1 detected significantly lower levels of non-chlorinated VOC; B134A (0.14 mg/l total) and B134B (1.8 mg/l total). Chlorinated VOC were detected throughout the IWS 2 area. The highest levels of chlorinated VOC were measured at wells ERT 1 (76 mg/l total), B132 (5.7 mg/l total), and B105 (4.0 mg/l total). However, as with non-chlorinated VOC, the two companion wells to ERT 1 detected significantly lower levels of chlorinated VOC; B134A (0.08 mg/l total) and B134B (0.036 mg/l total). At well location B108, B108I (screened at the top of distal) is significantly higher in VOC concentrations than either the bridging well (B108A) or the top of rock well (B108B),screened in the distal (see cross-section 3-3', Plate G).

Figures 4-18 and 4-19 present total phenolics and total other SVOC concentration ranges, respectively, in plan view for IWS 2 wells. Phenolic compounds were not detected, or detected near the detection limit, in wells B106A, B108A, B108B, B135A, B134A, and B132. The highest concentrations of phenolics were measured at wells B106B (6.7 mg/l total), B105 (3.0 mg/l total), and B107 (3.6 mg/l total). Concentrations of other SVOC were generally low in all IWS 2 wells, the highest concentration measured at well B106B (0.093 mg/l total).

Figures 4-20 and 4-21 present total iron, manganese, and aluminum concentration ranges and total heavy metals concentration ranges, respectively, in plan view for IWS 2 wells. The highest metals concentrations were measured in wells B106B (351 mg/l total Fe, Mn, Al; 1.29 mg/l total heavy metals), B105 (300 mg/l total Fe, Mn, Al; 2.8 mg/l total heavy metals), and B107 (346 mg/l total Fe, Mn, Al; 1.2 mg/l total heavy metals).

4.2.1.4 IWS 3

Wells B101B, B102A, B102B, B103A, B103B, B103C, B104 and B133 were installed around IWS 3. In addition, existing well MW10A was incorporated into the study of IWS 3 as a shallow companion well to G104. Complete analytical results for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals are provided in Appendix J on Tables J-15, J-16, and J-

17, respectively. A zero in the data field indicates that the analyte was not measured on that sample.

Table 4-24 provides a summary of compounds detected in groundwater at IWS 3. A blank indicates that the compound was not detected in that well in any sampling round. If a compound was detected only in one round in a well, that value is presented. If a compound was measured in more than one round, a range is provided.

Figures 4-10 and 4-11 present non-chlorinated and chlorinated VOC concentration ranges, respectively, in plan view for IWS 3 wells. Levels of non-chlorinated VOC were generally at or near detection limits for IWS 3 wells. The highest level of non-chlorinated VOC were measured at well B103C (0.16 mg/l total). Chlorinated VOC were generally detected at low concentrations at IWS 3, with the highest concentration measured in the bridging well at B103A (1.2 mg/l total). The highest levels of chlorinated VOC were measured below IWS 3 at wells B133 (11 mg/l total) and MW10 (11 mg/l total). Wells MW10 and B133 are screened in the Upper Proximal, (bridging and top of distal, respectively). Groundwater samples from well B104, screened in the distal at top of rock at this location, detected only very low levels of chlorinated VOC (0.006 mg/l total).

Figures 4-12 and 4-13 present total phenolics and total other SVOC concentration ranges, respectively, in plan view for IWS 3 wells. Concentrations of phenolic compounds were at or near detection limits for all IWS 3 wells. Concentrations of other SVOC were generally low in all IWS 3 wells, the highest concentrations measured at wells B101B (0.069 mg/l total), the designated background well, and B102B (0.033 mg/l total).

Figures 4-14 and 4-15 present total iron, manganese, and aluminum concentration ranges and total heavy metals concentration ranges, respectively, in plan view for IWS 3 wells. The highest metals concentrations were measured in wells B103B (273 mg/l total Fe, Mn, Al; 5.1 mg/l total heavy metals), and B133 (406 mg/l total Fe, Mn, Al; 2.7 mg/l total heavy metals).

4.2.1.5 Other Areas

Wells B118A, B118B, B119A, B119B, B119C, B120A, B120B, B120C, B120D, B121A, B121B, B122, B125, B126A, B126B, B127A, B127B, B127C, B131B, B131C, B136A, B136B, B136C, and B140A were installed in areas outside the Landfill. Existing wells HB1S, HB1D, HB2, HB3, HB4S, HB4D, HB5, HB6, MW4A, MW6A, and MW8A were incorporated into the study of areas outside the Landfill. Complete analytical results of TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals are provided in Appendix J on Tables J-15, J-16, and J-17, respectively. A zero in the data field indicates that the analyte was not measured in that sample.

Table 4-25 provides a summary of compounds detected in groundwater in areas outside the Landfill. A blank indicates that the compound was not detected in that well in any sampling round. If a compound was detected only in one round in a well, that value is presented. If a compound was measured in more than one round, a range is provided.

Figures 4-22 and 4-23 present non-chlorinated and chlorinated VOC concentration ranges, respectively, in plan view, for wells in other areas. Levels of non-chlorinated VOC are generally low throughout the other area wells. The highest concentrations of non-chlorinated VOC were measured in wells B120D (0.40 mg/l total) and B126B (0.14 mg/l total), which are bedrock wells. The highest levels of non-chlorinated VOC measured in overburden wells was at well B121B (0.10 mg/l total). Chlorinated VOC were measured in bedrock wells B120D (0.063 mg/l total) and B136C (0.13 mg/l total). Concentrations of chlorinated VOC are generally low throughout overburden wells in other areas. The highest concentrations of chlorinated VOC in overburden wells were measured at wells B125 (0.14 mg/l total) and B119C (0.051 mg/l total). As shown on cross-section 6-6' (Plate I), the series of overburden wells along Brown Farm Road (B126A,HB1-D&S, B121A&B, and B122) detected chlorinated VOC only at, or near, the detection limit.

Packer Test Samples

Groundwater VOC samples were collected during packer tests at B126B, the Curran residential well (B127D), and the Riverside School private well (B120E). Table 4-26 presents a summary of the compounds detected in the groundwater samples collected from each packer test. Duplicate samples were collected at the Riverside School well and are designated -A and -B.

The analytes measured at the Curran and Riverside School wells are consistent with Long-Term Monitoring analytical data obtained from these locations (presented in Section 4.2.4).

4.2.2 Summary of Groundwater Analytical Results

Plate P shows VOC groundwater concentrations across the Study Area. Concentration values shown are the maximum concentrations measured in any groundwater sampling round. Concentrations are provided for TCE, DCE, total other chlorinated VOC, and total non-chlorinated VOC, using color coded bar graphs.

A discreet list of analytes were measured in excess of Federal MCLs or Vermont Enforcement Standards. Table 4-27 presents the analytes which exceeded either standard in any groundwater sample, during any groundwater sampling round. Table 4-27 also provides the Federal and State standard concentration for each analyte.

Only one SVOC exceeded the Federal or State standards: bis(2-ethylhexyl) phthalate. Generally, the levels exceeding these standards were very near the action level of 0.004 mg/l. The CRQL for bis(2-ethyl hexyl) phthalate is 0.010 mg/l, so that most exceedences were the result of estimated values below the CRQL. The occurrence of phthalates in the environment are very frequent and phthalates are common contaminants in sampling and testing equipment.

Tables 4-28, 4-29, 4-30, 4-31, and 4-32 show the analytes exceeding either standard and the well locations where exceedences occurred,for the SWDA, IWS 1, IWS 2, IWS 3 and other wells respectively. Plate Q shows the VOC and metal analytes exceeded at each well location outside the Landfill, provides the sample concentration which resulted in an exceedence, and the standard concentration. For metals, analytical results for total and dissolved metals are provided.

The results for the groundwater sample collected from the Riverside School well (G120E) did not exhibit the levels of VOC measured in previous Riverside School samples collected from their influent tap (see Section 4.2.4), nor the levels of VOC measured in the sample collected during the packer test of that well. The major groundwater bearing fracture zone found in the well was within the bottom 10 feet of the open bedrock well. Other zones of potential inflow were indicated, but did not yield significant water flow. Presumably, the everyday use of the well would assure that the influent sample would be representative of the major contributing fracture.

During groundwater sampling, a pump was placed at the bottom of the well and three well volumes were removed. The VOC sample was collected with a bailer, lowered to the top of the water column within the bedrock well. It is possible that dilution from Upper fracture zones, and inadequate opportunity within the well for mixing, resulted in the anomalous low concentrations in the bailed sample. Additionally, placement of the purge pump in the bottom of the well most likely resulted in purging of the lower portion of the well with little if any impact on the stagnant water in the Upper portion of the well. Future groundwater samples should be obtained through the centrifugal purge pump rather than through the use of bailers.

4.2.3 Additional Residential Wells

At the request of EPA, three residential drinking water wells (Haywood, Clark Sr., and Berry; see Plate D), not part of the Long Term Monitoring, were sampled and analyzed for VOC during the Round 2 groundwater monitoring. Table J-15 in Appendix J presents the results of those analyses. The analytical data indicates the following:

- No VOC were detected in any of the three samples, above the CRQL.

4.2.4 Long Term Monitoring

Table 4-33 presents a summary of compounds detected in five rounds of sampling and analysis of residential wells, completed during the RI field investigations. Sampling rounds were conducted in July and October, 1991, in January, April, July, and October 1992, in January, April, July, and October 1993, and in January 1994.

The Curran and Nadeau residences are not always available for sampling during the winter, as both families close their homes. The Gadappe residence was removed from the program prior to the January, 1992 sampling because it was connected to the new Village water supply line. The Riverside School and Hoffman, Curran, Griffith, and Jones residences were removed from the program prior to the July, 1992 sampling because they were connected to the new Village water supply line. Table 4-33 indicates the total number of rounds sampled at each location.

A blank on Table 4-33 indicates that the analyte was not detected in any sampling round at that location. If an analyte was measured during only one sampling round, that value is shown. If an analyte was measured in more than one round, a range is provided.

The sample numbers for each sample location are as follows:

R601 Riverside School
R602 Griffith Residence
R603 Curran Residence
R604 Jones Residence
R605 Hoffman Residence
R606 Sheltra Residence
R607 Boulanger Residence
R608 Gadappe Residence

R609 Nadeau Residence

R610 Mosher Residence

4.3 SURFACE WATER AND SEDIMENT

Complete analytical results for sediment for TCL-VOC, TCL- A/BN and TCL-Pesticides/PCB, and TAL-Metals are presented in Appendix J on Tables J-18, J-19 and J-20, respectively. Complete analytical results for surface water for TCL-VOC, TCL-A/BN and TCL-Pesticides/PCB, and TAL-Metals are presented in Appendix J on Tables J-21, J-22, and J-23, respectively. Table 4-34 presents a summary of compounds detected in surface water or sediment. A blank indicates that the analyte was not detected in that sample in either sampling round. If an analyte was measured in only one round, that value is presented. If an analyte was measured in both rounds a range is provided. Table 4-35 presents the results of water quality testing on the surface water. As shown on Tables 4-34 and 4-35:

- None of the surface water or sediment samples tested above the CRQL for pesticides, PCB's, or A/BN compounds.

- Volatile organic compounds were not detected at concentrations that are considered toxic to aquatic organisms in either short- or long-term bioassays (i.e., 0.10 mg/L, USEPA Ambient Water Quality Criteria documentation).

- None of the metals detected in surface water, with the exception of silver, are notably toxic to aquatic organisms. While not known to be very toxic, maximum concentrations reported for calcium, manganese, iron, sodium, potassium, magnesium, and barium were all from samples taken at Station 402.

- Laboratory water quality data presented in Table 4-35 shows a decrease in water quality parameters' concentrations with distance from 402 downstream toward the Passumpsic River.

- Station 402 also showed maximum concentrations reported for many of the metals analyzed in sediment. Arsenic, while detected infrequently, had anomalous results for sediment sampled at Station 402, as the initial sample was 16.5 mg/kg while the replicate was 1,908 mg/kg. Based upon the anomalous arsenic result at station 402, on September 9, 1992, duplicate sediment samples were collected from station 402 and analyzed for TAL-Metals, specifically arsenic. The replicate samples contained 1.3 and 1.4 mg/kg arsenic, respectively.

- Mean values for other metals in sediment fell within ranges considered near background for soils and sediment by several authors (Baudo et al., 1990; Long and Morgan, 1990).

Stations 401, 405, and 411 were delineated as background locations. Station 401 is upgradient of the Landfill. Stations 405 and 411 are located in streams upgradient of the unnamed stream traversing the Landfill, and flow into the unnamed stream. These locations were selected during a site-walkover by representatives of the Respondents, EPA, DEC, and U.S. Fish & Wildlife Department.

Table 4-36 presents the average metal concentrations for the three background locations and a comparison of sample metals results to that mean. As can be seen from Table 4-36, the ratio is below 3.0, except for location 402.

Based on the physical and chemical data, it is evident that no persistent compounds, capable of bioaccumulation or biomagnification, were detected in any of the samples taken. Therefore, injury to organisms higher up in the food web is not a concern. A change in water and sediment quality is evident at Station 402, primarily as a result of dissolved solids (e.g., iron/manganese) that are typically found in leachate from landfills. This sampling station, as well as Station 403 and 404, are very shallow and flooded on a seasonal basis, and the likelihood of significant fish populations in these areas is low. Therefore, any risk to the fish community within these areas would be quite low.

4.4 ECOLOGY

ESE completed a Phase IA preliminary ecological risk assessment (ERA). The USEPA Region I Superfund Ecological Assessment Team (SEAT) also performed an ecological assessment which evaluated the distribution and concentration of constituents of concern in surface water and sediment, and subsequent putative effects on ecological receptors. The purpose of this section is to briefly summarize the previous investigations.

4.4.1 Background

The Phase IA investigation included a preliminary ecological assessment which provided the Region I SEAT with data and information necessary to finalize the ERA. It included a site walkover, a wetland delineation, a water quality survey, and a bioassessment of benthic macroinvertebrates. The following discussion briefly summarizes the major conclusions of the field work.

- The narrow, shrub-scrub wetlands in the vicinity of the landfill (Stream 1 and Stream 2 on Figure 4-24 are primarily fed by groundwater and sheet flow of precipitation within the unsaturated zone. With the exception of small segments of the streams the majority of the reaches are losing surface water to groundwater (Plate R). Stream 1 contributes a negligible portion of the total discharge of Stream 2.

- The background sampling locations (401, 405, 409, and 411) chosen within these streams represent natural conditions.

- Isolated physical and chemical impacts are confined to the presence of fill/sand/silt deposited as a result of erosion of the landfill cap, the precipitation of amorphous iron oxide, and subsequent growth of iron-dependent microflora (e.g., *Ferrobacillus*).

- Of the monitoring stations evaluated, Station 402 showed the greatest decrease in water and sediment quality. Constituents that historically have presented ecological concern, such as PCBs, mercury, and organchlorine pesticides, were not defected.

4.4.2 Study Area Map

A study area map, depicting the general types of land use or habitat (upland forest, wetland, hayfield, etc.) near or adjacent to the site, is presented in Figure 4-24. This map also presents surface water monitoring stations (401 through 411) utilized during the Phase IA investigation and biological monitoring stations (BS-01 through BS-08) utilized during the Phase IB field investigation (Section 4.4.3). An in-depth delineation and description of the wetland and upland vegetation, soils, and hydrology is presented in the RI/FS Work Plan (ESE, 1991).

4.4.3 Water Quality and Benthic Macroinvertebrate Survey

A third round of water quality parameters (pH, dissolved oxygen, specific conductance, temperature, oxidation-reduction potential (ORP)) was taken on August 20, 1992. These data are presented alongside of measurements obtained during the previous monitoring rounds (Table 4-37). The stations are oriented within the table in an upstream to downstream manner so trends might be observed. No obvious trends in pH and temperature can be seen within a specific sampling round. Changes in dissolved oxygen, specific conductivity, and ORP are evident at monitoring locations near the landfill (402, 403, and 404). It is important to note, however, that this is a low energy wetland. Consequently, surface water flow within this area is shallow, diffuse, and poorly oxygenated.

Typical of municipal landfills, reduced iron within the leachate is oxidized by iron-dependent microorganisms (e.g., *Ferrobacillus spp.*) or dissolved oxygen present upon discharge to surface water. The deposits of the iron oxide and the mucilaginous colonies of iron bacteria extend approximately 200 yards downstream of the confluence of Stream 1 with Stream 2. Although these deposits are unsightly, they improve water quality by providing a physical (very large surface area to volume ratio) and chemical (complexation, coprecipitation) means by which dissolved metals and organics can be removed from the water column. These deposits also appear to have no detrimental effects upon aquatic biota, as fish, amphibians and aquatic insects successfully colonized an artificial substrates placed within this depositional reach.

A better long-term reflection of both water quality and habitat is the composition of the benthic macroinvertebrate community (USEPA, 1989). Because of the low surface discharge and the obvious physical impacts to the wetland adjacent to the landfill, an upstream-downstream field study was designed to evaluate the influence of Stream 1 on Stream 2.

Cool, first-order streams are generally not very productive environments because they receive a limited input of particulate organic matter (USEPA, 1989). Artificial substrates (rock baskets, herein referred to as samplers) were therefore employed to enhance the natural habitat, as well as to minimize variability in the sampling program.

Conventional water quality measurements were made at all of the sampling stations (BS-01 through BS-08) during sampler placement (August) and sampler removal (October). Figures 4-25, 4-26, 4-27, and 4-28 present measurements of specific conductivity, dissolved oxygen, oxidation/reduction potential (ORP), and pH, respectively. A marginal increase in conductivity, dissolved oxygen, and pH occurs downstream of the Stream 1/Stream 2 confluence. A decrease in ORP, a result of the presence of reduced iron, is seen at BS-04. Ferrous iron is rapidly oxidized, and the ORP subsequently increases with increasing distance from the landfill.

Table 4-38 presents the benthic macroinvertebrate data. Taxa richness (total number of orders) did not appear to vary from station to station. The total number of individuals collected from each substrate was higher downstream of the landfill.

The proportion of insects from the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), commonly known as EPT, is frequently used as a functional endpoint. As seen in Table 4-38, Station BS-05 had the lowest proportion of EPT, while station BS-04 appears to be unaffected. The EPT/Diptera ratio, which should decrease with a decrease in water quality, was also the lowest at BS-05.

BS-04 should, theoretically, receive the highest concentrations of landfill-derived materials and consequently show the greatest impact. Observations made in the field indicated that this was the case, as the sampler was coated with amorphous iron oxide precipitate (BS-04 was located immediately downstream of the confluence of Stream 1). The taxonomic data, however, do not support this. BS-05 has the lowest number of individuals and the lowest proportion of EPT. Station BS-05, however, had the highest proportion of predatory Megaloptera, which may explain the observed decrease in EPT. Furthermore, assuming the impact at BS-05 is genuine, the presence of taxa which are sensitive to pollutants (*Ephermeroptera, Plecoptera, Trichoptera*) at stations BS-06, -07, and -08 indicate a rapid recovery of the stream. Snails and freshwater clams, which are sensitive to toxic metals, are also abundant at these downstream stations.

The major conclusion drawn from this survey is that the effect of landfill leachate on the structure of the macroinvertebrate community is minimal and transitory. The presence of sensitive individuals downstream suggests that adverse effects are not the result of metal intoxication.

4.4.4. Receptor Inventory

An inventory of wildlife observed near or within the confines of the landfill are presented in Table 4-39. The dominant predators within the wetland appear to be fox and raptors. Two fish (slimy sculpin) were caught within samplers taken from BS-01 and BS-08. Other types of fish were not observed within the stream. One amphibian (unidentified salamander) was caught in sampler BS-04.

4.4.5 Ecological Risk Assessment

The Region I USEPA subcontracted TRC Environmental Corporation to perform an ERA, which is contained in a separate document along with the human health risk assessment. The ERA utilized field data generated during the Phase 1A and Phase 1B field studies, as well as constructing idealized exposure scenarios for anticipated ecological receptors, such as the meadow vole and the red fox.

Toxicity criteria used for assessing risk were either derived from available toxicity literature or from dietary requirements for surrogate species. Much of the risk that could be attributable to the landfill was due to metals (e.g., aluminum, iron, barium) which have not been traditionally associated with either acute or chronic adverse effects. The assessment concludes that "surface water and sediment contamination within the Parker Landfill streams are unlikely to result in adverse effects to resident aquatic biota" but that "impacts from siltation and sedimentation of the Parker Landfill streams may result from erosion of the cap". Although not evaluated in the risk assessment, the latter is responsible for most of the current impact to Stream 1.

Hazards to terrestrial animals were evaluated for the industrial waste areas, although the uncertainties associated with this type of assessment are very much greater than those associated with aquatic risk. The ERA concluded that metals were also the major constituents of concern within these locations, especially iron and aluminum.

4.4.5 Wetland Evaluation Technique (WET II)

The Region I EPA Superfund Ecological Assessment Team requested that a WET II be conducted on the wetlands that are adjacent to the landfill. This evaluation is subsequent to the wetland delineation (ESE, 1991) and the ecological risk assessment (USEPA, 1993).

The WET II methodology was originally developed in 1983 by the Federal Highway Administration to assist in the evaluation of wetlands relative to environmental impacts. The methodology was later revised by the U.S. Army Corp of Engineers and is currently available as a hard copy and/or a computer based model (Adamus *et al.*, 1991; Adamus *et al.*, 1987). The WET II procedure defines eleven different functions that wetlands perform as a natural resource. These functions, along with a brief explanation of each (as defined primarily by the original authors) are presented as follows:

- Ground Water Recharge: the potential for a wetland system to recharge an aquifer (surface water losing to ground water)

- Ground Water Discharge: the potential for a wetland system to recharge a surface water body (ground water moving to surface water)

- Floodflow Alteration: synchronizing or stabilizing peak surface water runoff by storing or delaying discharge in the downslope journey to a river

- Sediment Stabilization: preventing removal of soils/sediment by shoreline anchoring of vegetation; dispersing erosive forces caused by waves

■ Sediment/Toxicant Retention:	removal of suspended solids and chemical contaminants that may be adsorbed to them from the water column, through deposition and retention
■ Nutrient Removal/Transformation:	storage of nutrients within sediment or plant substrate and transformation of inorganic nutrients to organic form (e.g., nitrate/nitrite to ammonia)
■ Production Export	flushing of relatively large amounts of organic material downstream, providing nourishment to primary and secondary consumers
■ Wildlife Diversity/Abundance	support of a notably great on-site diversity and/or abundance of wetland-dependent birds (also includes other animals that utilize the wetland for breeding, migration, overwintering, food or shelter)
■ Aquatic Diversity/Abundance	support of a notably great on-site diversity and/or abundance of fish or invertebrates which are mainly confined to water and saturated soils
■ Uniqueness/Heritage	the use of wetlands for aesthetic enjoyment, nature study, education, scientific research, open space, preservation of rare/endemic species, protection of archaeologically or

geologically unique features, or maintenance of historic sites

- Recreation — includes both consumptive (sport fishing, hunting) and nonconsumptive (swimming, canoeing, boating, birding) forms of water-dependent recreation

Each of these functions, in turn, is qualitatively ranked as "low", "moderate" or "high" under three separate categories: social significance, effectiveness, and opportunity. As described in the methodology:

> "Social significance assesses the value of a wetland to society due to its special designations, potential economic value, and strategic location. Effectiveness assesses the capability of a wetland to perform a function due to its physical, chemical, or biological characteristics. Opportunity assesses the opportunity of a wetland to perform a function to its level of capability."

The authors (Adamus, *et al.*, 1991) also point out that, under most circumstances, the results of the WET II should not be used as a criteria for determining whether mitigation is required, but rather how much mitigation effort is justified.

Much of the information on the many variables required to complete the WET II process is taken from previous studies and available documentation. This includes data obtained from the Phase 1A and Phase 1B field operations, topographic maps, natural resource inventory documents, wetland classification documents, etc. For a better understanding of the nature of the wetlands assessed here, the reader is advised to peruse both the wetland delineation presented in the original workplan (ESE, 1991) and the final version of the Ecological Risk Assessment (USEPA, 1993).

Several areas of the watershed must be identified for input to the WET II model. The assessment area (AA) is generally defined as the immediate wetland area being evaluated. The input zone (IZ) is the upland or subwatershed area that supplies the AA with snowmelt or runoff resulting from precipitation events. The service area (SA) is generally an area downstream of the AA to which the functions or "services" are delivered. Figure 4-29 presents the map used to identify the AA, the IZ, and the SA. Most of the input for the model is in the form of a yes/no response to a question, and over 95% of this input is primarily concerned with the AA.

For this assessment, two wetlands were considered: the wetland surrounding Stream 1, or "AA1" and the wetland surrounding Stream 2, or "AA2". The summary of the evaluation results for AA1 are as follows (SS = social significance; EF = effectiveness; OP = opportunity; L = low; M = moderate; H = high; U = uncertain; * = model does not evaluate):

FUNCTION EVALUATED	SS	EF	OP
Ground Water Recharge	L	U	*
Ground Water Discharge	L	H	*
Floodflow Alteration	L	H	M
Sediment Stabilization	L	H	*
Sediment/Toxicant Retention	L	M	H
Nutrient Removal/Transformation	L	H	H
Production Export	*	M	*
Wildlife Diversity/Abundance	L	H	*
Aquatic Diversity/Abundance	L	L	*
Uniqueness/Heritage	L	*	*
Recreation	L	*	*

For AA1, social significance ranked low for all categories. This category "flags" any feature that makes the wetland individually unique from the perspective of educating or enlightening society (e.g., the presence of a rare or endangered species or its location relative to a heritage program). Under the effectiveness category, functions that ranked "high" included groundwater discharge, floodflow alteration, sediment stabilization, nutrient removal/transformation, and wildlife diversity/abundance. Under the opportunity category, sediment/toxicant retention and nutrient removal/transformation ranked high. The "broad" interpretation of the WET II results for AA1, are as follows:

- *biologically*, the wetland does not provide adequate habitat for aquatic organisms but does provide potentially adequate habitat for wetland-dependent birds;

- *physically*, the wetland serves to prevent landfill-derived erosion/sediment from moving into the Passumpsic River and to retain water volume and synchronize runoff from storms or snowmelt, alleviating floodflow within the former; and

- *chemically*, the wetland serves to retain or transform landfill-derived nutrients and contaminants, precluding migration downstream into the Passumpsic River.

A model was also generated for AA2, which includes Stream 2 (upstream of the confluence with Stream 1). This model was generated by using the same general input required for Stream 1 (the wetlands share many similar characteristics), but changing answers to questions which only applied (and were unique to) Stream 2. The summary of the evaluation results for AA2 are as follows (SS = social significance; EF = effectiveness; OP = opportunity; L = low; M = moderate; H = high; U = uncertain; * = model does not evaluate):

FUNCTION EVALUATED	SS	EF	OP
Ground Water Recharge	L	U	*
Ground Water Discharge	L	H	*
Floodflow Alteration	L	M	M
Sediment Stabilization	L	H	*
Sediment/Toxicant Retention	M	L	H
Nutrient Removal/Transformation	L	L	L
Production Export	*	M	*
Wildlife Diversity/Abundance	L	H	*
Aquatic Diversity/Abundance	L	M	*
Uniqueness/Heritage	L	*	*
Recreation	L	*	*

The output for AA2 was similar to that of AA1, except that, under social significance sediment/toxicant retention went from "L" to "M"; floodflow alteration went from "H" to "M", sediment/toxicant retention went from "M" to "L", nutrient removal/transformation went from "H" to "L", and aquatic diversity/abundance went from "L" to "M". Under opportunity, nutrient removal/transformation went from "H" to "L". All of these minor changes seen between the output of the model for AA1 vs. AA2 can primarily be attributed to:

- the presence of the landfill within the input zone of AA1

- the presence of a continuous surface water flow within AA2

- the difference in slope, topography, and wetland dispersion between AA1 and AA2

The logistical output for both models is presented in Appendix Q. The last page of the appendix also presents the answers to the model questions that were different between AA1 and AA2 (y, yes; n, no; i, not applicable or not enough information).

5.0 CONTAMINANT FATE AND TRANSPORT

This section discusses the environmental fate and transport parameters associated with the compounds detected during the Remedial Investigation. Section 5.1 details the theoretical basis for the evaluation of fate and transport characteristics, and Section 5.2 summarizes the site-specific fate and transport values. Section 5.3 discusses the potential migration pathways in the study area.

5.1 THEORY

Migration, persistence, and relative distribution of compounds between air, water, and soil depend on both hydrogeologic and compound-specific parameters. The following discussion addresses each of these parameters as they may affect behavior of compounds within the Study Area.

5.1.1 Advection by Groundwater Flow

Within a porous medium (soil), the advection rate of dissolved or aqueous-phase compounds under transient conditions is based on Darcy's law (Bear, 1979):

$$v = \frac{-Ki}{n_e R_d}$$

where,

v = average pore velocity (length/time)

K = hydraulic conductivity (length/time)

i = hydraulic gradient (dimensionless), which equals the piezometric head difference between two points on a groundwater pathline divided by the distance between the two points.

n_e = effective or drainable porosity (dimensionless) of the soil, approximately equal to the specific yield.

R_d = retardation factor ($R_d \geq 1$), a dimensionless parameter that represents the ratio of groundwater pore velocity to the actual advection rate in a sorbing (onto immobile soil grains) porous medium under transient concentration conditions.

5.1.1.1 Sorption

R_d represents the attenuation of a plume's frontal advancement due to sorption, i.e., temporary storage, on soil particles, and particularly on organic matter in the soil. Retardation within bedrock aquifers is typically very limited, as the organic carbon content of the rock is negligible. Examples of analyses for which retardation must be considered include (1) calculation of the time required for contamination to reach a given downgradient location, and (2) determination of the time required to remediate a contaminated aquifer.

The retardation factor is defined by the following relationship (Freeze and Cherry, 1979):

$$R_d = 1 + \rho_b K_d / n_e$$

where ρ_b is the bulk dry density of the soil (mass/volume), n_e is the effective porosity of the soil (volume of voids/total soil volume), and K_d is the soil-water partition coefficient (volume/mass), often referred to as the distribution coefficient.

The soil-water partition coefficient is the relative magnitude of the chemical concentration on solid particles and in pore water for a particular soil (Lyman et al., 1982):

$$C_s = K_d C_w$$

where,

C_s = concentration of the compound sorbed to the solid phase of the soil (mass chemical/bulk dry mass soil)

C_w = concentration of the compound in the pore water of the soil (mass/volume)

In this expression it is implicitly assumed that an equilibrium exists between the solid and water phases and that the sorption process is linear (Freundlich isotherm with exponent equal to unity) over the range of concentrations considered.

For non-ionic organic compounds such as VOC's, K_d can be calculated from the measured fraction of organic carbon naturally occurring in the soil, f_{oc} (grams organic carbon/gram dry soil), and the organic carbon sorption coefficient, K_{oc} (Tinsley, 1979):

$$K_d = f_{oc} K_{oc}$$

Values of K_{oc} for many common organic compounds are available in the literature. K_{oc} is also related to the octanol-water partition coefficient, K_{ow}, for which a large data base is also available (e.g., Hansch and Leo, 1979). For fine-grained soil particles, K_{oc} and K_{ow} are related as follows (Karickhoff et al., 1979):

$$K_{oc} \cong 0.63 K_{ow}$$

Chemical-specific relationships between K_{oc} and K_{ow} also exist for several VOC (e.g., Lyman et al., 1982).

5.1.1.2 Transport by Dissolved Organic Carbon

For certain families of organic compounds, the presence of dissolved organic carbon (DOC) in groundwater can partially reverse the sorption process to soil particles and release sorbed constituents to groundwater. As a result, the migration of these compounds, under certain circumstances, can be enhanced (Enfield and Bengtsson, 1988). Increases in mobility are greatest for very hydrophobic (high K_{oc}) compounds such as pesticides, polycyclic aromatic hydrocarbons (PAH) and, dioxins. Due to their characteristically low K_{oc}'s, VOC transport in groundwater is generally unaffected by partitioning to DOC unless DOC concentrations exceed 10,000 mg/L (Enfield and Bengtsson, 1988). Typically natural DOC concentrations in groundwater range from 1 to 10 mg/L.

5.1.2 Dispersion

Dispersion is a dilution process by which an initial volume of aqueous solution continually mixes with increasing portions of the flow system. Dispersion occurs on a small or microscopic scale due to molecular diffusion in the water phase, nonuniform velocity distributions within the pore space, and to a large degree the tortuous pathlines that groundwater follows during movement through interconnected soil pores of different sizes and shapes. On a macroscopic scale, dispersion results from geologic heterogeneities such as layers and lenses of contrasting soil type (i.e., hydraulic conductivity). In practice, dispersion is primarily due to variations in hydraulic conductivity which produce large gradients in advective transport. It is well known that aquifers contain horizontal layers or lenses of coarser and finer grained materials, compared to the average material type, that can result in zones of significantly higher and lower permeability, respectively, than the depth-averaged permeability determined from pumping and slug tests. Factor of ten permeability variations over the thickness of an aquifer are not uncommon (Freyberg, 1986; Gelhar et al., 1985; Robertson et al., 1991; and Sudicky et al., 1983). For contaminant transport, the higher permeability zones are more important because they determine the maximum distance over which dissolved constituents will migrate from the source area.

With respect to chemical migration from a source area to an arbitrary downgradient location, dispersion will cause contaminants to arrive in a shorter time interval than the travel time based on the mean groundwater pore velocity (Section 5.1.1). This reduced travel time associated with dispersion is due to advection in the higher permeability zones of the aquifer that causes the concentration distribution in the longitudinal (flow) direction to spread out or disperse. The additional length, L_d, that a chemical may migrate due to dispersion can be estimated from the following relationship (Bear, 1979):

$$L_d = \sqrt{2 \frac{D_L}{R_d} t}$$

where,

t = total time of groundwater travel ($= \overline{V}/L_{total}$)
R_d = retardation factor
D_L = longitudinal dispersion coefficient (length ^{2}/time)

In a porous medium, the longitudinal dispersion coefficient can be estimated as follows:

$$D_L = \alpha_L \cdot v$$

where,

v = groundwater pore velocity

α_L = longitudinal dispersivity of the aquifer (length)

The percent reduction in travel time along a pathline due to longitudinal dispersion can be calculated using the equation (Bear, 1979):

$$\Delta t = \frac{L_d}{L_{total}} * 100$$

where,

Δt = reduction in travel time along a pathline due to longitudinal dispersion (%)

L_d = additional distance (in excess of advection distance) that chemical migrates due to longitudinal dispersion

L_{total} = total distance of travel by mean advection (groundwater flow)

An excellent summary of estimated longitudinal dispersivity values for numerous sites is given by Gelhar et al., (1985).

5.1.3 Advection Due to Fluid Density Differences

Advective transport can also occur due to fluid density differences in cases where the total dissolved solids (TDS) concentration is very high. A typical example is salinity intrusion into an aquifer, where the greater density of the salt water (TDS 35,000,000 ppb) causes it to sink within the fresh water aquifer. This causes downward advection of groundwater and results in stratification of the aquifer into varying zones of salinity. However, density effects can be caused by any dissolved compound, if the concentration is high enough. Laboratory experiments have shown that density effects begin to be observed when the total dissolved concentration in a plume exceeds background levels by about 1,000,000 to 5,000,000 ppb (Schincariol and Schwartz, 1990; Schwille, 1988).

5.1.4 Attenuation

In recent years groundwater scientists have begun to understand the role of microorganisms in the subsurface transformation of organic chemicals. Recent studies have shown that large numbers of organisms can exist in the subsurface environment. In many cases, organic compounds can be completely degraded to harmless products. However, by-products can also be produced which are more mobile and toxic than the parent compound. These transformations can make it difficult to correlate groundwater contamination with particular sources. Quantitative predictions of the fate of biologically reactive chemicals are approximate at best. This is due to a lack of understanding of the biochemical transformation process and variability of transformation rates in an aquifer (e.g., as much as two orders of magnitude over a distance of less than 1 m). For example, Wood et al., (1980) have demonstrated in the laboratory and observed in the field the following anaerobic transformations of parent compounds to daughter compounds:

carbon tetrachloride → chloroform → methylene chloride

trans-1,2-dichloroethene
PERC → TCE → cis-1,2-dichloroethene → vinyl chloride
1,1-dichloroethene

1,1,1-trichloroethane → 1,1-dichloroethane → chloroethane

The transformation of PERC (tetrachloroethylene) and TCE (trichloroethylene) to vinyl chloride is an example of a transformation to a daughter compound which is considerably more toxic than its parent compound.

Persistence in the environment can be described by a parameter known as the environmental half-life of a compound. The environmental half-life, $t_{1/2}$, is related to a decay constant, λ (1/time), in a first-order decay process:

$$\lambda = ln(2) / t_{1/2}$$

where $\ln(2) \cong 0.693$. The product of the decay constant and the porewater concentration is equal to the rate (mass/time/unit volume) at which a compound degrades into another form of compound. In practice, the parameter half-life is an empirical parameter that quantifies mass loss due to biological, photochemical, chemical, or physical (e.g., volatilization) degradation mechanisms.

Within the subsurface, biological activity is believed to be the principal cause of the mineralization (i.e., transformation to inorganic constituents) of organic compounds (Alexander, 1978). Hydrolysis is the reaction of compounds with water or the hydroxide or hydromium ions associated with water. However, organic functional groups such as halogenated aromatics (e.g., TCE, TCA, PCE), ketones, benzenes, and phenols are generally resistant to this mechanism (Lyman et al., 1982). Oxidation (loss of electrons during a chemical reaction) and reduction (gain of electrons during a chemical reaction) can also alter and attenuate organic compounds. In a shallow surface water body or in the upper few centimeters of a soil column, volatilization is often an important loss mechanism for organic compounds. For most inorganic compounds, geochemical transformations are the most important degradation mechanisms. Due to the complexity of degradation processes and the fact that little data is typically available to adequately model the loss mechanisms, prediction of decay rates in the field, as discussed above, is very difficult and not often feasible, especially for biodegradation.

5.1.5 Other Fate Parameters

Additional compound-specific properties that characterize organic compound fate in the subsurface are:

Property	Fate and Transport Process
Henry's Law constant (air-water partition coefficient)	Aqueous-phase volatilization
Aqueous Solubility	Dissolution
Density (specific gravity) of NAPL (1)	Advection of NAPL (1)

(1) NAPL = Non Aqueous-Phase Liquid

Each of these properties are addressed below.

5.1.5.1 Air-Water Partition Coefficient

The Henry's law coefficient (Morel, 1983) relates the equilibrium concentrations in air and water for volatile compounds in a multi-phase system such as the unsaturated zone of the subsurface or the air-water interface of a water body:

$$H = C_a / C_w$$

where H is the dimensionless Henry's law coefficient (derived as follows: $\frac{atm\text{-}m^3/mole}{0.024}$) and C_a and C_w are the chemical concentrations in air and water, respectively. The coefficient is used in the calculation of volatilization from a water body or soil and for the determination of solids, water, and air concentrations resulting from chemical partitioning in a contaminated, unsaturated soil.

Organic compounds with Henry's law coefficients greater than 10^{-3} atm-m^3/mole are generally considered to be highly volatile. These compounds can volatilize relatively rapidly from water at air-water interfaces such as surface water bodies or groundwater tables. The rate of volatilization tends to be controlled by diffusion in the water phase. Table 5-1 summarizes values of the Henry's law coefficient for selected organic constituents.

5.1.5.2 Aqueous Solubility

The solubility of a compound in water is the maximum amount of that compound that will dissolve in pure water at a specified temperature. Water solubility is one of the most important fate and transport parameters and dictates the mechanism by which the majority of contamination is transported in the Study Area. If additional compound is added to a solution at the solubility limit, two phases will be formed if the organic compound is a solid or liquid at the system temperature: 1) a saturated aqueous solution (with concentration equal to the solubility), and

2) a solid or liquid organic phase (Lyman et al., 1982). Highly soluble compounds tend to have relatively low K_{oc} values and Henry's law coefficients and tend to be more readily biodegradable by microorganisms in soil.

5.1.5.3 Density/Specific Gravity

The density of a fluid (mass/volume) is used to determine whether non aqueous phase liquid (NAPL), when present, will sink (dense non aqueous phase liquid, DNAPL) or float (light non aqueous phase liquid, LNAPL). Recently published research suggests that aqueous phase concentrations that are within 1 to 10% of the solubility of that chemical are indicative of the presence of NAPL (Feenstra et al., 1991).

The mobility of DNAPL is dependant on the volume of free product existing at its source. A small quantity of DNAPL present in the subsurface can quickly become bound in the soil matrix due to capillary attraction between the DNAPL and soil grains. DNAPL existing in this state is considered "residual DNAPL". In order for DNAPL to begin to migrate, to the DNAPL release must be large enough in quantity to exceed the residual storage capacity of the soil matrix in the immediate vicinity of the release. If the release volume is sufficiently large, migration will in general be vertically downward due to gravitational forces. If the DNAPL encounters a low-permeability layer, it will collect or pool above the layer and, depending on the surface slope of the layer, and the release volume, migrate horizontally.

5.2 AREA-SPECIFIC CHARACTERISTICS

Table 5-1 summarizes chemical specific parameter values for selected constituents. The range of f_{oc} values used in the calculation of K_d and R_d were presented in Table 3-2. Due to the site-specific nature of biodegradation and the lack of accurate methods for estimating parameter values, environmental half-lives are not included. Accordingly, chemical degradation is conservatively ignored in the following evaluations.

Laboratory analyses of soil samples were completed in order to evaluate the degree of partitioning, for the selected compounds, onto soil and to estimate the resulting attenuation (retardation) during advective transport by groundwater through the overburden. Laboratory soil analysis for physical parameters was performed on six composited soil samples during Phase 1A and four additional soil samples during Phase 1B. A description of the process for selection of sample composite groups and the testing methodology is presented in Appendix F and was briefly summarized in Section 3.6 of this Report. Composite soil groups and a summary of data were presented in Tables 3-1, 3-2, and 3-3.

5.3 PRIMARY GROUNDWATER MIGRATION PATHWAYS

This section discusses the primary contaminant migration pathways in Study Area groundwater. The potential migration pathways include non-aqueous, vapor phase, and aqueous phase transport.

5.3.1 Potential Migration as a Nonaqueous Phase Liquid

From field and laboratory studies the presence of DNAPL in an aquifer has been determined to be reliably indicated by groundwater concentrations of DNAPL constituents that exceed 1 to 10% of their aqueous-phase solubilities (Feenstra et al., 1991; Schwille, 1988). Using TCE as a DNAPL indicator compound (solubility = 1,100 ppm), TCE concentrations in groundwater exceeding 10 to 100 mg/liter indicate that DNAPL is likely to be present in the subsurface. The groundwater data collected in the Study Area to date, within the boundaries of IWS 2 (Plate P), suggests that the only location residual DNAPL may be present is near ERT1 where aqueous-phase TCE concentrations exceeding 20 to 40 ppm have been measured.

Analytical data for soil samples from the IWS 2 area were also evaluated to determine DNAPL presence, using TCE as the indicator compound. As presented in Section 5.1.1.1, the TCE concentrations in soil, C_s, and groundwater, C_w, are related as follows:

$$C_S = f_{OC} K_{OC} C_W$$

where K_{oc} = 126 cm^3/g for TCE and f_{oc} = 0.003 for a mixture of Distal and Proximal soils. With the above relationship and parameter values,

$$Cs_{TCE} = 0.4 \ (C_w)_{TCE}$$

The maximum soil concentration that can exist with aqueous-phase TCE in the pore water is given by the above equation with C_w = solubility (1,100 mg/liter for TCE). Accordingly, soil concentrations exceeding about 200 to 600 mg/kg (ppm) TCE are indicative of DNAPL presence in the soil matrix. This method of evaluating DNAPL presence in the subsurface has been increasingly utilized in recent years (e.g., Feenstra et al., 1991).

Considering the above soil concentration range (200 to 600 mg/kg), the following soil samples collected in the IWS 2 area are likely to contain DNAPL (refer to Plate N):

- TP906I-B (2,500 ppm TCE at 9 feet below ground surface, bgs), and
- TP906I-B (200 ppm TCE at 5.6 feet bgs), and

- Boring B129I (1,000 ppm TCE at 0-2 feet bgs).

Most importantly, soil and groundwater concentrations below ERT1 are very low:

Location of Sample at IWS 2	Groundwater Concentration of TCE	Soil Concentration of TCE
Boring B134. 42-44 ft. below grade (12 ft. above screen for B134A)		0.003 ppm
B134A	0.004 ppm	
B134B	0.005 ppm	

Note that the soil and groundwater concentrations beneath ERT1 are very consistent (e.g., 0.4 * 0.005 ppm = 0.002 ppm in soil, which is approximately equal to the measured value of 0.003 ppm in boring B134 (42-44 feet).

In summary, both soil and groundwater data beneath the shallow screen depth of well ERT1 are consistent and exhibit very low concentrations.

Similar consistency between soil and groundwater concentrations was also found at depth adjacent to ERT1 at Boring B107 and wells B135A and B135B:

Location of Sample at IWS 2	Groundwater Concentration of TCE	Soil Concentration of TCE
Boring B107. 152-154 ft. below grade (top of bedrock)		0.011 ppm
B135A	0.029 ppm	
B135B (top of bedrock)	0.026 ppm	

Note: 0.4 * 0.029 ppm = 0.012 ppm which is approximately equal to the soil concentration in boring B107 (152-154 feet).

None of the above data indicate that DNAPL has likely migrated beyond the immediate vicinity of ERT1. It is possible that the sandpack or a pocket within the borehole annulus may provide a small localized reservoir of residual DNAPL, which is not impacting other surrounding wells. Although these data suggest that DNAPL is naturally contained to the ERT 1 vicinity, they do not eliminate the possibility that DNAPL may have migrated beyond this area.

5.3.2 Advection Due to Density Differences

Aqueous phase concentrations in the vicinity of IWS 2 are not great enough to induce density driven flow. Combined dissolved concentrations detected in groundwater in the Study Area are generally less than 100,000 ppb, more than a factor of ten times lower than levels that could cause density-induced advection. There is only one (ERT1) location where total dissolved contaminants might approach levels that would cause density differences great enough to induce flow. However, the combined levels at ERT1 are still 2 to 5 times less than 1,000,000 ppb. In addition, a wealth of vertically spaced data exist within the immediate area to suggest that vertical flow due to density differences is not occurring. The concentration of TCE in ERT1 is 500 times greater than seen in the two wells screened vertically below it (B134A and B134B). Aqueous phase concentrations at other locations in the Study Area are typically less than those observed at IWS 2. Therefore, this transport mechanism is not considered a major one within the Study Area and will not be evaluated further.

5.3.3 Volatilization

The mechanism of volatilization can introduce vapor phase constituents into the unsaturated zone. Field monitoring for the presence of vapor phase VOC has shown that this migration pathway is limited, as discussed in Section 4. Therefore, further analysis of this migration pathway is not warranted at this time.

5.3.4 Aqueous-Phase Migration

The hydrogeology of the Landfill is comprised of three primary flow regimes (see also Section 3.7 Hydrogeology).

1) South-southwesterly flow of groundwater in the Upper Proximal, which is generally underlain by the lower permeability Distal.

2) Southwesterly and south-southwesterly regional groundwater flow of groundwater in the Lower Proximal, and

3) Southwesterly groundwater flow through fractured bedrock, generally consistent with the J_1 joint set.

Vertical flow of groundwater within the aquifer is a function of vertical gradients within the respective Proximal portions of the aquifer. Field data indicate a downward gradient in the Upper Proximal but no significant vertical gradients within the Lower Proximal. A limited volume of groundwater may also flow from the Upper Proximal to the Lower Proximal through the Distal due to the strong vertical gradient between the two units, as discussed in Section 3.7.2.1.

The focus of this section is to present the migration of aqueous phase VOC constituents in groundwater within the Study Area. This discussion does not specifically address the transport of semi-volatile compounds (SVOC), as only one SVOC exceeded the Federal or State standard, (bis-2-ethylhexyl) phthalate. As discussed in Section 4.2.2, the occurrence of phthalates in groundwater is not uncommon and it is often detected in groundwater samples due to sampling and testing equipment. Additionally, transport of metals is not included for the following reasons:

- There are only four locations in the Study Area at which the dissolved concentration of a given metal exceeded the Federal or State standard, all of which are in the Landfill and are as follows:

  MW10 - Antimony
  107 - Arsenic
  134B - Antimony
  115A - Arsenic and Nickel

- In nearly all cases, the total metals concentration greatly exceeded the dissolved metals concentrations (Plate Q, Tables 4-27 through 4-31), suggesting the metals present are sorbed to the particulates in soil.

- Metals tend to have extremely high K_d values and very high retardation factors which are typically 10 to 1000 greater than that of organic compounds (Table 5-1).

- There does not appear to be an observable pattern to the distribution of dissolved metals detected in groundwater in the Study Area, suggesting that the presence of a discrete plume of migrating metals is not occurring.

The difference in metals concentrations in total versus dissolved groundwater samples is significant to the potential for transport of metals in groundwater. Although infrequent measurements of metals were detected in groundwater samples downgradient of the Landfill, exceedances of MCLs occurred only in samples for total metals, not for samples for dissolved metals.

Extensive research on monitoring well sampling techniques (Backhus, et al., 1993) has established that typical approved methods for collection of groundwater samples frequently result in significant overstatement of concentrations for hydrophobic compounds, such as PAH, PCB, and metals. This is because most of the chemical mass for these types of compounds in a groundwater sample is sorbed onto colloids and not dissolved in the water. This results in measured levels of metals, in unfiltered samples, which over estimate the actual concentration in groundwater by as much as a factor of ten. For this reason, dissolved metals analyses more accurately predict the actual concentrations of metals in the groundwater flowing through the aquifer. As demonstrated in the RI, the occurrence of metals outside the Landfill is infrequently greater than the MCLs and is never in excess of MCLs for the dissolved fraction.

5.3.4.1 Migration within the Upper Proximal from IWS 3

There appear to be two groundwater pathways from IWS 3, one in the Upper Proximal and one in fractured bedrock. Organic compounds, primarily chlorinated organic compounds, originating in IWS 3 follow the top of the Distal and enter the Upper Proximal west and southwest of IWS 3. The organic compounds are transported to and enter the Lower Proximal in the vicinity of IWS 2. A more detailed discussion of the Upper Proximal migration pathways follows. Migration within fractured bedrock is discussed under <u>Bedrock Transport From the Landfill Area</u>.

Organic compounds from IWS 3 are expected to travel through the Upper Proximal along the paths shown in Figures 5-1 and 5-2. As discussed in Section 3.7.2.2, the vertical hydraulic conductivity of the Distal is estimated to be almost 45 times less than the horizontal hydraulic conductivity of the Distal (approximately 1 order of magnitude) and 1200 times (approximately three orders of magnitude) less than the hydraulic conductivity of the Proximal. The tangent law for the refraction of groundwater (Freeze and Cherry, 1979) can be used to calculate preferential horizontal flow in the Upper Proximal:

$$\frac{K_1}{K_2} = \frac{\tan\theta_1}{\tan\theta_2}$$

where:

K_1	=	hydraulic conductivity of the first formation
K_2	=	hydraulic conductivity of the second formation
θ_1	=	angle of flowline in the first formation
θ_2	=	angle of flowline in second formation

solving for θ_2, the equation becomes:

$$\theta_2 = \tan^{-1}\left(\frac{K_2}{K_1}\tan\theta_1\right)$$

It is assumed that a flowline leaves the Upper Proximal (the higher hydraulic conductivity layer, K_1) and enters the Distal (the lower hydraulic conductivity layer, K_2). A range of θ_1 (corresponding to the range in K_1, K_2) ranging from 89° (near horizontal flow in the Upper Proximal) to 45° (equal vertical and horizontal flow in Upper Proximal), can be assumed, where θ_2 would then be 90° (vertical flow in the Distal). Or, as stated in Freeze and Cherry (page 173): "In aquifer-aquitard systems with permeability contrasts of 2 orders of magnitude or more, flowlines tend to become almost horizontal in the aquifers and almost vertical in the aquitards".

The groundwater chemistry data also support the interpreted flow maps and suggest that the Distal is effectively attenuating transport of contaminants vertically (Plate P). For example, the levels of VOC in groundwater above the top of the Distal are significantly higher than at the bedrock surface (as at the MW10 cluster and B139 cluster).

Organic compounds from the IWS 3 area would appear to have migrated toward IWS 2, based on the following:

- The surface topography of the Distal, which is the base of the Upper Proximal, appears to influence the groundwater flow direction in the saturated portion of the Upper Proximal. This can be seen from a comparison of the pathlines in the Upper Proximal (Figure 5-1) computed from groundwater elevations and those computed along the top of Distal (Figure 5-2). The pathlines in Figure 5-2 were computed by using the Distal surface to infer flow direction. Beyond the limits of the area shown in Figure 5-1, the Upper Proximal unit is unsaturated and the influence of the distal surface topography would be restricted to unsaturated zone moisture movement.

- The concentrations of chlorinated organic compounds detected in wells B139 and B104, screened below the Distal, are two-to-three orders of magnitude lower than the concentrations of non-chlorinated organic compounds detected in adjacent wells screened above the Distal, suggesting that vertical transport through the Distal is limited.

Near IWS 2, the Distal is missing, apparently eroded prior to deposition of the Esker Delta. The Esker Delta, considered as hydraulically similar to the Lower Proximal, provides a hydraulic connection between the Upper Proximal and the Lower Proximal from the IWS 2 area, (see cross section 3-3′, Plate G).

The migration of organic compounds in the Lower Proximal is discussed in the following section.

5.3.4.2 Migration Through the Lower Proximal from IWS 2 and the SWDA

The Lower Proximal is a groundwater transport pathway for chlorinated and non-chlorinated organic compounds originating in the SWDA, IWS 1, IWS 2, and IWS 3. Non-chlorinated compounds originating in the SWDA enter the Lower Proximal at the eastern side of the SWDA where the Distal is thin or missing, in the IWS 2 area where the Distal is missing, and possibly within the SWDA through gaps in the Distal.

Chlorinated VOC at IWS 2 are vertically distributed throughout the Upper Proximal and saturated Distal. This distribution appears to be primarily the result of aqueous-phase VOC transport from IWS 3, as discussed above. Secondary sources may be due to be transport across the top of the Distal from IWS 1 (discussed below), and sources within IWS 2. Groundwater flow from IWS 2 and beneath the SWDA is westerly to southwesterly. The aqueous-phase chlorinated and non-chlorinated VOC within the Upper Proximal, saturated Distal, and regolith at IWS 2, and within the Lower Proximal beneath the SWDA, migrate radially in a westerly and southwesterly direction as indicated on Figure 3-13.

If TCE is chosen as an appropriate indicator constituent for the transport analysis of chlorinated VOC, because TCE is the most widely distributed chlorinated VOC constituent of concern in the Study Area, transport times can be estimated using formulas presented in Section 5.1.1. Using an hydraulic conductivity of 1.5E-03 cm/sec, a gradient range of 0.002 to 0.07 ft/ft (consistent with various likely gradients in and around the Landfill), an effective porosity of 0.05, and the TCE retardation factor of 2.2, TCE velocity would range from 0.1 to 3.0 ft/day, depending on the particular gradient over the path chosen.

The pathlines and associated travel times for TCE, if originating in the IWS 2 area and/or SWDA area, suggest that aqueous-phase TCE could reach the vicinity of B119 in approximately 40 years. However, longitudinal dispersion reduces this travel time[1]. Therefore, a combination of advection and dispersion could account for transport of VOC from the IWS 2/SWDA area to the vicinity of B119 within 20 years as indicated by the groundwater chemistry data. This correlates with the fact that the sources of VOC in the IWS areas are roughly 20 years old.

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[1] From Gelhar et al., (1985) α_L the longitudinal dispersivity of the Lower Proximal is estimated to range from 10 to 100 meters (30 to 300 feet). The groundwater pore velocity ($\overline{V}$) in this area is approximately 50 to 100 ft/yr and L_{total} is approximately 2,000 feet. Using these values and equations presented in Section 5.1.1, D_L is 1,500 to 30,000 ft^2/yr, L_d is 350 to 1549 ft, and Δt = 17% to 77% for a 40-year time period.

Table 5-1 also presents the estimated retardation factors expected for the non-chlorinated solvents detected in the Study Area. The majority of these constituents (2-butanone, methylene chloride, benzene), exhibit a lower affinity (K_d) for the organic carbon in soils, which results in a lower retardation factor and a greater travel velocity through the aquifer. Using the same parameters provided above for TCE, but using a retardation factor of 1.0, the velocity for non-retarded VOC would range from 0.2 to 6.0 ft/day depending on the gradient over the path chosen. The predicted pathlines and associated travel times shown for non-retarded VOC originating at IWS 2, IWS 3 and along the eastern margin of the SWDA suggest that non-chlorinated contaminants could reach the vicinity of B119 and the Riverside School in 20 years, ignoring dispersion. Taking into account dispersion, it is likely that non-chlorinated VOC would reach there in approximately 10 years. Similarly, overburden TCE contamination at B127B and B127C is unlikely to have resulted from transport in the overburden, given the transport times discussed above.

5.3.4.3 Bedrock Transport From the Landfill Area

The organic compounds found in bedrock appear to have mainly originated in IWS 3 with minor contributions from the IWS 2 area. The contribution of chlorinated organic compounds from IWS 2 to bedrock appears to be limited. With the exception of well ERT1 (further discussed below), the concentrations of chlorinated organic compounds in, and downgradient of IWS 2 are one-to-two orders of magnitude lower than the concentrations found near and downgradient of IWS 1 and IWS 3. The organic compounds in the fractured bedrock therefore migrate to the southwest.

Chlorinated VOC have been detected immediately above the bedrock and in bedrock at IWS 2, B132, and at the B136 well cluster. However, the chlorinated VOC found at these locations cannot be readily explained by migration from IWS 2. First, VOC levels in B106B, located directly between IWS 2 and B132, are low. Second, flow from IWS 2 is generally southwesterly (in the Upper Proximal portion of the aquifer) and westerly at depth. Third, SWDA constituents, which are present at IWS 2, are not present at B132. Finally the constituents present at B132 are similar to those measured at MW10/B139 (screened in the Upper Proximal and downgradient of IWS 3) at similar but slightly lower concentrations (refer to Plate P). The constituents measured at IWS 2 include a large fraction of non-chlorinated constituents in addition to chlorinated constituents. This mix of chlorinated and non-chlorinated VOC constituents is also present in bedrock wells (B120D and B120E) at the Riverside School. The distribution of constituents suggests:

- Chlorinated organic compounds originating in IWS 3 enter a bedrock fracture or fracture zone, which is likely to be parallel to the trend of the J_1 joint set. This fracture zone is encountered at B132 and is hydraulically connected to the bedrock fracture zone at B136. These fractures are not clearly hydraulically impacted, in the area of B136, by the fracture zone that transports mixed volatile compounds (chlorinated and non-chlorinated) from IWS 2 to the Riverside School area.

- There appears to be a bedrock hydraulic connection between IWS 2/SWDA and the Riverside School area. It is likely that this hydraulic connection consists of one or more fractures aligned consistent with the orientation of the J_1 joint set. The potential fractures likely extend from the vicinity of the Landfill, below and west of IWS 2, towards the Riverside School area.

- The fractures encountered at B136, assumed to be connected to bedrock beneath B132, likely also contribute chlorinated volatile constituents to the Riverside School area, downgradient of B136, with sub-parallel fracture sets carrying mixed constituents from IWS 2/SWDA.

The organic carbon within a porous media is the primary factor which controls the magnitude to which a non-ionic organic contaminant is retarded with respect to the groundwater flow through the aquifer (see Section 5.1.1). However, in a fractured bedrock media, groundwater flow is not confined to porous media, but rather a system of discrete fractures and sound bedrock. Flow through the open fractures dominates the transport of groundwater through the bedrock in the Study Area as a whole, and chemical retardation due to partitioning is limited because the organic content of rock is very low and the pore water is exposed to a more limited fraction of aquifer matrix.

The hydraulic conductivity of fractured bedrock can be extremely high within fractured zones, but rather low in less fractured rock. Packer testing completed in the Study Area was completed in both fractured and non-fractured rock. The more fractured locations (B115 and B139) exhibited hydraulic conductivities in the range of 10^{-2} to 10^{-3} cm/sec, respectively. These numbers suggest that the velocity through fractured zones in the bedrock could be high. Given an assumed hydraulic conductivity of 10^{-3} cm/sec (1035 ft/year, the highest K value measured) and a head difference of 33 feet over a horizontal distance of 1950 feet between B139C (located near IWS 2) and B120E (located near the Riverside School) and an assumed porosity range of 0.05 to 0.1, the average Darcy velocity of groundwater travelling through the fracture zone would be 350 ft/year to 175 ft/year. Accordingly, groundwater could travel from the IWS 2 area to the Riverside School area in 5 to 11 years.

5.3.4.4 Transport From IWS 1

Organic compounds originating in the IWS 1 area apparently migrate easterly, at or in the Distal, then enter the Lower Proximal at the eastern side of the SWDA where the Distal is thin or missing, in the IWS 2 area where the Distal is missing, and possibly within the SWDA through holes in the Distal. These compounds then migrate west, then southwest towards the Passumpsic River. Factors impacting transport of VOC from IWS 1 are discussed below.

Since the unsaturated zone (Distal) is approximately 100 feet in thickness, VOC must travel through 100 feet of nearly horizontally structured silt and sand deposits before it is able to reach groundwater. Because the Distal strata dip to the south and east, infiltrating water would primarily migrate horizontally along dipping bedding interfaces rather than vertically. Lateral flow through the unsaturated zone would be parallel to the dip such that constituents would travel as predicted by the pathlines presented in Figure 5-2.

Consequently, constituents originating in the surface soil at IWS 1 may be: (1) traveling eastward and entering the Lower Proximal portion of the aquifer beneath the SWDA where the top of the Distal intersects the groundwater at an elevation of approximately 718 feet, or (2) travelling vertically downward within the annulus of the abandoned dry monitoring wells MW11 and MW12. In either case, the constituents are expected to enter the Lower Proximal portion of the aquifer and flow westward with regional groundwater flow.

5.4 SURFACE WATER TRANSPORT

The unnamed stream represents, if any, a secondary migration pathway for contaminants originating in the SWDA and IWS areas. As discussed in Section 3.7.4, the unnamed stream alternates between gaining and losing reaches throughout the Study Area. Furthermore, flow direction through the stream bed is strongly influenced by precipitation events and the subsequent drainage of pore water from surficial soils into the unnamed stream. Based on this established surface water hydrology, the water quality of the unnamed stream may have a limited influence on groundwater concentrations in the Lower Proximal south and southwest of IWS 2. The degree of influence cannot be accurately quantified based on the existing data base.

The surface water quality data summarized in Table 4-34 are important in evaluating potential surface water quality impacts on groundwater. For example, TCE was detected in surface water at levels ranging from 0.003 to 0.021 ppm at stations 406, 407, and 408 which are located downstream from IWS 2. TCE was not detected upstream of IWS 2. In comparison, TCE concentrations detected in groundwater (Lower Proximal) downgradient from IWS 2 varied from 0.033 to 0.044 ppm at well 125 and 0.076 to 0.59 ppm at location 136. Since concentrations in surface water recharging groundwater (i.e., leakage through bed sediments) in losing sections of the unnamed stream would be significantly diluted upon mixing with groundwater in the

Lower Proximal, it appears that surface water impacts on groundwater quality are minimal along the first one-third to one-half of the reach downstream from IWS 2. Along the lower half of the downstream reach, extending from IWS 2 to the Passumpsic River, surface water impacts on groundwater quality could be proportionally larger due to the low VOC levels detected in groundwater in this area. Nevertheless, the impact would be very small due to the low surface water concentrations and the surface to groundwater dilution mentioned above.

6.0 CONCEPTUAL MODEL

This Section presents a conceptual model for the Study Area. The conceptual model integrates data collected from all RI investigations to develop an overall picture of nature, extent, and migration of constituents. The conceptual model provides the framework for the selection of remedial alternatives and the development of the feasibility study. For that reason the conceptual model focuses primarily on the media likely to impact the remedial process. Remedial activities at the Parker Landfill, necessary to address each media potentially impacted, will primarily involve potential sources and groundwater.

6.1 EVALUATION OF POTENTIAL SOURCES

Four potential source areas have been identified during the completion of the Phase 1A and Phase 1B investigations. The identified source areas are the SWDA, IWS 1, IWS 2, and IWS 3.

6.1.1 SWDA Source Identification

The SWDA contains approximately 1.4 million cubic yards of solid waste, covering approximately 14 acres in area and averaging 70 feet in thickness. The primary waste source associated with the SWDA is leachate. Analytical testing of leachate and groundwater indicate that the constituents associated with the SWDA consist mainly of ketones (acetone, 2-butanone, 2-hexanone, 4-methyl-2- pentanone), benzene, ethyl benzene, toluene, xylene, phenolics (methyl phenol, benzoic acid, phenol), and various metals.

Precipitation percolates through the waste mass across the entire SWDA. The "layering" structure within the SWDA (based on historical operation of the SWDA) likely consists of alternating layers of waste and daily cover material. Historical information indicates that sand deposits suitable for construction purposes (generally coarse to medium sand) were mined from the SWDA vicinity prior to use of this area as a solid waste disposal facility. Borrow operations were most likely centered around generally northwest to southeast oriented melt water distributary channel deposits within the Proximal, as well as the Esker Delta. Historical data indicate borrow activity ceased when coarser sand deposits were played out and nothing but silty fine sand, silt, and clay deposits remained. This information indicates the excavation preceding initiation of solid waste operations was terminated in the locally extensive Distal, as discussed in Sections 3.1 and 3.5, and shown on Plates F, G, and H. A remnant of the Upper Proximal is located above the Distal along the entire length of the eastern access road, as shown on Plates F, G, H, J, K, and L.

As shown on Plates F, G, and H, the base of the SWDA is interpreted to slope toward the east, with maximum SWDA thickness concentrated along the axis of the SWDA. Disposal of waste within the SWDA began at the lowest point near the center of the SWDA axis and expanded radially away from this point. SWDA expansion was primarily toward the west, south, and east with vertical expansion concentrated along the axis. Daily SWDA operations have involved disposal of waste at high spots in the SWDA followed by spreading of waste downslope with a front-end loader. Daily cover material, consisting of 0.5 to 1.0 feet of excavated Proximal and Distal deposits was placed over the waste at the end of each day. These operations have resulted in the development of alternating layers of highly permeable trash bounded by layers of less permeable sand, silty fine sand and clay. Apparent random distribution of Proximal and Distal daily cover material has likely resulted in an extremely heterogenous distribution of permeability values across and within the SWDA.

Leachate is generated across the entire SWDA and is conveyed to the groundwater in varying quantities across the SWDA. Therefore, individual source areas within the SDWA cannot be identified and the whole SWDA must be considered a single diffuse source.

6.1.2 IWS 1 Source Identification

IWS 1 is adjacent to, and portions overlie the general footprint of, the SWDA. The contaminant source within IWS 1 is limited to the disposal area delineated on Figure 3-6. Disposal of solid waste and liquid wastes has resulted in contamination of the soil column beneath and adjacent to IWS 1. No evidence of buried intact drums of liquid wastes was indicated during the geophysical and test pit surveys.

As shown on Table 4-19, the majority of chlorinated VOC detected at IWS 1 are located in the vicinity of test pit P908. The soil below the waste contains only low concentrations (maximum of 0.022 mg/kg) of chlorinated VOC. Test boring B130, however, shows higher concentrations of chlorinated VOC in the natural soil, at a depth of 24 to 26 feet (see Table 4-10). Plate M provides a cross-sectional view of the analytical results for samples within IWS 1. IWS 1 directly overlies the Distal. The relatively low permeability and fine grained nature of the Distal likely results in slow vertical and horizontal migration and concentration attenuation due to adherence to the soil matrix. VOC analyses of waste, and underlying soil samples obtained from test pits, further indicate rapid attenuation of contaminant concentrations with depth.

6.1.3 IWS 2 Source Identification

The majority of soil column contamination at IWS 2 exists in the western portion of this area, and is associated with two or three distinct disposal locations, as shown on Figure 3-7. The analytical data (Table 4-14) from test pits P905 and P906, as well as test pits excavated by ERT1, (ERT 1987), indicate concentrations of chlorinated VOC and concentrations of petroleum related VOC (benzene, toluene, and xylene). Generally, ketones were not detected in test pit samples or in the test boring installed within IWS 2 (B129). The analytical results for soil samples from B129 indicate significant reduction in VOC concentrations between depths 0 to 2 feet and 18 to 20 feet. The groundwater table was encountered at a depth of 18 feet. Plate N provides a cross-sectional view of the analytical results for soil samples within IWS 2. Chlorinated VOC are present in Disposal Areas 1 and 3 in the overburden soils.

6.1.4 IWS 3 Source Identification

Waste materials within IWS 3 are limited to the three waste disposal locations identified on Figure 3-8. Soil from test pits excavated at IWS 3 (see Table 4-19) indicate that the majority of chlorinated VOC are located in the vicinity of P902. These VOC are located primarily in the soil beneath the waste. Boring B128 is located approximately 50 feet west of P902. Soil samples collected from B128 indicate VOC concentrations in the upper 15 feet, with a significant reduction in VOC between 15 feet and 50 feet. Plate O provides a cross-sectional view of the analytical results of samples within IWS 3.

6.2 HYDROGEOLOGY

The saturated portions of the major soil and rock units within the Study Area can be grouped into three primary hydrogeologic units: the Upper Proximal, the Lower Proximal and Fractured Bedrock. Over most of the site the Lower Proximal and Fractured Bedrock are separated from the Upper Proximal by the Distal, which is a semi-confining unit. The transmissivity of the Lower Proximal is approximately two orders of magnitude greater than the transmissivity of the Fractured Bedrock, and the Upper Proximal is very limited in areal extent. Therefore, in terms of groundwater flow volume, the Lower Proximal is the principal water-bearing unit in the Study Area.

Although the Upper Proximal is found across the northern two-thirds of the study area, only a small portion of the Upper Proximal along the unnamed stream is saturated. The saturated portion of the Upper Proximal is approximately 1400 feet long, up to 450 feet wide and up to 30 feet thick. The long axis of the Upper Proximal trends northeast to southwest. The Upper Proximal is bounded on the northwest by the contact of the water table with the top of the

Distal, on the southeast by the contact of the water table with either bedrock or the top of the Distal, and on the southwest by the Esker Delta deposit. The top of the saturated Upper Proximal is the water table. The bottom of the Upper Proximal is the top of the Distal.

The Lower Proximal is found across the entire site except under the SWDA, where it may be pinched out by the Distal. The Lower Proximal is bounded on the west by the esker deposit and on the east by the bedrock valley wall. The Lower Proximal does not have physical northern or southern boundaries. The top of the saturated Lower Proximal is the water table, except in the area of the SWDA, where the Lower Proximal is bounded by the Distal. The bottom of the Lower Proximal is the bedrock surface. The saturated thickness of the Lower Proximal is on the order of 100 feet. The saturated thickness of the Lower Proximal ranges from 0 feet at the bedrock valley wall to over 125 feet in the southwest corner of the Study Area. Within the Landfill, the saturated thickness ranges from 0 to approximately 90 feet.

Hydraulically, the Esker Delta deposit in the immediate vicinity of the Landfill is very similar to the Lower Proximal. The regolith (weathered bedrock) is also hydraulically similar to the Lower Proximal in this area. Therefore, the saturated portions of these deposits have been grouped with the saturated portion of the Lower Proximal.

The Distal is a lower permeability unit that bounds the bottom of the Upper Proximal east of the SWDA and at IWS 2. The Distal appears to act as a leaky confining layer between the Upper Proximal and the Lower Proximal. The Distal terminates on bedrock at IWS 2 and increases in thickness and elevation from IWS 2 to the northwest (toward B109, B110), such that the bottom of the Distal rises above the water table between B108 and B109 (Plate F). Accordingly, the Distal is saturated at IWS 2, ranging from 9 feet in thickness at B106 to 73 feet thick at B108B, but unsaturated and 78 feet thick at B109 south of IWS 1.

Bedrock underlies the Lower Proximal and Distal across the entire Study Area. In general, the bedrock hydraulic conductivity is too low to transmit significant volumes of water and bedrock acts as a lower confining layer. However, as previously described, a 700 to 800 foot wide fracture zone apparently extends through the IWS 3 Area towards the Riverside School area. Higher hydraulic conductivities within the fracture zone allow the movement of groundwater.

6.2.1 Hydrogeological Influence on SWDA Constituents

The SWDA waste mass is interpreted to be in direct contact with the Distal over the western 90% of the SWDA (see Plates F and G). The proximity of the SWDA wastes to the water table is not known, but is inferred from the data obtained from borings around the SWDA. The eastern margin of the SWDA waste mass sits above and adjacent to a narrow wedge of Proximal deposits perched above the underlying Distal, along the eastern boundary of the SWDA. Leachate generated across the entire SWDA is interpreted to migrate within the unsaturated zone in a southeasterly direction along waste layers, the interface between the Distal and the SWDA mass, and along suspected bedding planes within the Distal. Portions of this flow is apparently discharged to the Upper Proximal portion of the aquifer (perched wedge of Proximal material) along the eastern margin of the SWDA and at IWS 2. The Distal forms a leaky semi-confining layer resulting in a perching of the aquifer east of the SWDA. This relationship is evident from the geology detailed in Plates F, G, and K and apparent of large vertical hydraulic gradients at well clusters B114, B115, B117, B108, B103, MW10A, B133, B104, and B139. The water within the Upper Proximal is primarily comprised of infiltration, leachate from the SWDA, lateral recharge from the eastern uplands, and groundwater from IWS 3.

The Distal overlies a Lower Proximal which extends beneath the SWDA except in the northeastern portion. The Lower Proximal is a thin stratigraphic layer along the eastern margin of the SWDA, as shown on Plates G and K. The Lower Proximal increases in thickness to the west. The Lower Proximal laterally contacts regolith and weathered bedrock to the east and beneath IWS 3. The Lower Proximal portion of the aquifer is apparently recharged by groundwater within the regolith and Lower Distal east of the SWDA. Some of the leachate from the SWDA, which percolates along bedding planes in the Distal, eventually reaches the Lower Proximal portion of the aquifer. Under the eastern portion of the SWDA this leachate enters the groundwater within the Distal and is inferred to flow southeasterly with the groundwater until it either enters the underlying Proximal or encounters the broad bedrock fracture zone in the vicinity of IWS 2. Once groundwater, containing SWDA leachate leaves the Distal and enters the Lower Proximal, migration is generally toward the west, in the Lower Proximal portion of the aquifer. Windows of the exposed Lower Proximal deposits likely exist beneath the SWDA due to prior excavation activity and surficial erosion of the Upper Proximal and Distal. If present, the windows would serve as pathways for westerly and northwesterly migration of contaminated groundwater from the SWDA.

Under the western portion of the SWDA, the Distal directly overlies the Lower Proximal. In this region the Distal is located entirely within the unsaturated zone except for the lower most portion of the unit at B130. Downward and southeasterly migrating SWDA leachate within the unsaturated zone is interpreted to be discharged to the groundwater within the Lower Proximal portion of the aquifer (Lower Proximal). Once the SWDA leachate enters the groundwater within the Lower Proximal, migration is toward the west to southwest, influenced by the regional groundwater flow.

Based on the above discussion, it is evident that the SWDA serves as a source for shallow and deep groundwater contamination, along the eastern and southern margin of the SWDA, and shallow to deep groundwater contamination along the western margin of the SWDA.

6.2.2 Hydrogeological Influence on IWS 1 Constituents

Rainwater percolating through the soil and solid waste at IWS 1 must pass through a minimum of 78 vertical feet of Distal deposits prior to reaching the regional groundwater table. At IWS 1, the groundwater table is located within the Lower Proximal. Due to bedding attitude in the unsaturated zone (Distal), rainwater and snow melt is inferred to migrate in the unsaturated zone in a southeasterly direction from IWS 1 toward the SWDA as shown in Figure 5-2. Beneath the SWDA, the rainwater and snow melt crosses the Distal/Lower Proximal interface and enters the regional groundwater table, at which point migration occurs within the saturated zone and is toward the west and southwest. This migration path results in the introduction of IWS 1 constituents at various depths within the Lower Proximal portion of the aquifer to the east of IWS 1. This multiple depth introduction has likely caused stratification of constituents within the aquifer in the vicinity of IWS 1. As seen at well cluster B109, IWS constituents are prevalent in the shallow portion of the aquifer (B109A), whereas constituents from the SWDA are dominant in the Lower portion of the aquifer (B109B and B109C; refer to Plate M).

6.2.3 Hydrogeological Influence on IWS 2 Constituents

At IWS 2, the aquifer consists of the Upper Proximal and the underlying Distal. The IWS 2 vicinity is a collection point for southeasterly and southerly migrating SWDA and IWS 3 constituents, as shown on Figures 5-1 and 5-2. SWDA Constituents and IWS constituents are delivered to, and commingle in the vicinity of IWS 2.

Chlorinated VOC at IWS 2 are vertically distributed throughout the Upper Proximal and saturated Distal. This distribution appears to be primarily the result of aqueous-phase VOC transport from IWS 3, as discussed above. Secondary sources may be due to be transport across the top of the Distal from IWS 1 (discussed below), and sources within IWS 2. Groundwater flow from IWS 2 and beneath the SWDA is westerly to southwesterly. The aqueous-phase chlorinated and non-chlorinated VOC within the Upper Proximal, saturated Distal, and regolith at IWS 2, and within the Lower Proximal beneath the SWDA, migrate radially in a westerly and southwesterly direction as indicated on Figure 3-13.

South and west of IWS 2, the Upper Proximal portion of the aquifer and the Lower Proximal portion of the aquifer merge and groundwater flows toward the west and south-southwest (Plates G & K). Groundwater quality data for monitoring wells located south and southwest of the Landfill indicate a decrease in constituent concentrations within the overburden aquifer. This overburden flow, as shown on Figure 3-13, is indicated by contaminants found at B125/MW4A. Levels of contaminants in the overburden in the area of Brown Farm Road have decreased to at or near the detection limit, indicating the extent of migration in the overburden aquifer.

6.2.4 Hydrogeological Influence on IWS 3 Constituents

There appear to be two groundwater pathways from IWS 3, one in the Upper Proximal and one in fractured bedrock. Organic compounds, primarily chlorinated organic compounds, originating in IWS 3 follow the top of the Distal and enter the Upper Proximal west and southwest of IWS 3. The organic compounds are transported to and enter the Lower Proximal in the vicinity of IWS 2. Organic compounds from IWS 3 are expected to travel through the Upper Proximal along the paths shown in Figures 5-1 and 5-2. The groundwater chemistry data also support the interpreted flow maps and suggest that the Distal is effectively attenuating transport of contaminants vertically (Plate P). For example, the levels of VOC in groundwater above the top of the Distal are significantly higher than at the bedrock surface (as at the MW10 cluster and B139 cluster).

The transition from shallow semi-confined groundwater contamination at B139A to deep overburden contamination at B132 indicates a potential breach in the Distal between B139 and B132, as discussed in Sections 3.1.4, 5.3.4.1, and 5.3.4.2, and shown on Plates G & J. Discharge of constituents from IWS 3 in groundwater to the fractured bedrock apparently occurs in the general vicinity of IWS 2 and also appears to occur independently somewhere between B139 and B132. Bedrock transport is summarized in more detail in Section 6.2.5.

6.2.5 Bedrock Transport

The organic compounds found in bedrock appear to have mainly originated in IWS 3 with minor contributions from the IWS 2 area. The contribution of chlorinated organic compounds from IWS 2 to bedrock appears to be limited. Chlorinated VOC have been detected immediately above the bedrock and in bedrock at IWS 2, B132, and at the B136 well cluster. However, the chlorinated VOC found at these locations cannot be readily explained by migration from IWS 2. Although the presence of a fracture zone is conjectural, based on all available data, the distribution of constituents suggests:

- Chlorinated organic compounds originating in IWS 3 enter a bedrock fracture or fracture zone, which is likely to be parallel to the trend of the J_1 joint set. This fracture zone is encountered at B132 and is hydraulically connected to the bedrock fracture zone at B136.

- There appears to be a bedrock hydraulic connection between IWS 2/SWDA and the Riverside School area. It is likely that this hydraulic connection consists of one or more fractures aligned consistent with the orientation of the J_1 joint set.

- The fractures encountered at B136, assumed to be connected to bedrock beneath B132, likely also contribute chlorinated volatile constituents to the Riverside School area, downgradient of B136, with sub-parallel fracture sets carrying mixed constituents from IWS 2/SWDA.

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